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Research into Spinal Deformities 5

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D. Uyttendaele and P.H. Dangerfield (Eds.)
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Preface

The 6th Biennial Meeting of the International Research Society of Spinal Deformities was held on 21–24 June 2006 at "Het Pand" in Ghent, Belgium.

More than 140 papers and posters were presented, covering many different fields of research from genetics and molecular biology to surgical treatment. During the last decade the field of research has widened and new research groups have emerged, reflecting the changes in the world's economical and political scene. In this context globalisation definitely has a positive meaning.

Progress has been made, but the goals of our Society have not been reached yet.

Our understanding of the mechanisms leading to spinal deformity is improving, but further research into all fields concerned is mandatory.

This book reflects our current knowledge and is intended for readers with a scientific, critical and open mind. It will serve as a basis for future research and as a source of discussion. The content of the papers is each individual author's responsibility.

It has been an honour to be your host in Ghent and to act as your editor.

This would have been impossible without the enormous help of my co-editor, our secretary for life, Peter Dangerfield. As a native speaker, he had the immense task of putting all the papers into proper English, for which we owe him very much.

Lieve Ectors and Luc Niville from King Conventions did an exemplary job and if we reached all the deadlines, it is thanks to them.

Publishing this book would have been impossible without the assistance of our sponsors.

We are greatly indebted to DePuy Spine, Spine Vision, Stryker and Medtronic.

May your stay in Ghent have been an enjoyable one and an inspiration for future work.

Gent, 15 June 2006

Dirk Uyttendaele, MD, PhD

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The Role of Melatonin Receptor 1B Gene (MTNR1B) in Adolescent Idiopathic Scoliosis - A Genetic Association Study

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Abstract: Many studies have demonstrated the role of melatonin in the etiology of AIS. Previous studies have shown that there is no evidence of mutations in the melatonin receptor 1A gene in AIS patients. In this study, we have examined the role of melatonin receptor 1B in predisposition for AIS. Using haplotype block tagging technique, a set of tagging SNPs were defined for MTNR1B from the Han Chinese data of the International HapMap project. The association between the tagging of single nucleotide polymorphisms (tSNPs) in MTNR1B region and the occurrence of AIS was studied. Method: 473 AIS girls and 311 normal controls were recruited. The age range of the patients was between 10 and 18 years old. The maximum Cobb was recorded at latest follow-up in AIS patients. Three of five tSNPs were studied; they were all located within the coding region of the MTNR1B gene. Results: There was no significant difference in the genotype or allelic frequencies (AF) of the 3 tSNPs between AIS and controls. In a case-only analysis, no difference in curve severity in AIS patients was found among patients with different genotypes (by one-way ANOVA). Discussion: The 3 tSNPs showed no association with either the occurrence of AIS or the maximum Cobb angle within AIS girls. Further analysis of the remaining tSNPs within the regulatory region of the MTNR1B gene and other related genes in the melatonin signaling pathway may provide further information on the role of the melatonin in AIS girls.

Keywords: adolescent idiopathic scoliosis, melatonin receptor 1B, polymorphism

Introduction

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional deformity of the spine that most commonly occurs in adolescent girls at their peripubertal period. Although the etiology of the disease has not been established, the role of genetic factors in its development is widely accepted [1-5]. Several linkage analysis studies have reported possible relationships between marker loci and idiopathic scoliosis [6-10].

Miller et al [10] recently carried out a linkage analysis which involved 202 families and 1198 individuals. The results of this study suggested several potential candidate regions, indicating that substantial clinical and genetic heterogeneity may be involved.

On the other hand, the hypothesis of melatonin deficiency as the cause of AIS has generated considerable interest. This hypothesis is based on the experimental chicken scoliosis model using pinealectomy [11-15]. It has been suggested that a deficiency in melatonin, the main product of the pineal gland, is responsible for this deformity. However, the results of measuring the concentration of melatonin and its metabolites in AIS patients are controversial [16-18]. This led us to edxamine the melatonin receptors in the signal transduction pathway of melatonin.

Two subtypes of melatonin receptors have been characterized as the melatonin receptor 1A (MTNR1A), and the melatonin receptor 1B (MTNR1B) [19]. Although previous studies have shown that there is no evidence of mutations in the melatonin receptor 1A gene in AIS patients [20], the MTNR1B gene, being in the candidate region for AIS as suggested by Miller et al. [10], was examined in this study for the role of melatonin receptor 1B in the predisposition of AIS.

1. Subjects and Methods

1.1. Subjects

473 AIS girls and 311 normal controls with ages between 10 and 18 years old were recruited. Patients with AIS were examined with the forward-bending test for rotational prominence and a standing radiograph. The curves were measured by the Cobb method. AIS girls with a Cobb >20° with a rotational prominence were included in this study. The maximum Cobb angle was recorded at latest follow-up. Patients with congenital scoliosis, neuromuscular scoliosis, scoliosis with skeletal dysplasia, or scoliosis with known endocrine and connective tissue abnormalities, or prior treatment for scoliosis before being recruited into the study were excluded. The normal healthy subjects included if they had a negative forward bending test. If there is any uncertainty, the subjects were advised to have an x-ray check. The study protocol was approved by the university human research ethics committee.

1.2. Genotyping with tagging SNPs

Total genomic DNA was extracted from peripheral blood samples using a DNA extraction kit according to the manufacturer's instruction (Roche, USA). Using haplotype block tagging technique, 5 tagging SNPs (tSNPs)—rs2166706, rs4753426, rs10830963, rs3781637, rs10830964 were defined for MTNR1B from the Han Chinese data of the International HapMap project. Three out of 5 tagging SNPs (tSNPs) for the MTNR1B gene were chosen in this preliminary study. The primers listed in Table 1 were designed to incorporate the polymorphic site at rs10830963 (C/G), rs3781637 (G/A), rs10830964 (T/C). PCR was performed to amplify the genomic DNA. Each reaction mixture (12.5 ml) contained 0.3 units MBI Taq polymerase, 1.0 ml of each primer, 20 mM Tris-HCl (pH 8.4), 50 mM KCl and 2.0 mM MgCl2. Each of the 35 amplification cycles consisted of 30 sec. at 96°C, 45 sec. at 60°C and 30 sec. at 72°C.

The final elongation step was 7 min at 72°C. For restriction enzyme digestion, 7 ml of the PCR product was subjected to 3 units of the required enzyme in the presence of the accompanying buffer in a final volume of 14 ml incubated at the temperature with optimal activity of the enzyme overnight. The enzymes used and restriction fragments were listed in Table 1. Polymorphism was visualized by separating the digested PCR product in a 4% (rs10830963) or 2% (rs3781637, rs10830964) agarose gel with ethidium bromide. To validate the genotyping results, repeated genotyping was performed in 10% of the samples to confirm the results.

Table 1. Primer sequence and enzyme for the analysis of the three SNPs in MTNR1B

SNPs	primers sequences 5'-3'	PCR Product bp	Enzyme	Size after enzyme digestion, bp
rs10830963	Forward: ATGCTAAGAATTCACACCAGCT	125	Pvu II	C: 125
	Reward: CACAGTGCAGACTGTTTCTAATC			G: 20+105
rs3781637	Forward: TAGGTTCTTGGTGCTCTATTCGTG	412	Hinc II	G: 358+54
	Reward: TATTCCCATTTGTGCCCTGTCT			A: 185+175+54
rs10830964	Forward: TCCCTGGTGATTATTGACG	662	Ava I	T: 662
	Reward: GCTAAGATTGCCCAGAGTG			C: 439+223

1.3. Statistical Analysis

Statistical analysis of genotype distribution and allele frequencies was performed by $\chi 2$ test (SPSS for Windows; 13.0). One-way ANOVA was used in the comparison of mean maximum Cobb angle with different genotypes in case only analysis.

2. Results

The genotype distribution for rs10830963, rs3781637 and rs10830964 polymorphisms are presented in Table 2. No significant deviation of genotype frequencies from the Hardy-Weinberg equilibrium was noted in both the control and AIS group. The association between genotypes MTNR1B and the occurrence of AIS was shown to be not significant. In addition, no correlation between the allelic frequencies and AIS were found (data not showed).

In a case-only analysis, the mean maximum Cobb angle was 33.3±10.7, 34.7±12.4 and 36.5±13.3 for genotype CC, CG, GG of SNP rs10830963, respectively. For the rs3781637 SNP, the Cobb's angle was 36.0±16.6, 33.4±11.7 and 34.3±11.0 for genotype GG, GA, and AA, respectively. For rs10830964 SNP, 31.9±7.9, 33.0±9.6 and 35.6±13.5 for genotype TT, TC, and CC, respectively. The Cobb angles of different genotypes were similar to each other ($p>0.05$)

Table 2. MTNR1B polymorphisms in AIS in a Chinese population

genotypes	Control		AIS		χ2 p value
	n	%	n	%	
rs10830963					
CC	98	33.9	145	32.3	
CG	149	51.6	237	52.8	0.901
GG	42	14.5	67	14.9	
rs3781637					
GG	7	2.4	7	1.6	
GA	86	29.0	118	26.3	0.496
AA	203	68.6	323	72.1	
rs10830964					
TT	10	3.3	17	5.9	
TC	118	39.5	167	36.6	0.242
CC	171	57.2	262	57.5	

3. Discussion

In the present study, there is no association between the MTNR1B gene and the occurrence of AIS and the maximum Cobb angle of the AIS patients. This indicated that MTNR1B is not a disease predisposition gene and disease modifying gene in the presently studied SNPs. It is similar to the previous finding of an association between the MTNR1A and familial AIS. Although previously reported by Sobajima et al [23] who suggested the dysfunctional melatonin receptors or second messenger systems maybe the causes of spinal deformities in the hereditary lordoscoliotic rabbit, the present study has shown that MTNR1B would not be involved in AIS. Moreau et al [24] also showed that post-translational modifications affecting Gi protein function rather than the melatonin receptors maybe the possible mechanism for the abnormal melatonin signal transduction pathway in AIS patients. In a recent report on pinealotomy of the non-human primate [25], it was not shown that reduced expression of melatonin in higher level animal would cause scoliosis. Therefore, with the controversy of melatonin and its signal pathway in AIS, it is not conclusive at this present stage.

Using haplotype block tagging technique, prior knowledge of putative functional variants is not required, and an indirect association study would be handled in the whole candidate gene region [26]. In the current studies, three of 5 tSNPs in MTNR1B gene represent the coding region of the MTNR1B gene, and they could capture most sequence variations within the coding region of the MTNR1B gene. Hence, the present results suggest that there may not be any functional variants in the coding region of MTNR1B gene which are associated with the occurrence or curve severity of AIS.

With the genetic association study, additional phenotypes of the disease would be advantageous to further identify the possible candidate gene. Several studies on growth have shown that arm span, corrected height and other body segmental lengths of AIS patients were significantly greater than those of controls after the onset of puberty, and that lower weight and body mass index were consistently found in AIS throughout puberty [27-29]. Furthermore, generalized osteopenia in both axial and peripheral skeleton has been found in AIS [30-32]. It was reported that melatonin promoted osteoblast differentiation and bone formation [33-35]. Ladizesky et al [34] showed that melatonin increases estradiol-induced bone formation in ovariectomized rats. Koyama et al [35] suggested that melatonin at pharmacological doses increases bone mass by suppressing resorption through down-regulation of the RANKL-mediated osteoclast formation and activation. Since melatonin plays an important role in bone metabolism, we could undertake an association study between MTNR1B polymorphisms and other abnormal phenotypes, such as anthropometric measurement and bone mineral density in further studies.

The present negative results may be due to the nature of genetic association study which is sensitive to sample size. The sample size of the present study is relatively small. Hence, if there is a weak association between genetic variants of the MTNR1B gene and occurrence or curve severity of AIS, a larger sample size may be needed. Moreover, further analysis of the remaining tSNPs along the regulatory region of MTNR1B gene and other related genes in the melatonin signaling pathway may provide further information on the role of the melatonin in AIS girls.

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Correlation between Cytogenetic Abnormalities in Cells and Metabolic Shifts in Children with Spinal Deformities

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Abstract. We studied the relationship between cytogenetic abnormalities in buccal epithelial cells and metabolic shifts in children with scoliosis and kyphosis. The incidence of nucleus abnormalities and the corresponding metabolic shifts were found to depend on the presence of spinal deformities and ecological factors. The problem of formation of risk groups for spinal deformities in ecologically unfavorable regions is discussed.

Keywords. Buccal epithelial cells, kyphosis, laser correlation spectroscopy, oropharyngeal washout fluid, scoliosis, ecology

Introduction

Being a polygenic disease, scoliosis is characterized by genetic defects at various levels. According to the hypothesis proposed by R.G.Burwell, P.H.Dangerfield [1], cells with X-chromosome mosaicism or microchimerism should be present in tissues of patients with scoliosis.

Our aim was to study nucleus abnormalities in buccal epithelial cells from patients with scoliosis and kyphosis and their relationships with metabolic shifts observed in children with musculoskeletal pathologies [2].

Methods

We examined a group of 9-12-year-old children in three schools: a general education school (25 pupils), a Moscow boarding school for children with scoliosis and kyphosis (73 pupils), and a country school in ecologically clean Novgorod region (23 pupils). In all pupils cytogenetic analysis of buccal epithelial cells was carried out and laser correlation spectroscopy (LCS) of oropharyngeal washout fluid (OPWF) was performed for evaluation of predominant metabolic shifts [3].

Before buccal epithelium sampling, the children were asked to rinse thoroughly the oral cavity with a sterile physiological saline. Then, epithelial cells were gently brushed from the buccal mucosa with a sterile spatula and transferred to a slide. The samples were dried, fixed in methanol for 24 h, and after hydrolysis in 3N HCl (30 min at 37°C) were stained after Feulgen (30 min at 37°C). At least 1000 cells were analyzed in each slide. The incidence of cells with the following nucleus abnormalities (NA) was determined: micronuclei (MN), binucleated cells, karyorhexis, karyolysis, "beaten eggs". This classification of NA is used by the majority of authors, but the data on all above listed abnormalities are not always presented and analyzed for the same sample.

Method of LCS allows determining the dispersion composition of the studied fluid by the relative contribution of particle components into light scattering. The size distribution of particles presented after mathematical processing in the form of a histogram allows characterization of the dispersion composition of a certain biological fluid and classification of the distribution according to chosen informative zones of the spectrum. The increase in the area of low- and medium-molecular-weight modes of LC spectra attests to predominance of processes of biosubstrate degradation, and vise versa increase in the area of high- and superhigh-molecular-weight modes indicates predominance of biosubstrate polymerization. These principles underlie classification determining three types of LC spectra by the character of particle distribution: "normal" spectra and spectra with predominance of anabolic and catabolic processes, respectively (Figure 1). The samples were obtained and the measurements were performed as had been described previously [2].

The data were analyzed using Statistica 6.0 software (one-way dispersion analysis, nonparametric tests).

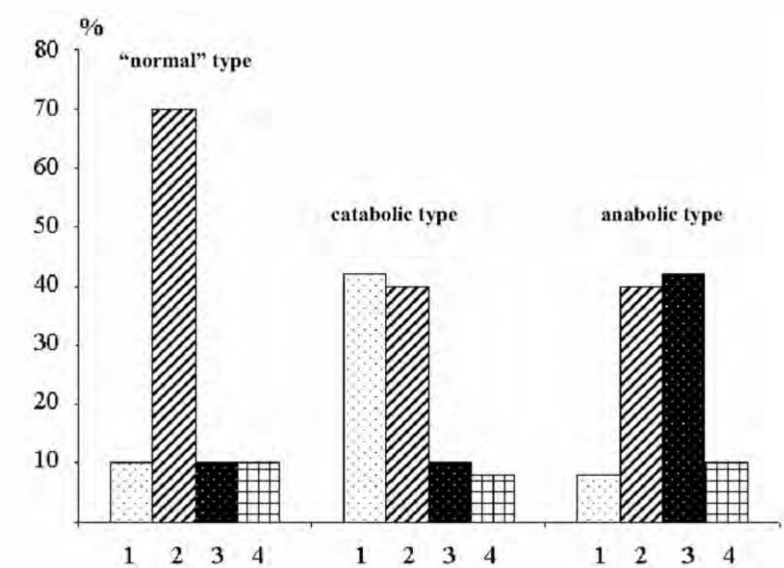

Figure 1. Histograms of size distribution of particles in oropharyngeal washout fluids corresponding to different types of metabolic processes. Size of particles constituting informative zones of the spectrum: 1 – <50 nm; 2 – 51-400 nm: 3 – 401-2000 nm; 4 - >2000 nm. Ordinate – contribution of particles of the corresponding zone into light scattering (%).

Results

As is seen from Table 1, the mean incidence of cells with karyorhexis was minimum in children from the country school in ecologically clean region and maximum in Moscow schoolchildren (higher by ~13 times). In the children from the boarding school the incidence of cells with karyorhexis was found to be intermediate.

These three groups differed also by the incidence of cells with karyolysis: this parameter was minimum in the Moscow schoolchildren, significantly higher in children from the Novgorod region, and maximum in children with musculoskeletal disorders.

Analysis of spectra with consideration for the predominant type of metabolic processes (Figure 1) showed that in children from country school normal spectra and anabolic spectra were most incident (44.0 and 40.0%, respectively), while the incidence of catabolic spectra was low (16.0%) (Figure 2). In children from the Moscow school the percentage of anabolic spectra decreased compared to the corresponding parameter in children from country school ($P<0.05$), which led to an increase in the percentage of catabolic spectra ($P<0.05$). In children with musculoskeletal disorders catabolic spectra were even more incident (66.1%), while the percentage of normal spectra was reliably lower than in the group of country schoolchildren ($P<0.001$). All three of the groups examined differed by the distribution of predominant direction of metabolism ($P<0.001$). The most drastic differences were demonstrated for the contribution of catabolic shifts.

Table 1. Incidence of main nucleus abnormalities in buccal epithelial cells in children from different schools

School	Number of children	Incidence of abnormalities (mean number of cells per 1000 analyzed cells in the sample)					
		Binucleated cells	Pyknosis	Karyorhexis	Karyolysis	Micronuclei	"Beaten eggs"
Boarding school (Moscow)	73	6.04±0.4	14.3±2.3	121.6±8.8[a,b]	31.4±5.1[a]	0.19±0.05	0.6±0.1
School (Moscow)	25	5.3±0.4	7.6±1.2	170.6±23.5[a]	3.0±0.4	0.13±0.07	0.6±0.2
School (Novgorod)	23	4.7±0.4	12.2±2.9	13.9±8.5	7.8±1.9[c]	0	0.3±0.2

Note: a – P<0,001 compared to school in Novgorod region
b – P<0,05 compared to Moscow school
c – P<0,01 compared to Moscow school.

Discussion

Data correlation analysis of the total sampling of the examined children (N=110) revealed a relationship between the direction of metabolic process and the incidence of some NA. In children with catabolic LC spectra we found the maximum number of cells with karyorhexis (r=0,33, P<0.0001 Spearman test) and karyolysis (r=0.2, P<0.05). It can be hypothesized that the release of degraded nuclear material from cells and its lysis increased the contribution low-molecular-weight subfraction into light scattering, which is typical for catabolic processes. These finding agree with previous data on the predominance of catabolic processes in children with spine deformities [2, 4].

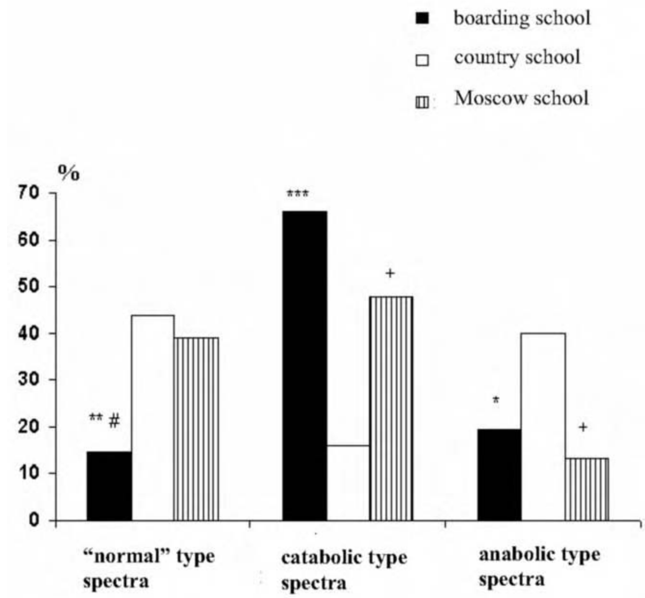

Figure 2. Incidence of spectra characterizing metabolic processes of different directionalities. Ordinate - % of children with the corresponding direction of metabolism from the total number of children in group.

*, **, *** – P<0.05; 0.005; and 0.0001, respectively, compared to country school; # – P<0,02 compared to Moscow school; + – P<0.02 compared to country school (precise two-way Fisher test).

Conclusions

The data produced by the above two methods correlated well: it was found that musculoskeletal diseases and living under ecologically unfavorable conditions is accompanied by a similar genetic and metabolic shift. It is well established that the incidence of musculoskeletal diseases directly correlates with the degree of environmental pollution [5]. The combination of cytogenetic analysis of buccal epithelial cells as peripheral marker of damage to the genetic apparatus and LCS can help to determine risk groups for the development of spinal deformities under conditions of ecological hazard.

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Aggrecan Gene Expression Disorder as Aetiologic Factor of Idiopathic Scoliosis

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Abstract. A pathogenetic mechanism of the idiopathic scoliosis (IS) has been established on the basis of in-depth morphological and biochemical investigations of structural components of the spine in patients with IS (surgical material). We have shown that IS develops on the basis of disturbance of proteoglycans (PG) synthesis and formation in vertebral growth plates. The found keratan sulphate-related fraction is likely a marker of genetic changes in PGs in IS. Long-term our studies demonstrated a major-gene effect in IS. The study has shown that aggrecan gene expression is significantly decreased in cultivated chondroblasts from patients with IS. The presence of keratan sulphate-related fraction and keratan sulphate increase are associated with luminicene increase

Keywords. Pathogenetic mechanism, idiopathic scoliosis proteoglycans

Introduction

Idiopathic scoliosis (IS) has been studied throughout the centuries and problems of its etiology and pathogenesis are the subject of considerable discussion. Not one of the existing theories is commonly accepted. The biomechanical nature of IS has been widely discussed [1, 2, 3] but the cause of the development of deformity without assymetrical load remains unclear, besides, the unloading (brace treatment, bed rest) does not prevent IS progression. The concept of initial injury of central nervous system at different localizations cause a reasonable concern [4, 5]. Neurological disorders are associated only with major spinal deformities when accompanied by spinal cord stenosis. The theory of endocrine nature of IS is not still rejected and opponents rightfully notice the absence of any other symptoms of hormonal disorders in IS children – there are actually no changes in the growth, development, and hormone concentration in the blood [6, 7, 8]. Over the last decades most of authors have accepted that there is a genetic cause on influence in the development of IS genetic nature of the IS development [9, 10, 11, 12].

The study was designed to prove a genetic determination of idiopathic scoliosis. The previous studies of representative samples of pedigrees (three hundreds and sixty families in which the proband had II-IV (second-to-forth) grade idiopathic scoliosis) have proven the major-gene control of high-grade forms of this pathology [9]. The next stage included a search for markers of gene pathology. Such markers were found to be proteoglycans – the most important parts of the growth-plate cartilage matrix.

Morphohistochemical analysis has shown a disturbance of sulphated glycosaminoglycans (GAGs) synthesis in chondroblasts of growth plates at the concave side of deformity in IS early stages (II grade). This is confirmed by a sharply decreased reactivity for RNA (ribonucleic acid) in chondroblast cytoplasm, Furthermore, the enzyme identification of proteoglycans followed by agarose gel electrophoresis not only confirmed the increase of keratan sulphate amount in the matrix of vertebral growth plate of IS patients, but also revealed a fraction still not mentioned in the literature – keratan sulphate linked fraction. The question arises: what processes induce a conversion of synthesis to keratan sulphate one? These changes are most expressed in the most actively synthesing layer – proliferation zone. It could be supposed that changes relate to the structure of aggrecan, the most "representative" proteoglycan in a cartilage growth plate of the vertebral body, namely, the decrease of chondroitin sulphate chains number and the increase of keretan sulphate chains number. The age-related changes in intervertebral disc show a similar situation. Counterargument can be the following: the growth plate is presented by provisional cartilage, and involutive processes for such tissue are unlikely. It must be emphasized that changes revealed in II-IV grade scoliosis persist in late (III-IV (three-to-fourth)) stages that is the evidence of pathognomony of these changes in IS.

In such case the most probable is the change of proteoglycan spectrum in matrix and in cells of vertebral growth plate in idiopathic scoliosis. To test the stated hypothesis we studied aggrecan, lumnican, and biglycan genes in chondroblasts of 15(fifteen) patients with IS (III-IV grade). Chondroblasts were isolated from vertebral growth plates (surgical material) and cultured in vitro. Biglycan, aggrecan and lumnican were studied in cells and in cultured media by RT-PCR method. The aggrecan gene expression was sharply lowered both in cells and in cultured media. Lumnican gene shows a higher expression on this background.

Protein products of these proteoglycans were studied by western blot analysis. Aggrecan core protein also was deficient. Aggrecan gene changes at transcription and translation level testifies to the involvment of aggrecan gene in the IS development. At the same time the revealed high level of lumnican gene expression explains the increase of keratan sulphate amount and occurrence of keratan sulphate linked fraction which can also be the marker of IS development. The next stage of the study is a sequencing of aggrecan gene sequence to determine the exact localization of gene mutation.

Pathogenetic mechanisms of idiopathic scoliosis development. Development of deformity is based on an asymmetrical growth disorder. The time-prolonged growth process consist in intensive synthesis, reproduction of matrix and cells of the growth plate. Side-by-side chondroblasts differentiation and pre-osteogenesis take place.

This process is accompanied by the expression of different genes. Aggrecan gene expresses in all zones of the growth plate, while lumnican gene – in zones of hyperthrophic cells and osteogenesis. The change in aggrecane gene expression results in disturbance of the growth plate main functions, such as metabolite diffusion, barrier function, receptor function – link to hormonal system and signal transduction, chondroblast contact interactions, regulation of cell and matrix reproduction by type of contact inhibition or stimulation of proliferative activity. At a morphological level these disorders manifest as a sharp weakening of reactivity to chondroitin sulphates in cells and in matrix, as a change of chondroblast architectonics, as matrix dissociation, as disturbance of cell ultrastructural organization. Against this background a keratan sulphate amount increases both in matrix and in cell cytoplasm. Proliferative activity of chondroblasts sharply decreased. The osteogenesis process against a disturbance of cells and matrix reproduction is not only unchanged but is activated. Vessels penetrate into proliferation zone, and here bone tissue forms, on one side, due the absence of barrier function and disturbance of anti-invasive factor synthesis, and on the other side, due the increased expression of lumnican – factor of osteogenesis in the growth plate deep layers. Progression of the process results in the growth asymmetry and spine scoliotic deformity. The point of growth asymmetry can be explained by the following: each vertebral anlage forms autonomally, and gene regulation also occurs autonomally. Depending on localization of mutant gene expression, either right-side or left-side scoliotic deformity forms.

One of the complex problems of scoliosis pathogenesis is a manifestation of the spine deformity during the period of intensive growth, which is a time parameter of the mutant gene switching. It is known that the process of development assumes the presence of multilevel system of cell specialization. With the onset of chondrogenic differentiation of vertebral bodies a similar transcription of DNA sequences in chondroblasts occurs. The result is a common metabolic ground for subsequent specific differentiation of cells. This period is characterized by synthesis of receptor proteins which identify inducing substances. During the second period genome regions are transcribed which encode proteins specific for certain organs and cells. This period is characterized by formation of different cell clones and complex system of proliferation and interaction. Cascade multilevel system of genetic control of cell specialization requires special mechanisms for initialisation of transcription processes. As for the formation of structural ensembles in the growth plates – first of all secondary mediators (small RNAs, cyclic AMP) are switched on by the growth hormone and membrane receptors of chondroblasts. Proceeding from the concept of multilevel gene switching, one can suppose that disruption of aggrecan gene transcription occurs in periods of intensive growth, therefore cell and matrix reproduction is violated. The increased expression of lumnican gene results in intensive osteogenesis. If aggrecan gene does not express itself in other structural components of the spine, then why structural changes in the disc and in bone tissue are less apparent? The following theory seems to be valid: disc and growth plate have different functions. Intervertebral disc (annulus fibrosus and nucleus pulposus) performs a cushion and biomechanical functions. It has following structural features: elastin, large amount of collagen and associated with it small proteoglycans (biglycan, fibronectin, and others). Aggrecan provides a diffusion of metabolites. Disruption of metabolite diffusion results in fibrotization and dystrophic degeneration of the disc.

Conclusion

Thus, the study results allow to formulate a following definition of idiopathic scoliosis: genetically dependent spinal deformity inherited by autosomal-dominant type, with incomplete gender- and age-related penentrance of genotype. Pathogenetic mechanism of spine deformity formation is a mutation in aggrecan gene which encodes synthesis and modification of lateral parts of vertebral bodies.

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Genetic Association Study of Insulin-like Growth Factor-I (IGF-I) Gene with Curve Severity and Osteopenia in Adolescent Idiopathic Scoliosis

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Abstract: IGF-I has a pivotal role in bone growth and could be one of the putative disease-modifier genes in AIS. Two SNPs in IGF-I gene promoter region were studied for any association with occurrence of AIS and for their effect on the curve severity among AIS. Methods: 506 AIS girls (Cobb>20°) and 227 age-matched Chinese girls were recruited. The spine (L2-L4) and hip BMD of the subjects were measured by DXA. A subgroup of AIS patients (N=340) who were followed-up to skeletal maturity and the maximum Cobb's angle was recorded. Two SNPs were genotyped by PCR-RFLP (rs5742612 and rs2288377). The chi-square test and one-way ANOVA were used to test the association between genotypes and quantitative parameters, respectively. Results: No association was between the genotypes and the occurrence of AIS and the BMD of the spine and hip. The allelic frequency of T allele was 0.69 in AIS and control. However, the Cobb's angle was higher in patients with the homozygous T allele (Mean Cobb's angle: 38.1° in TT vs 35.9° in TC vs 33.2° in CC group; p=0.04). Discussion: Interestingly, IGF-I polymorphism affects the curve severity of AIS though it was not associated with onset of AIS per se. It indicates that IGF-I may be a disease modifying gene. The importance of IGF-I in skeletal growth makes it a good candidate gene which would play a role in the documented association of rapid growth with curve progression in AIS.

Keywords: Genetic Association, Insulin-like Growth Factor-I, Bone Mineral Density, Curve Severity, Adolescent Idiopathic Scoliosis

Introduction

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional deformity of the spine that most commonly occurs in girls between ages 10-16 during the pubertal growth spurt. The incidence of AIS has been reported to range from 2-4% [1-4]. The conventional clinical prognostic indicators of curve progression such as Risser grade, age, and curve types, have been used for the prescription of bracing. However, the controversy on the necessary of bracing [5,6] indicated that there are, in addition to the compliance with and the design of bracing, unknown predetermined factors which cause the orthotic treatment ineffective [7,8]. Therefore, additional objective prognostic factor(s) during early diagnosis are important to a precise prediction of curve progression in AIS and evaluation of potential treatment efficiency.

The genetic component in AIS has been well accepted [9-13]. In linkage studies, several different loci in different chromosomes have been demonstrated [14-16]. In a recent paper [17], primary candidate regions on chromosomes 6, 9, 16, and 17 have been proposed to be closely related the AIS. Additionally, genetic association study is a method of choice in study of polygenic traits. Although genetic association studies on melatonin 1A receptor and γ1-syntrophin genes produced negative results [18,19], using a case-only sample of 304 Japanese AIS patients, Inoue et al reported an association between the XbaI polymorphism of estrogen receptor-α gene (ESR1) and curve severity of AIS [20]. The case-only study design indicated that XbaI polymorphism was a disease-modifier gene in AIS [21]. To carry out a genetic association study in AIS patients requires identification of additional phenotypes of AIS girls. It has been shown that there is generalized low bone mass in AIS patients [22,23]

The expression of IGFs in skeletal tissues is regulated by GH, estradiol [24]. Previous study showed that newly synthesized IGF-I may directly increase osteoblast proliferation and collagen synthesis [25]. In the growth plate, PTH/PTHrP stimulates chondrocytes proliferation in part by stimulating the production of IGF-I. Thus the IGF-I plays an important role in skeletal growth and bone formation.

We hypothesized that IGF-I gene may have association with occurrence of AIS and their effect on the curve severity among AIS.

Subjects and Methods

Five hundred and six female AIS patients with Cobb's angle above 20° were included as cases and 227 healthy female adolescent as controls. Only Chinese subjects were included. They were first seen between the ages of 12 and 16 years. They all underwent clinical and standard radiological examinations to establish the diagnosis of AIS. Exclusion criteria:- were congenital scoliosis, neuromuscular scoliosis, scoliosis of metabolic etiology, scoliosis with skeletal dysplasia, or scoliosis with known endocrine and connective tissue abnormalities, or prior treatment for scoliosis before being recruited into the study [26]. The curve severity was measured independently by two orthopedic surgeons. For patients with more than one curve in the deformed spine, the curve with the greatest angle was used as the Cobb's angle for analysis. All the controls were examined to rule out any scoliosis. In case of any uncertainty, the clinician would refer the subjects for an x-ray to ensure the absence of any scoliosis. The subject recruitment and study protocol had been approved by the university ethical committee.

The effect of the SNPs of the IGF-I gene on the curve severity of AIS was analyzed in a subgroup of patients (N=340) who had been followed up to skeletal maturity at age 16 and the maximum Cobb's angle was recorded as either the last

Cobb's angle at age 16 for non-operated cases or the largest Cobb's angle before the spinal corrective surgery.

Areal Bone Mineral Density (BMD) by Dual-energy X-ray Absorptiometry (DXA)

BMD measurement of the lumbar spine (L2-4) and bilateral proximal femurs were performed by DXA (XR-36, Norland Medical System, Inc., USA). Standardized protocols for the spine and the femoral neck measurement were followed according to the manufacturer.

Genotype Analysis

The genotyping of the IGF-I gene was preformed on the genomic DNA which was extracted from peripheral blood leukocytes using standard phenol/chloroform extraction[27]. The genotypes were characterized by PCR-RFLP in all 733 subjects. Two SNPs of IGF-I promoter region were choosen (dbSNP#: rs5742612, rs2288377). Standardized PCR protocol was used [28] The PCR products were digested with Bsl I and Ahd I restriction endonucleases and then separated in a 1.5% agarose gel. T was for the absence of the restriction site and C for the presence of restriction site. During the preliminary study, two SNPs of IGF-I promoter were characterized from the 80 individual DNA samples with mix of AIS girls and control subjects, the two sites (Bsl I and Ahd I) were completely linked due to their close vicinity. Thus, only the BslI SNP was genotyped on the complete samples and it was used in the subsequent analysis.

Statistical analysis

The association between genotype of the SNPs and the AIS and the Hardy-Weinberg equilibrium of genotypes were examined by Chi-square test. The BMD was standardized to z-score with age-specific norm. The effect of genotypes on curve severity and BMD was analyzed by one-way ANOVA. Statistical tests of significance were carried out using SPSS 13 for Windows (SPSS Inc., Chicago, IL, USA) with $p<0.05$ as statistically significant.

Results

Association with the Occurrence of AIS

The IGF-I gene polymorphism at the promoter region (IGFI-P) was not shown to be associated with the occurrence of AIS (Table 1).

Association with the curve severity

Significant difference in maximum Cobb's angle between AIS with TT genotype of and those with other genotypes was found (Table 2).

Association with areal BMD by DXA

The z-scores of the spine (L2-L4) BMD and the bilateral femoral neck BMD of AIS girls with different genotypes of the genes showed that the AIS girls had lower BMD. When this is compared to the AIS girls between different genotypes, there was no association of the SNPs of and IGFI-P with any of the BMD measurements even the subjects' laterality and the convexity of the spinal curve were taken into consideration.

Table 1: Association between IGF-I gene polymorphisms at promoter region and AIS

		IGF-I Prom.(rs5742612)				Allele frequency (AF)	
		TT	TC	CC	Total	T	C
AIS	Count	245	209	49	503	69%	31%
	%	48.7%	41.6%	9.7%			
Control	Count	107	94	26	227	68%	32%
	%	47.1%	41.4%	11.5%			
Chi-square between genotypes:		0.768		Chi-square between alleles:		0.530	

Table 2: Association of IGF1 gene promoter with curve severity in term of maximum Cobb's angle of AIS.

	IGF1 Promoter genotypes			
	TT	TC	CC	Total
N	169	138	33	340
Max. Cobb	38.1±12.1	35.6±12.0	33.3±9.0	
	ANOVA: p=0.042			

Table 3: Association of insulin-like growth factor I gene promoter (IGF1P) polymorphism with age-adjusted z-scores of various sites of bone mineral density (BMD) by DXA

	IGF1P (T/C SNP) (a)						
z-score of	Genotype	N	Mean±SD	**z-score of**	Genotype	**n**	Mean±SD
SBMD	TT	242	-0.533±0.918	**SArea**	TT	242	0.194±0.916
	TC	208	-0.516±0.909		TC	207	0.153±0.961
	CC	49	-0.387±0.856		CC	49	0.193±0.908
	Total	499	*P=0.589*		Total	498	*p=0.892*
LFNBMD	TT	241	-0.395±0.980	**RFNBMD**	TT	242	-0.335±0.991
	TC	208	-0.289±0.960		TC	207	-0.289±0.964
	CC	49	-0.323±0.904		CC	49	-0.251±0.962
	Total	498	*P=0.506*		Total	498	*p=0.805*
CvFNBMD	TT	242	-0.417±1.063	**CcFNBMD**	TT	242	-0.339±0.984
	TC	207	-0.320±0.982		TC	207	-0.293±1.062
	CC	49	-0.274±0.952		CC	49	-0.299±0.916
	Total	498	*P=0.493*		Total	498	*p=0.883*
DFNBMD	TT	242	-0.340±0.991	**NDFNBMD**	TT	242	-0.390±0.979
	TC	207	-0.290±0.960		TC	207	-0.288±0.964
	CC	49	-0.243±0.970		CC	49	-0.330±0.894
	Total	498	*P=0.762*		Total	498	*p=0.536*

SBMD: Lumbar Spine L2-L4 Bone Mineral Density; SArea: Lumbar Spine L2-L4 Bone Area; LFNBMD: Left Femoral Neck BMD; RFNBMD: Right Femoral Neck BMD. CvFNBMD: Femoral Neck BMD of the convex side of the curve; CcFNBMD: Femoral Neck BMD of the concave side of the curve; SD: Standard Deviation. (a) The p values shown in the table was obtained from one-way ANOVA.

Discussion

In the present study, the AF of the AIS patients with T (69%) and C (31%) of IGF-I gene was similar to the control subjects. This is also comparable to the data published in HapMap project with 45 Chinese which is shown to be 73% T and 27% C. However, the gene polymorphism of the IGF-I gene promoter region was shown to be significantly associated with the maximum Cobb's angle. The patients with TT genotype of IGF-I promoter would have larger Cobb's angle when compared with other genotypes Although the association of the TT genotypes with the bone mineral density did not show any statistical significance, AIS girls with TT genotypes had lower femoral neck BMD. Thus, the IGF-I gene and it related regions with linkage disequilibrium would play an important role in the pathogenesis of the AIS as a disease modifying gene.

IGF-I plays an important role in growth [29]. In the study on gene polymorphism of IGF-I in postmenopausal women in Korea, the polymorphism at the promoter region of IGF-I gene would affect the serum level of IGF-I and bone mineral density of the women [30]. It is also supported by another studies [31] showing that the polymorphism at the promoter region of the IGF-I gene influences the age-related decline in IGF-I levels. In the present study, even though the site of polymorphism is different from the previous studies mentioned, the polymorphism is also at the promoter region of the IGF-I gene. Further investigation is required to look at the linkage between the present SNPs and the polymorphism reported previously[30,31] to confirm the possible role between the two polymorphism and the association between the present SNP and the serum level of IGF-I in AIS girls. At this stage, it is speculated that the polymorphism of the IGF-I gene promoter would affect the growth rate of the AIS patients during pubertal growth spurt. The rapid growing phase in AIS has been well accepted to be a key element for curve progression.

The present study has indicated that the C allele of the IGF-I gene in the Chinese population occurred in lower frequency than the T allele. When we associated the IGF-I genotypes with curve severity, the screening of the C allele would help to further classify the AIS patients with different curve severity. However, further characterization of IGF-I gene in the role of etiopathogenesis of AIS should be warranted before any clinical genetic application.

In summary, IGF-I SNP was found to be associated with the curve severity of AIS, although the underlying mechanisms of the functionality of the polymorphism of the IGF-I gene is not clear: its characteristic as a disease modifying gene requires further studies to confirm its exact role and its application to other ethnic populations in the prediction of curve progression in AIS patients.

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Chapter 2

Etiology and Pathogenesis

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Changes in Vertebral Neural Arch Morphometry and Functional Tethering of Spinal Cord in Adolescent Idiopathic Scoliosis – Study with Multi-planar Reformat Magnetic Resonance Imaging

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Abstract. With the use of multiplanar reformat Magnetic Resonance imaging, AIS patients were found to have significantly reduced pedicle widths on concavity. Pattern of vertebral asymmetry was also exaggerated with smaller pedicle width, length and area on concavity. The cord appeared more roundish and was deviated to the concavity at apical vertebra in AIS. A tethering force might therefore be present on the cord along the transverse axis in AIS, accounted by the relatively fixed position of the exit nerve roots and deviation of the cord from the exit foraminae of the corresponding vertebra.

Keywords. Magnetic Resonance, Neural arch, Cord, Epidural space

Introduction

Our previous study showed the presence of relative overgrowth of the anterior spinal column in adolescent idiopathic scoliosis (AIS) which is significantly different from normal controls [1]. A significantly reduced spinal cord to vertebral column ratios in AIS patients with severe curve was also found, suggesting a disproportional growth between the neural and skeletal system [2]. Together with the clinical observation of increased incidence of low- lying cerebellar tonsil [3] and abnormal somatosensory study in AIS [4], we have hypothesized that the spinal cord is likely to be subjected to abnormal tethering force from the two ends.

In this study, with the application of multi-planar reformat magnetic resonance (MR) imaging, we sought to investigate the neural arch morphometry and spinal cord shape on the true axial plane of the scoliotic spine.

There are two main areas of interest: Firstly, we sought to compare the neural arch morphometric measurements and symmetry in AIS comparing to normal subjects and to determine any significant differences between the two groups. Secondly, we sought to determine the cross-sectional morphometry (ratio of AP/TS diameter) of the spinal cord and its relative position (ratio of epidural space at convexity / concavity) at the apical vertebra in AIS patients in comparison with normal controls.

1. Methods

1.1. Subjects Population

The study included 45 adolescent girls aged 12 to 15 years. There were 15 healthy controls randomly recruited from two local schools, 30 AIS patients with primary right-sided thoracic curve were randomly selected from the database of our scoliosis center. Among the AIS patients, 15 subjects had mild to moderate curve (Cobbs angle 10˚-35˚, mean 27˚) and 15 subjects had progressive curve (Cobbs angle 40˚-78˚, mean 55˚) requiring instrumentation surgery. Their apical vertebral levels ranged from T7 to T10. All the subjects were age- and sex matched. Using the Cobbs angle, the AIS patients were assigned into the mild to moderate group (<=40 degrees) and severe group (>=40 degrees).

1.2. MRI Examination

Magnetic Resonance Imaging examinations were performed with the use of a 1.5-tesla Unit (Siemens, Sonata, Erlanger, Germany). T2-weighted sagittal image of the whole spine was obtained for screening of any vertebral or spinal abnormalities. Transverse image of the whole thoracic column (T1-T12) was then performed in all subjects using a three-dimensional Tubo spin-echo T2-weighted sequence. Multi-planar reconstruction was performed on a workstation., which allowed simultaneous display of the sagittal, coronal and axial views of the vertebral column while selection of the true axial section through the targeted vertebra was made. Measurements of each vertebra were made at the midpedicle level on a true axial plane, which was parallel to the superior endplate of that particular vertebra regardless of the presence of scoliotic curve. For the AIS patients, the apical vertebra in the primary thoracic curve was selected for measurement while measurements were made from T6 to T10 vertebra in the normal subjects (which included all levels of apical vertebra in the included AIS subjects).

1.3. Neural Arch Morphometry

Computer-assisted on-screen measurements recorded for each vertebra included posterior body length (PBL), pedicle length (PL), lamina length (LL), total pedicle and lamina length (TL), pedicle width at three positions (PW1, PW2, PW3), pedicle area (PA) and pedicel perimeter (PP). Method of measurements of the above parameters was adopted from the paper by Rajawani et al [5]. The details of each measurement are given in Figure 1 and 2.

The PL, LL, TL, PW, PA and PP measurements were taken on both right and left sides of each vertebra. Indexes were calculated by dividing the measurement on the right by the measurement on the left (which was equivalent to dividing the measurement on the convexity by the measurement on the concavity in AIS subjects). Each index was a measurement of asymmetry between the two sides of the vertebra. The same method was adopted by Rajawani et al. A total of eight indexes were obtained which included pedicel length index (PLI), lamina length index (LLI), the total length index (TLI), the pedicel area index (PAI), pedicle perimeter index (PPI) and the pedicle width indexes at each of the pedicle widths (PWI1, PWI2, PWI3).

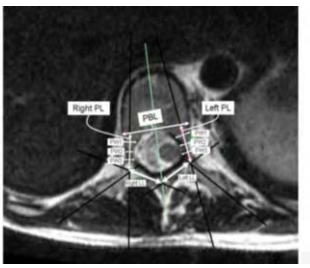

Figure 1
Measurement of length parameters parameters on neural arch

PBL= posterior body length
PL= pedicle length
LL= lamina length
PW1= pedicle width at anterior ¼ portion
PW2= pedicle width at the mid portion
PW3= pedicle width at posterior ¼ portion

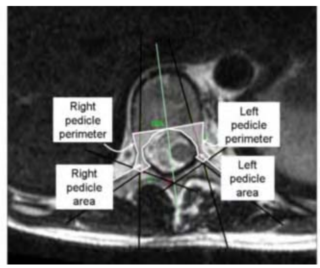

Figure 2
Measurement of perimeter and area on the neural arch

PP= pedicle perimeter
PA= pedicle area

1.4. Spinal Cord Shape and Epidural Space

Measurements of anteroposterior (AP), transverse (TS) diameter and their ratios of the spinal cord, the ratio of epidural space around the cord over the convexity and concavity of the curve were obtained at the apical vertebra parallel to superior endplate in all AIS patients. Same parameters were obtained from the T6 to T10 vertebra in normal subjects and the ratio of CSF space was calculated as right versus left side. The mean values in each normal control were then obtained. Details of the above measurement are illustrated in Figure 3 and 4.

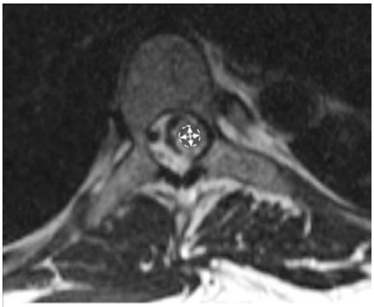

Figure 3
Measurement of Anteroposterior (AP) and transverse (TS) diameter of the cord at the apical vertebra level.

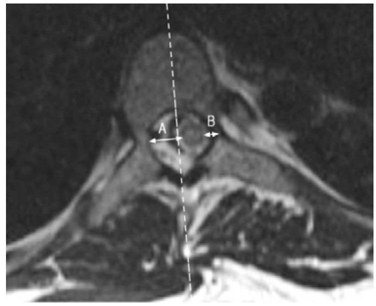

Figure 4
Measurement of epidural space on the convex (a) and concave (b) side of the cord at the apical vertebral level.

1.5. Statistical Analysis

1.5.1.Neural Arch Symmetry and Absolute Value

1.5.2.Comparing Symmetry Indexes Between AIS and Controls

To assess the symmetry of the neural arch, indices for each parameter were expressed as a ratio of right (R)/ left (L), which corresponded to convexity/ concavity in AIS subjects. Values on the right> left if the index >1 and vice versa. The symmetry indexes of each normal subject were calculated as the mean of indexes from T6 to T10 vertebra while only the apical vertebra was measured in AIS subjects. One way Anova and post hoc test was used to compare the indexes in the three groups.

1.5.3. Comparing Absolute Value of Each Parameter Between AIS and Controls

In the normal subjects, the mean and standard deviation of each parameter was calculated for individual vertebra (T6-T10) based on data obtained from the 15 subjects. A z-score was calculated for each parameter at the apical vertebra of the AIS subjects with reference to the mean value obtained at the same vertebral level in the normal subjects. Z-score=0 if value was the same as normal controls; z- score >0 if the measurement was larger in AIS; z-score <0 if measurement was smaller in AIS. One sample t-test was then used for comparison between each AIS group and the normal controls.

1.5.4. Spinal Cord Shape and Epidural Space

The AP/TS ratios of the spinal cord and the ratio of epidural space at convexity/ concavity at the apical vertebra of AIS patients were compared with the mean value of the same parameters in normal control using one-way ANOVA and post hoc test. Correlations of the above parameters were made with Cobbs' angle, ratio of cord length to vertebral column length, position of the cerebellar tonsils and SSEP results using nonparametric Spearman's rho correlations.

Two-tailed probability values <0.05 were considered significant. SPSS for Windows statistical software (Release 13, SPSS Inc., Chicago, Illinois) was used in the analysis.

2. Results

Neural arch morphometry data (expressed as a z-score with reference to the normal controls) and the symmetry indices are summarized in Table 1.
Cord shape and epidural space measurements are given in Table 2.

2.1. Comparing Symmetry Indexes Between AIS and Controls

Normal subjects showed a slightly wider pedicle on the left side at two positions (Pedicle width index, PWI 1=0.87; PWI 2= 0.96). There was no significant asymmetry of the pedicle length while the pedicle perimeter was slightly larger on the right side (Indexes of 0.99 and 1.08 respectively).

For AIS patients with right- sided thoracic curve, they showed a significantly reduced pedicle width or thinner pedicle on the left / concavity side than the right/ convex side. (PWI 1= 1.19 and 1.39 and PWI2=1.50 and 1.54 respectively for moderate and severe scoliosis, $p<0.05$). In the severe AIS group, significant neural arch asymmetry was also observed in the pedicle length and area, which were reduced on the left/ concavity side. (Pedicle length index, PLI= 1.11 and Pedicel area index, PAI= 1.39, $p<0.05$). The above asymmetry was also observed in the moderate group but not yet reached a significant difference when compared with the control groups.

2.2. Comparing Absolute Value of Each Parameter Between AIS and Controls

At the apical vertebra, both severe and moderate AIS groups showed significant ($p<0.05$) reduced pedicle width at three positions on the concavity (max z score –1.22) and at the mid and posterior positions at the convexity (max z score –0.63) when compared with controls. The pedicle and lamina lengths on the concavity were also reduced (mean z score= -0.29 and –0.69 respectively) but not statistically significant.

2.3. Comparing Cord Shape and Epidural Space between AIS and Controls

There was significant increase in AP/TS ratio of the cord (0.91, i.e. more roundish in appearance) in AIS patients at the apical vertebral level than the mean value in normal controls (0.78). The ratio of epidural space around the cord in AIS (convexity/ concavity =7.6 in severe group and 3.3 in moderate group) was also significantly different ($p<0.05$) from that in normal control (R/L= 1.03).

The above ratios were positively correlated with Cobbs'angle and negatively correlated with ratio of cord length to vertebral column length and tonsillar level (all $p<0.05$). AIS patients with abnormal SSEP results had a slightly higher AP/TS cord ratio (ratio=0.99) when compared with those with normal SSEP results (ratio=0.89) but not statistically significant ($p=0.14$).

Conclusions

(1) There was suggestion of abnormal ossification pattern at the neural arch of AIS with significantly reduced pedicle widths on the concavity. The pattern of vertebral asymmetry was also exaggerated with smaller pedicle width, length and area on the concavity.

(2) The cord appeared more roundish in cross-sectional shape and was markedly deviated to the concavity at the apical vertebra in AIS patients. Those with abnormal SSEP results had a slightly higher AP/TS cord ratio. A tethering force might be present on the cord along the transverse axis in AIS, which could be accounted by relatively fixed position of the exit nerve roots and deviation of the cord from the exit foraminae of the corresponding vertebra.

Table 1. Neural arch morphometry and symmetry indices in 15 severe scoliosis (Cobb's angle 40-78, mean 53), 15 moderate scoliosis (Cobb's angle 10-35, mean 27) and 15 sex and age-matched healthy subjects.

	Severe scoliosis (N=15)	Moderate scoliosis (N=15)	Control (N=15)	P value (* significant at 0.05 level)
Posterior body length (PBL) z score	0.427	0.264	0	0.14
Pedicle length (PL)				
Right side (z score)	0.66	0.44	0	0.104
Left side (z score)	-0.29	-0.49	0	0.838
Symmetry index (R/L or convex/concave)	1.11	1.02	0.99	**0.002***
Lamina length (LL)				
Right side (z score)	-0.54	-0.49	0	0.313
Left side (z score)	-0.69	-0.42	0	0.072
Symmetry index (R/L or convex/concave)	1.13	1.09	1.03	0.118
Pedicle width anterior (PW1)				
Right side (z score)	0.58	0.31	0	0.265
Left side (z score)	-0.56	-0.37	0	**0.001***
Symmetry index (R/L or convex/concave)	1.39	1.19	0.87	**<0.001***
Pedicle width mid (PW2)				
Right side (z score)	-0.20	-0.23	0	**0.01***
Left side (z score)	-1.22	-0.93	0	**<0.001***
Symmetry index (R/L or convex/concave)	1.54	1.50	0.96	**0.001***
Pedicle width posterior (PW3)				
Right side (z score)	-0.63	-0.57	0	**<0.001***
Left side (z score)	-1.14	-1.101	0	**<0.001***
Symmetry index (R/L or convex/concave)	1.35	1.36	1.06	**0.019***
Pedicle perimeter (PP)				
Right side (z score)	0.77	1.11	0	**0.005***
Left side (z score)	0.34	1.64	0	**<0.001***
Symmetry index (R/L or convex/concave)	1.07	1.00	1.08	0.15
Pedicle area (PA)				
Right side (z score)	1.25	0.93	0	**0.024***
Left side (z score)	-0.74	0.12	0	0.624
Symmetry index (R/L or convex/concave)	1.39	1.11	1.13	**0.003***

Table 2. Demographic parameters and MR measurements of all subjects. Data are expressed as mean (standard deviation).

	Control	Moderate scoliosis (Cobbs' angle <30)	Severe scoliosis (Cobbs' angle> 40)
Age (years)	13.8 (1.25)	13.3 (0.47)	13.75 (0.45)
Standing height (cm)	155.5(4.86)	157.9 (3.01)	156.4 (10.1)
Cobbs' angle	0**	22.9 (8.3)**	55.1(13)**
Ratio AP/TS cord	0.78 (0.04)**	0.93 (0.15)**	0.91 (0.17)**
Ratio of CSF around cord (R/L)	1.03 (0.14)**	3.35 (1.55)**	7.58 (3.81)**
Total cord length	382.2 (23.4)	373.5 (19.5)	368.2 (27.9)
Total vertebral length (mm)	522.5 (22.9)**	533.0 (23.2)**	546.4 (23.7) **
Cervical vertebral length (C1-C7) (mm)	107.3 (6.59)	108.7 (5.95)	110.1 (5.62)
Thoracic vertebral length (T1-T12) (mm)	257.9 (11.1)**	263.7 (17.0)**	273.3 (12.1)**
Lumbar vertebral length (L1-L5) (mm)	157.2 (7.13)	160.6 (5.5)	163.0 (11.3)
Cord/ vertebral length ratio	0.73 (0.02)**	0.70 (0.02)**	0.67 (0.05)**
Position of cerebellar tonsils from BO line (mm)	4.4 (3.9)**	-0.26 (2.9)**	-0.27 (3.0)**

**One-way ANOVA , p<0.05

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"Syndrome of Contractures" (according to Mau) with the Abduction Contracture of the Right Hip as Causative Factor for Development of the So-called Idiopathic Scoliosis

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Abstract. The article provides basic explanation of "syndrome of contractures" (Mau) at newborns and babies and it's conjunction with biomechanical etiology of the so-called idiopathic scoliosis (Karski 1995-2006). The authors analyzed children with "syndrome of contractures" and noted its relevance to some clinical symptoms at children with scoliosis. Newborns and babies with clinical signs of „syndrome of contractures" require further spine examination already at age of 3-4 in order to detect "danger of oncoming scoliosis" and to introduce neo-prophylaxis. The research based on "syndrome of contractures" can explain predominance of female gender of patients with scoliosis, sides of curves, side of rib hump, progression and sensibility to new rehabilitation exercises.

Key words.„Syndrome of contractures", etiology of the so-called idiopathic scoliosis

1. Introduction

A lot of malformations of skeletal system can be related to deformations already taking place in last months of pregnancy. These deformations are called „syndrome of contractures" („*Siebener [Kontrakturen] Syndrom*"). This „syndrome" has been described primarily by May [1, 2] and also among others by: Hensinger [3], Howorth [4], Green & Griffin [5], Vizkelety [6], Komprda [7], Karski [8, 9, 10, 11, 12], Tarczyńska, Karski & Karska [13]. The causes of the „syndrome of contractures" can be related with fetus itself (large weight, large length) or with mother conditions (small belly during pregnancy, lack of amniotic fluids, pelvic bone type: "androidal" or "platypeloidal"– inconvenient for proper fetus growth [13]).

2. Information about „Syndrome of Contractures"

In most cases of pregnancies we observe left sided "syndrome of contractures". That is connected with first fetus position during pregnancy which is most common at 80%-85% (90%) of all pregnancies (Oleszczuk) [14]. The fetus body, meaning: head, trunk, pelvis are pressed to the left side of mothers spine. This may result in some typical deformations (primarily unfixed) of skeletal system called "ultra-positioning" by Dega [15].

The left-sidedness of fetus positioning provides a typical clinical view of the "syndrome of contractures" at newborns and babies and later at older children of typical topography of deformities (Karski). Professor Mau gave a detailed description of *„Siebener [Kontrakturen] Syndrom* [1, 2] – "the syndrome of seven contractures".

These are:

1. scull deformity /plagiocephaly/ - flattening of left forehead and temple regions, left chick atrophy, eyes asymmetry, nose and ears deformations
2. torticollis – usually left-sided. Can be related with plagiocephaly and lack of proper head positioning, and also with primary shortening of sterno-cleido-mastoideus muscle (neck muscle) torticollis with *tumor neonatorym*
3. *scoliosis infantilis* (infantile scoliosis) – usually right convex lumbo-thoracis curve. This type of spine deformity was during many years improperly added to the group of idiopathic scoliosis. This scoliosis usually recedes spontaneously [20, 22, 23]. Some authors described its disappearance at 80% of cases [4] or even at 100% (Mau) [1, 2]
4. contracture of adductor muscles of the left hip. Untreated contracture can lead to development of hip dysplasia, which primarily can be observed only at 10% of newborns [10]. The remaining 90% of dysplasia are cases of secondary deformity resulting from the contracture and are classified as "developmental hip dysplasia" (DDH). Untreated contracture of adductors enlarges dysplasia
5. contracture of abductor muscles of the right hip (Karski) [2, 9, 12, 16], described as *Haltungsschwäche* by Mau. This contracture may cause oblique positioning of pelvic bone observed at hip joint X-ray picture of babies and young children. With time it may lead to disturbances of biomechanics (asymmetry during gait, asymmetry in growth and development) and "permanent habit of standing on free only on the right leg" (the right leg is stronger and more stable due to the contracture!) which in result leads to development of the so-called idiopathic scoliosis (Karski 1995-2006) with division into three etiopathologial groups [17])
6. pelvic bone asymmetry – the abduction contracture can influence the pelvis positioning visible during X-ray examination for hip joint screening (Fig. 1)
7. feet deformities – such as: pes equino-varus, pes equino-valgus, pes calacneo-valgus or pes calacneo-valgus adductus

Figure. 1a, 1b – Girl, history number: 971029 (1a) - obliquity of pelvis caused by abduction contracture of the right hip 5 degree (examination in straight position of the joint), adduction contracture of the left hip - left hip dysplasia. (1b) – after successful DDH treatment – the oblique position of the pelvis remains. Necessity of spine examination after 3-rd year of life.

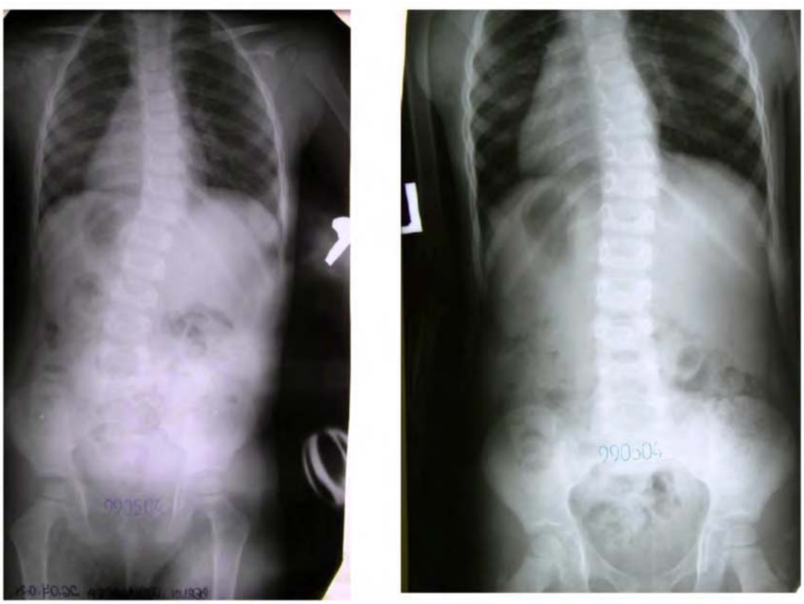

Figure. 2a, 2b - Girl, history number: 990504 (2a) X-ray examination at 3-rd year of life shows beginning of I-st epg of the so-called idiopathic scoliosis – "S" double scoliosis. (2b) Two years later - during new rehabilitation treatment.

3. Material and methods

3.1. Analysis of the Material of Newborns

The analysis was conducted on 300 histories of babies and children examined in Outpatient Department in the years 1999-2001 [13]. The age of children was from 3 weeks to 12 months. These children were examined for different problems of asymmetry, deformations and malformations of movement apparatus [3, 15]. At 97 children from this groups we noted different symptoms of „syndrome of contractures". These were 74 girls and 23 boys. „Syndrome of contractures" of the left side was noted at 55 children, of the right side at 42. The relation left:right was different than in fetus positioning (85%:15%) since the children [n. 300] were examined by general doctors with visible pathology and sent to specialist for further consulting. The analysis showed that most of these children were from first pregnancy (80%), mothers had small bellies during pregnancy (mother's reports), usually the bellies were "flattened". The mothers informed about lack of amniotic fluids. The newborns at birth were heavier or longer than normal [13]).

3.2. Analysis of the Material of Children with Scoliosis

An additional analysis was conducted on 100 histories of children with the so-called idiopathic scoliosis aged 5-8 years. At 20 of them we noted abduction contracture of the right hip ranging from 5 to 10 degrees or adduction movement 0 degrees, but at the left hip at the same time the adduction was 35-40-45-50 degrees. At these children we noted initial stages of the so-called idiopathic scoliosis typical for the I-st etiopathological group (I-st epg) [18]. We noted clinically: loss of spine flexion, disappearing of *processi spinousi* under the skin Th6- Th12, flat back sometimes with lordotic deformity of thoracic spine. In 3-dimensional [3D] deformity of scoliosis the rotation deformity is the first. The angles of curves at X-ray examination were of several to 10 degrees (Cobb). The children were included into prophylaxis programs. The second group of 80 children with primary "syndrome of contractures" showed only limitation of right hip adduction in comparison to the left one. Adduction of the right hip 10-15-25 degree, of the left hip 35-40-45-50 degree. We noted only slight waist asymmetry, functional shortening of left lower extremity with normal spine flexion (35 children). At remaining 45 children we noted "functional" left lumbar convex scoliosis in spine flexion-rotation tests (Lublin side bending test). At these children we noted initial stages of the so-called idiopathic scoliosis typical for the II-nd etiopathological group (II-nd epg) [17]) – lumbar left convex or sacro-lumbar left convex or lumbo-thoracic left convex scoliosis.

4. „Geography" and Some Clinical Symptoms of the So-Called Idiopathic Scoliosis in Relation to „Syndrome of Contractures".

Some unexplained question marks in etiology of idiopathic scoliosis can be answered in relation to "syndrome of contractures".

A/ Why scoliosis occurs mostly at girls? - Because the contracture of the right hip is connected with the "syndrome of contractures" which is mostly at girls (ratio boys:girls is 1:5) [1, 2].

B/ Why lumbar left convex and thoracic right convex scoliosis? Rib hump on right side? - the sides are connected with the "geography" of "syndrome of contractures". First fetus position is at 85% - 90% pregnancies when the child is placed on the left side of mother's uterus may cause the right hip abduction contracture. The „S" and „C" types of scoliosis (I-st and II-nd epg groups) depend on the range of right hip abduction contracture in comparison to the left hip [19].
C/ Progression of scoliosis in acceleration period of child's growth. Especially in second phase of acceleration the extremities grow faster than trunk [20]. Contractures (right hip abduction contracture also with flexion and external rotation – Karski, Cheneau, Matussek) [12] disturb radically the biomechanics of a growing child leading to fast progression of scoliosis especially in I-st epg (development of scoliosis connected with gait) [18, 19]. The faster growth of legs than trunk was also observed by Dimeglio [20].

Clinical observations indicate that progression in I-st epg is especially fast at children with joint laxity, rickets, pelvis and lumbar spine anatomy anomalies, chest and ribs deformities (*pectus infundibiliforme*). Early signs informing about danger of scoliosis are among others stiffness of spine with "flat back" and habit of permanent sitting straight up and stand "at free" only on the right leg.

The III-rd epg described in 2004 consists of older patients with "back pain" and stiffness of spine. The early symptoms at that group were similar to the beginning of scoliosis in I-st epg but the later development was different and no progression of curves was present over the years.

5. Conclusions

1. Newborns and babies require detailed examination to discover symptoms of „syndrome of contractures".
2. Early prophylactic and preventive programs should be introduced at theses children in accordance to type of skeletal malformation (scull, neck, spine, hips, feet).
3. Children aged above 1 year (after treatment of DDH if any) should be examined to discover the difference of adduction movement of hips and in case of asymmetry of adduction - periodical spine examination.
4. Any asymmetry of pelvis at X-ray examination of babies (in DDH screening) should be later remembered as possible danger for spine development at children 3-4 years old and later.
5. The spine X-ray in scoliosis screening should always comprise hip joints. Loading of both legs should be symmetrical, knees straight and feet should be placed together.
6. To evaluated danger of oncoming scoliosis we should use new clinical tests and early prophylactics programs already for children 3-4 years old [21]. Children should sit physiologically, never straight up; sleep in fetus position and stand "on free" on the left leg as easy but important protection against scoliosis.

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Scoliotic Progression Patterns in Prognostic Factors and Future Prediction of Spinal Deformity Progression

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Abstract. This study investigated how an adolescent idiopathic scoliosis progresses with time. 154 consecutive measurements from 26 consecutive AIS patients were analyzed. Each subject had at least four successive scans at six-month intervals.

Progression patterns of Cobb angle and apex lateral deviation were extracted from 34 serial data sets of the most common AIS type RT-LL, in the format of four serial data sets, by using the fuzzy c-means clustering technique. Progression of spinal deformity was predicted with previous serial data of Cobb angle and apex lateral deviation by using a GCV extrapolating technique alone and in conjunction with progression patterns.

Our results showed that scoliotic progression appears to follow progression patterns. Progression of spinal deformity has potential to be accurately predicted with previous serial spinal deformities by using GCV extrapolating technique with assistance of progression patterns.

Keywords. Scoliosis, progression pattern, prediction, fuzzy c-means, GCV technique

1. Introduction

Various factors are associated with curve progression, such as gender, age, curve pattern, curve magnitude, apex location, growth velocity [1-6], although it is not clear to what extent they can be used in predicting the course of the natural history of the scoliotic curve [7-10]. With serial natural histories of adolescent idiopathic scoliosis in six-month intervals, we showed that progression of scoliosis was more significantly associated with gender, curve pattern, curve magnitude, apex location and lateral deviation than age and spinal growth [11]. To date, it is still not clear whether the scoliosis progression follows a distinct pattern with time and how the scoliosis deformity progression can be predicted from the scoliotic torso surface asymmetry and the serial spinal deformities.

Thus, the purpose of the current study was to quantify temporal, prognostic scoliotic progression patterns and to predict the future deformities of spine based on the past serial spinal deformities. We hypothesized that spinal deformities of AIS patients would smoothly and predictably change with time.

2. Materials and Methods

Inclusion criteria were: (1) the diagnosis of AIS in patients older than 8 years; (2) no instrumentation/surgery during consecutive measurements; and (3) at least 3 successive follow-ups after the first visit in the 6-month interval. Two standing whole spinal radiographs in posteroanterior (PA) 0° and PA 20° angled down were obtained for all patients at each visit. A total of 26 consecutive patients with AIS (21 females and 5 males, 11.8 ± 2.0 yr, range 8.6–15.5 yr, Cobb angle 29.6 ± 10.4°, and range 12.2–55.0° at the first visit) met these criteria (1997 to 2002 database). There were 154 consecutive measurements in total (Table 1).

A 3D spinal curve was represented by the line passing through the pedicle centers of a geometric spine, reconstructed from PA 0° and PA 20° spinal radiographs [12-14]. Based on the terminology in the *Scoliosis Research Society*, a computed Cobb angle was calculated from the angle between perpendiculars to the spine curve at inflectional points, apex location, and apex lateral deviation the distance of apical point from the vertical line from L5. Spinal length was the distance from T1 to L5 on the coronal plane and in space.

The database of consecutive data of spinal indices of 154 AIS patient measurements further formed two sub-databases with four or five sequential values respectively.

Progression patterns of scoliosis were conducted on simultaneous changes of curve magnitude and apex lateral deviation with respect to the data at the first diagnosis with time by using the fuzzy c-means clustering algorithm [15]. By considering the generalization, progression patterns focused on Right Thoracic-Left Lumbar (RT-LL) pattern (measurements n = 73) only and were extracted from the major curves RT.

Prediction of scoliosis progression was conducted for both four ($[S_1\ S_2\ S_3\ S_4]$) and five ($[S_1\ S_2\ S_3\ S_4\ S_5]$) serial data sets by two methods: Generalized Cross-Validation (GCV) extrapolation [16,17] alone, and in conjunction with progression patterns.

(1) GCV Extrapolation Alone

Previous serial data (e.g., S_1, S_2, S_3 and S_4 of a five serial data set) were used to predict future scoliosis progression (e.g., S_5) with (GCV) extrapolation technique.

(2) GCV Extrapolation with the Assistance of Progression Patterns

First of all, the previous three serial data (S_1, S_2 and S_3) were used to predict future scoliosis progression (i.e., the fourth one S_4). A matched progression pattern (Ω_k) was obtained by finding the minimal root mean square error (RMS) of the first three serial data sets between the serial data set and progression patterns ($\Omega_i = [\Omega_{1,i}\ \Omega_{2,i}\ \Omega_{3,i}\ \Omega_{4,i}]$, $i = 1, 2, ..., c$, where c is the number of patterns). The progression tendency of the matched pattern (Ω_k) was used to guide the GCV extrapolation.

Further, all four serial data sets (S_1, S_2, S_3 and S_4) were used to predict future scoliosis progression (i.e., S_5). A matched progression pattern (Ω_k) was found by searching a minimal RMS error between the serial data set and the progression patterns (Ω_i). The progression tendency of the matched pattern (Ω_k) and the difference ($\Delta\Omega S_j$, $j = 1, 2, 3, 4$) between the serial data set and the progression pattern (Ω_k) were used to guide the GCV extrapolation.

Prediction accuracy was calculated by comparing the predicted data to the actual data. The relationships between predicted data and actual data were determined using Pearson's correlation coefficient (r).

3. Results

A total number of 128 and 71 data sets of Cobb angle and apex lateral deviation in four and five serial data, respectively, were extracted from the database of 26 AIS subjects. Thirteen AIS subjects (12 females and 1 male) with RT-LL had a mean age of 12.2 ± 2.3 yr (range 8.6–15.5 yr) and a mean Cobb angle of 31.7 ± 8.4° (range 16.6–42.7°) at the first visit. Serial measurements of those subjects formed 68 and 42 data sets in four and five serial data, respectively.

3.1 Progression Patterns

Five progression patterns in four serial data were extracted from 34 data sets of Cobb angle and apex lateral deviation of the major curves RT of double curve pattern (Figure 1). For the first pattern (P_1), Cobb angle (*Cobb*) and apex lateral deviation (*LatDev*) decreased linearly with time. In the second pattern (P_2), *Cobb* decreased at a moderate speed in the first year and then increased quickly, while *LatDev* changed smoothly in a

Table 1. Distribution of curve patterns and genders of AIS subjects and visits

Curve Patterns	Total Subjects	Female Subjects	Total Visits	Female Visits
Left Lumbar (LL)	2	1	13	4
Left Thoracic (LT)	2	2	13	13
Left ThoracoLumbar (LTL)	1	1	10	10
Right Lumbar (RL)	1	1	8	8
Right Thoracic (RT)	7	4	37	19
Right Thoracic and Left Lumbar (RT-LL)	13	12	73	63
Total	26	21	154	117

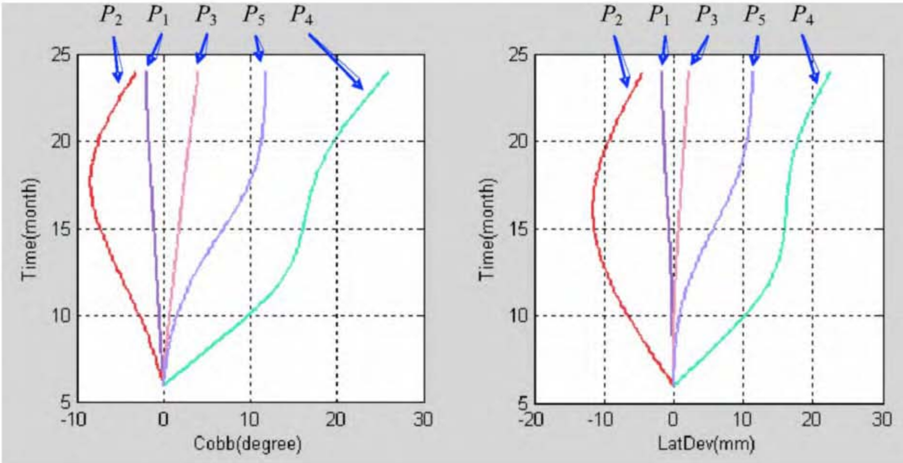

Figure 1. Five progression patterns of double curve ('RT-LL') type were extracted from four-serial data sets in 6-month intervals. Left pane: Cobb angle (*Cobb*) vs. time; Right pane: Apex lateral deviation (*LatDev*) vs. time.

quadratic curve. In contrast to P_1, *Cobb* and *LatDev* increased linearly with time in the third pattern (P_3). Spinal curves progressed rapidly in the fourth pattern (P_4). *Cobb* and *LatDev* increased quickly in the first 6 months, followed by moderate increases in the next 6 months, then increased at a high speed again. In an opposite progression manner of P_4, *Cobb* and *LatDev* increased slowly in the first 6 months, followed by rapid increases, and then slow increases again in the fifth pattern (P_5).

3.2 Prediction Accuracy by Using GCV Extrapolating Technique Alone

3.2.1 Four Serial Data Sets

For the overall 128 four-serial data sets, prediction accuracies with previous three serial data (S_1, S_2 and S_3) for the fourth data (S_4) were 3.1 ± 3.1° (3.7° within 95% confidence interval) and 3.1 ± 3.2 mm (3.6 mm within 95% confidence interval) for Cobb angle and apex lateral deviation, respectively. Regression *r*-values were 0.99 and 0.98 for Cobb angle and apex lateral deviation.

For the 34 four-serial data sets of RT-LL, prediction accuracies of RT curve were 3.2 ± 3.4° (4.4° within 95% confidence interval) and 3.6 ± 3.9 mm (4.9 mm within 95% confidence interval) for Cobb angle and apex lateral deviation. Linear regression *r*-values were 0.94 and 0.88.

3.2.2 Five Serial Data Sets

For the overall 71 five-serial data sets, prediction accuracies with previous four serial data (S_1, S_2, S3 and S_4) for the fifth data (S_5) were 3.3 ± 3.4° (4.0° within 95% confidence interval) and 3.1 ± 3.2 mm (3.8 mm within 95% confidence interval) for Cobb angle and apex lateral deviation, respectively. Regression *r*-values 0.99 and 0.98 for Cobb angle and apex lateral deviation. For the 21 five-serial data sets of RT-LL, prediction accuracies of RT curve were 3.7 ± 3.8° (5.3° within 95% confidence interval) and 4.0 ± 4.0 mm (5.7 mm within 95% confidence interval) for Cobb angle and apex lateral deviation. Linear regression *r*-values were 0.92 and 0.85.

3.3 Prediction Accuracy by Using GCV Extrapolating Technique with the Assistance of Progression Patterns

3.3.1 Four Serial Data Sets

With an assistance of progression patterns of four serial data, prediction accuracies of thirty-four serial data sets in the format of four serial data in six month intervals were 2.6 ± 2.9° (3.6° within 95% confidence interval) and 3.2 ± 3.0 mm (4.2 mm within 95% confidence interval) for Cobb angle and apex lateral deviation. Regression *r*-values were 0.96 and 0.92 (Figure 2).

3.3.2 Five Serial Data Sets

By considering the progression tendency of serial data sets and the differences between the serial data sets and the matched progression patterns, prediction accuracies of 21 serial data sets in the format of five serial data in six month intervals were 4.1 ± 3.7° (5.7° within 95% confidence interval) and 4.8 ± 3.9 mm (6.4 mm within 95% confidence interval) for Cobb angle and apex lateral deviation. Regression *r*-values were 0.95 and 0.86.

4. Discussion and Summary

The progression patterns were extracted from scoliotic data of double curve type RT-LL only in the current study. However, the methodology can be expanded into other curve types provided there is a large size of data available. The magnitudes of progression patterns may vary somehow with a large sample size, but the progression tendencies won't change because the data size used in this study was sufficiently large for generalization [15]. The results showed that the progression patterns of Cobb angle were similar to ones of apex lateral deviation.

For the prediction of future spinal deformity by three previous serial data in 6-month interval, prediction accuracies for double-curve type were improved from 4.4° and 4.9 mm with GCV extrapolation technology alone to 3.6° and 4.2 mm with an assistance of conjunct progression patterns of four-serial data set. These results indicated that the prediction of future spinal deformity took advantage of available progression patterns. Predictions by four previous serial data were more accurate with GCV alone than the combination of GCV and progression patterns. The reason may be that the GCV technique is more suitable for a non-linear problem [17].

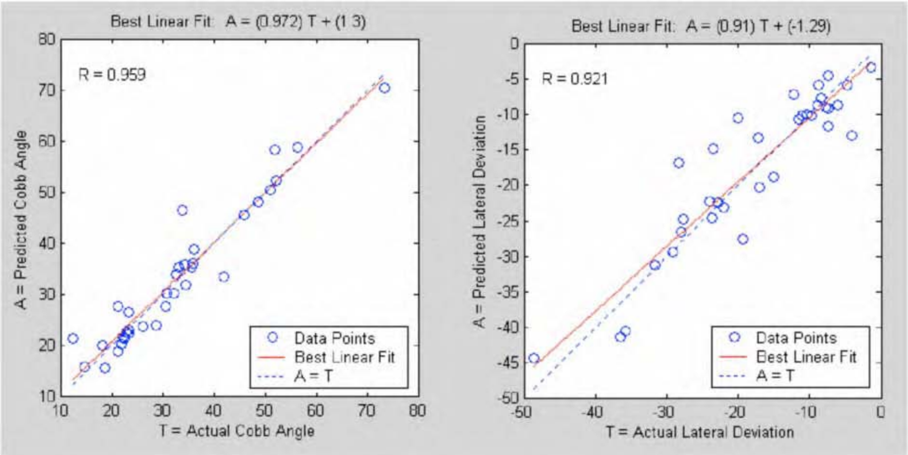

Figure 2. Prediction accuracies of Cobb angle and apex lateral deviation with previous three serial data by using GCV extrapolation technique with an assistance of progression patterns.

In summary, successful extraction of five progression patterns of four-serial data set of double-curve type for Cobb angle and apex lateral deviation indicated that scoliotic progression does follow certain progression patterns of prognostic factors. Progression of spinal deformity could be accurately predicted with previous serial spinal deformities by using GCV extrapolation technique and assistance of progression patterns. More precise prediction of spinal deformity may be expected from more accurate reconstruction of the 3D spine. GCV extrapolation technique is promising for prediction of scoliosis progression from torso surface asymmetry. Prediction of future spinal deformities of other types of curves will continue to be assessed and prediction of future deformities of a true 3D spine with previous serial 3D spines will be studied with an accurate 3D spine sample.

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Persistent Osteopenia in Adolescent Idiopathic Scoliosis - Longitudinal Monitoring of Bone Mineral Density until Skeletal Maturity

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Abstract. The aim of this study was to monitor BMD changes occurring during periods of rapid growth and to investigate whether osteopenia was a persistent phenomenon in skeletally matured AIS girls. 196 AIS Chinese girls and 122 healthy controls, aged 11-16, were follow-up for 3.5 years. Bilateral femoral neck bone mineral density (BMD) and volumetric BMD (vBMD) of the distal tibia were obtained by dual energy X-ray absorptiometry (DXA) and peripheral quantitative computed tomography (pQCT). Osteopenia was defined if the age-adjusted BMD was below or equal to –1 standard deviation (SD). The average age at the final follow-up was 16.8 years old. The median initial Cobb angle for this group of patients was 26°. The prevalence of osteopenia at the baseline measurement was 35.9%. Longitudinal BMD results demonstrated that 86.0% of osteopenic AIS girls had persistently low BMD at the time of skeletal maturity (age of 16). vBMD of distal tibia of AIS was significantly lower than that of the controls throughout the age of 13 to 17 during the period of rapid growth. In addition, there were also significant differences in vBMD among AIS (moderate and severe group) and the controls by one-way ANOVA ($p<0.05$). The present study for the first time revealed that over 86% of osteopenic AIS patients had persistently low BMD, at both distal tibia and femoral neck regions, at the time of skeletal maturity. Early detection and treatment of AIS-related osteopenia might help in maximizing peak bone mass during peripubertal growth that thereby minimizing risks of developing osteoporotic fractures later in life.

Keywords. Adolescent idiopathic scoliosis, Osteopenia, Bone mineral density

Introduction

Adolescent idiopathic scoliosis (AIS) is a three dimensional spinal deformity, with a lateral curvature of at least 10° [1]. Previous studies showed that girls with AIS had significantly lower bone mineral density (BMD) than that of the age- and sex-matched normal controls. A cross-sectional study consisted of 300 AIS and 250 normal controls demonstrated that osteopenia was manifested in about 27-38% AIS girls [2]. Recent studies demonstrated that there was an inverse correlation between osteopenia and curve severity [3]. Moreover, osteopenia was found to be one of the risk factors in predicting curve progression in AIS [4].

Osteopenia is not a localized problem in AIS patients. Using both axial and peripheral bone densitometries, systemic osteopenia was also found in both the spine and hip, as well as in the peripheral skeleton [2]. However, only a few studies reported the long-term changes of the bone mineral density in AIS girls. Thomas *et al.* (1992) [5] and Cheng *et al.* (1999) [6] performed longitudinal follow-up studies which found that girls with AIS, who found to be osteopenic at the baseline measurement, would consistently have osteopenia at follow-up measurements. The limitations of these studies were that the sample size is relatively small (less than 40) and the age of patients at end point measurement was not identical. Bone mineral accretion in the pubertal period is crucial for determination of peak bone mass in adulthood. A prospective study on the BMD changes in AIS is needed to confirm the previous observation of persistent osteopenia in AIS girls. The objectives of this study were to monitor BMD changes in both the axial and peripheral skeleton and to investigate whether osteopenia was a persistent phenomenon in skeletally matured AIS girls.

Methodology

196 AIS girls and 120 age-and sex-matched normal controls were recruited. All AIS patients were recruited in the Scoliosis Clinic, Prince of Wales Hospital (Hong Kong) and were diagnosed by experienced physician. Standard radiography was undertaken and the initial Cobb angle recorded. Normal controls were randomly recruited from local schools. All normal control subjects were screened with a forward bending test to confirm their status. All subjects with a history of congenital deformities, neuromuscular or endocrine diseases, skeletal dysplasia, connective tissue abnormalities or mental retardation were excluded from the study. Informed consent was obtained as appropriate prior to the BMD assessments.

Dual energy X-ray absorptiometry (DXA, XR-36, Norland medical systems, Inc., WI, USA) was used to measure the BMD of the bilateral proximal femora for all subjects. Areal BMD (aBMD) of the femoral neck region can be obtained from DXA scans. Spine BMD was not measured because it has been shown that the BMD values are significantly reduced when the lateral rotation of vertebra increases [7,8]. Therefore, the proximal femur was regarded as a reliable region for assessing bone mineral density in a patient with scoliosis. The *in-vivo* precision error of the femoral neck region was 2.07%. Age-adjusted BMD (Z-score BMD) was calculated for all BMD data. Osteopenia was defined if Z-score BMD $\leq$ -1 standard deviation (SD).

Volumetric BMD (vBMD) of the non-dominant distal tibia was measured by peripheral quantitative computed tomography (pQCT, Densiscan 2000, Scanco Medical, Switzerland). pQCT is a three dimensional multi-slice scanner which measures the true volumetric BMD (vBMD) of the peripheral skeleton [9]. Parameters can be obtained by pQCT include: vBMD, in g/cm^3, of the integral or total BMD (iBMD) and trabecular (tBMD) of the distal extremities, using a scanning resolution of 0.3mm [10]. The coefficient of variation (CV) of repeated measurement at the distal tibia was 0.82% for our study population.

Each subject underwent longitudinal follow-up assessment until they reached skeletal maturity or age $\geq$ 16. All BMD and anthropometric measurements, including body weight, body height and armspan, were recorded for at least 2 time points. AIS patients were categorized into moderate (Cobb angle between 20° to 39°) and severe

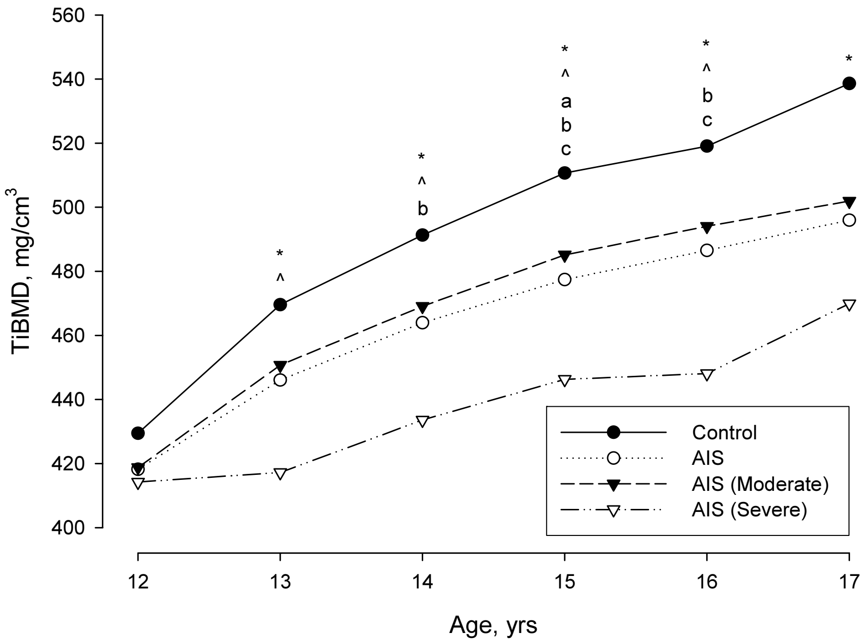

Figure 1. Graphic representation of site-specific BMD accrual for AIS (moderate and severe curve severity) and Controls by chronological age for vBMD of distal tibia (TiBMD)

* p<0.05: comparison between AIS and Control by t-test;

^ p<0.05: comparison among AIS moderate, severe and control by One-way ANOVA;

Post hoc Bonferroni multiple comparison:

a: p<0.05 (Control vs. Moderate),

b: p<0.05 (Control vs. Severe),

c: p<0.05 (Moderate vs. Severe)

groups (Cobb angle ≥40°) according to the initial Cobb angle. Descriptive data are expressed in mean ± SEM or median and inter-quartile range (IQR). Student's t-test was used for group comparison. One way ANVOA coupled with *post hoc* Bonferroni adjustment was used for the group comparison of longitudinal data. Data were analyzed by SPSS version 11.0 (SPSS Inc., Chicago, IL, USA).

Results

A total of 316 AIS patients and controls, aged 12-16, were recruited and completed the longitudinal measurements over an average of 3.6 years. At baseline, the mean age for AIS and controls were 14.5 and 13.8 years old respectively. 82.7% AIS patient had a moderate curve and the average Cobb angle (median and IQR) was 26° (19°-33°). The menarchal status for both AIS and controls were similar; 62.8% of AIS and 62.9% of normal controls were post-menarche at the baseline measurement. Results of femoral neck BMD demonstrated that the prevalence of osteopenia (Z-score ≤-1 SD) at the baseline measurement was 35.9% (n=71).

At the final follow-up measurement, the mean age of all subjects was 16.8 years old. The average Cobb angle of AIS patients was 28° (20°-35°). DXA results showed that 61 of the osteopenic AIS patients remained at a consistently lower BMD at skeletal maturity (86.0%). The longitudinal results of the vBMD of distal tibia showed that vBMD of AIS was significantly lower when compared to that of the controls from age 13-year through to 17-year ($P<0.05$), and that there were also significant differences in vBMD of tibia among AIS (moderate and severe group) and the controls by one way ANOVA ($P<0.05$) (Figure 1). *Post hoc* Bonferroni adjustment showed that vBMD of the severe group was significantly lower than that of the controls from age 14 to16 years ($P<0.05$), and that vBMD of the moderate group was significantly lower than that of the controls at age 15 years ($P<0.05$) (Figure 1).

Discussion and Conclusion

The present study revealed that about 86% osteopenic AIS girls had a persistently lower BMD than those of the age-matched controls. In the literature, there are a limited number of longitudinal studies monitoring BMD changes in AIS patients, all of which reported on small sample sizes [5,6,11]. Results from the present study supported the previous findings [6] in which AIS girls with osteopenia at the baseline remained osteopenic throughout the follow-up period. Thomas *et al.* (1992) followed up 22 AIS girls for 31 months and found that about 50% of the patients were osteoporotic in both the spine and femoral neck, with a BMD of less than -2 SD of their normal reference values. Findings from the present longitudinal study confirmed the findings of previous studies [2,12,13] in that generalized osteopenia exists in AIS patients and that osteopenia may persist throughout the growth period in adolescence.

Sub-optimal bone mineral accretion at skeletal maturity may lead to lower peak bone mass in AIS girls. Osteopenia was found to be associated with a low calcium intake, low physical activity and inversely correlated with curve severity in AIS girls [3, 14]. It is well known that nutritional intake is an important factor affecting skeletal development and BMD levels in adolescent. An association between AIS and poor nutrition has also been reported [15]. Studies have shown that a high calcium diet and weight-bearing physical activities have a positive association with bone mineral accretion in growing children [16,17]. Programmed exercise and increasing calcium dietary intake may be the possible interventions for osteopenic AIS patients and requires further investigation. More importantly, it has been shown that osteopenia is one of the risk factors in predicting curve progression [4]. Hung *et al.* (2005) demonstrated that AIS girls who had osteopenia at the time of diagnosis had a risk of curve progression which was doubled when compared with those who had normal BMD (odds ratio = 2.3). Moreover, the presence of osteopenia at skeletal maturity may lead to lower peak bone mass in adulthood which may also increase the chance of osteoporotic fractures in their later life.

In conclusion, AIS girls had a persistently lower BMD until they reach skeletal maturity. AIS girls with severe curvatures had a significantly lower BMD than that in the moderate group throughout the follow-up period.

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Prevalence of Scoliosis in Women with Visual Deficiency

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Abstract. Whether visual impairment influences the prevalence of scoliosis in humans or not remains controversial. The purpose of this study was to assess the prevalence of scoliosis in blind women in a Mediterranean region.
Material and Method: A total of 26 blind women aged 40 years (median, range 20 - 67) were screened for scoliosis. The existence of a possible trunk hump was measured by the forward bending test using the Pruijis Scoliometer. Reading of an Angle of Trunk Inclination (ATI) greater or equal to 7 degrees was used as a cut-off criterion for radiological examination. Standing postero-anterior and lateral spinal radiographs were obtained. Menarche and circadian rhythm was recorded.
Results : 11 out of 26 women had a scoliosis with an average Cobb angle of 19 degrees (range 12 - 28). The average ATI was 8 degrees. Thoracolumbar was the most common type of curve identified (9 out of 11, 6 were to the right and 3 to the left). The median age of menarche was 13 years (range, 11 - 15). None of the blind women reported any difficulty sleeping and had a circadian rhythm related to a 24-hour day.
Discussion: The prevalence of scoliosis was 42.3%, while the prevalence in the general population in the same regime is 2.9%. Blind women had a later age of menarche (13 versus 12.58 yrs) compared with normal girls. The postural etiology of scoliosis in blind people has been reported. The possible role of light in association to melatonin production, age at menarche and high prevalence of scoliosis in blind women is presented and discussed.

Keywords: idiopathic scoliosis, blindness, prevalence of IS, menarche, melatonin

1. Introduction

The cause of adolescent idiopathic scoliosis (AIS) in humans remains obscure. A wide range of aetiological causes have been proposed including neuromuscular abnormalities, connective tissue anomalies, vestibular dysfunction, melatonin secretion disturbance, platelet microstructure anomalies, mechanical factors, growth related and developmental problems, asymmetry of the brainstem, genetic factors, equilibrium dysfunctions and impairment of proprioception. These concepts have lead to the idea that a disturbance of postural control is involved but no single factor has been identified so far. Many authors consider that a relationship exists between the origin of scoliosis and problems of balance in the patients. Visual impairment has been shown to increase the prevalence of idiopathic scoliosis in human subjects when compared to the prevalence of the general population [1-6].

The objective of this study was to select data from scoliosis screening in an Institute of blind women in a Mediterranean region and study the prevalence of scoliosis in relation to the age at menarche, the lack of light stimulus and the possible role of melatonin.

2. Material and Method

2.1. The Study Population

A total of 26 blind women in an Institute for blind people with median aged 40 years (range 20 – 67 years) were screened for scoliosis. The causal pathologies for the blindness were various: retina or refraction problems, crystalline lens abnormalities, or oculomotor pathology. The patients with general neurological pathology were excluded.

2.2. The Measurements

The presence of a trunk hump was elicited by the forward bending test applying the Pruijis Scoliometer. An Angle of Trunk Inclination (ATI) greater or equal to 7 degrees was used as a cut-off criterion for radiological examination. For positive cases, a standing posteroanterior and lateral spinal radiograph was obtained. The Cobb angle was measured and a curve of 10 degrees or more was used to define a scoliosis following SRS guidelines.

2.3. The Age at Menarche and Circadian Rhythm

The blind women were questioned about their menarche and their circadian rhythm was also recorded.

3. Results

3.1. The Measurements

11 out of 26 women recorded a scoliosis, with an average Cobb angle of 19 degrees (range 12 - 28). The average ATI was 8 degrees (range 7 to 10 degrees). Thoracolumbar curves were the most common type identified (9 out of 11). 6 thoracolumbar curves were to the right and 3 were to the left. Of the remaining two cases, one had a lumbar curve to the right and the other a thoracic curve to the right.

3.2. The Age at Menarche and Circadian Rhythm

The median age of menarche of the 26 blind women was 13 years (range, 11 - 15). All blind women reported no difficulty in sleeping and had a normal 24-hour day circadian rhythm.

4. Discussion

The present study has demonstrated a prevalence of scoliosis in women with visual impairment as 42.3% against that of the general population in Greece of 2.9% [7].

4.1. The Postural Aetiology of Scoliosis in People with Visual Impairment

Vision by its function of environment exploration contributes to the postural control of the trunk. There is an association between idiopathic scoliosis and postural control in which vision is involved. Ponseti et al [8] found ocular problems in 32 patients with idiopathic scoliosis. In their study, the severity of the ocular lesions was related to the severity of the idiopathic scoliosis. Oculomotor modifications have also been found in association with idiopathic scoliosis. Close connections between the anomalies of the propio-oculo-labyrinthin and the scoliosis have been reported [9]. A genetic cause for posterior basicanium (PB) asymmetry and significant semi-circular canal malformation has also been reported in people with AIS [10]. Several studies report a family association of complete horizontal gaze palsy and severe progressive scoliosis [11]. In the series of Catanzariti et al [6] 18 out of 26 children who were visually impaired had a non-evolving three-dimensional scoliosis.

4.2. The Role of Melatonin in the Aetiology of Scoliosis in People with Visual Impairment

Data relating to scoliosis and melatonin in humans is relatively sparse and that already published does not clearly support a role for melatonin producing scoliosis in humans. The observation that experimental pinealectomy and a deficiency of melatonin (the principal product of the pineal gland in newborn chickens) leads to a spinal deformity similar to idiopathic scoliosis in man [12-14] lead to the development of a new neuroendocrine hypothesis for the cause of idiopathic scoliosis. However, no alteration in serum or urinary melatonin in patients with AIS has been recorded [15-18]. Moreover, an increased incidence of scoliosis has not been observed in children after pinealectomy or pineal irradiation because of pineal neoplasias, although they have may lack serum melatonin [19,20]. Thus the data regarding human melatonin levels is mixed at best and the melatonin deficiency as a causative factor in the aetiology of AIS cannot be supported.

4.3. Hypothesis

Melatonin is the main mediator that transfers changes in environmental light to human cells. Thus the diurnal variation of melatonin is due to environmental light conditions. Melatonin production is stimulated by darkness. Under conditions of darkness melatonin production increases and light reduces the melatonin production [21,22]. Bellastella et al [23] studied a group of 11 totally and 16 partially blind adult patients and found elevated melatonin levels both in patients with total blindness and in those with light perception compared to controls. Erren in 2002 [24] suggested that a lower incidence of cancer in blind people may be due to greater melatonin production.

The results of the current study suggest that melatonin might be involved in the pathogenesis of human idiopathic scoliosis in a way that could explain the higher prevalence of scoliosis in people with visual impairment. Melatonin overproduction due to lack of light stimulus in these people leads to late menarche and longer exposure to possible coexisting detrimental factors in the pathogenesis of AIS.

4.4. Melatonin and Age at Menarche

A controversy exists whether blind girls with no light stimuli experience delayed puberty. Zacharias in 1964 [25] reported an earlier age at menarche while Thomas in 1967 [26] reported no difference and Segos in 1995 [27] noted blind girls have a later age of menarche. Jafarey et al in 1971 [28] reported that artificial lighting results in a decrease in the age of menarche. Retinal responses to environmental lighting mediate an expanding list of neuroendocrine effects, including control of pubescence, ovulation, and a large number of daily rhythms [29]. Sexual maturation can be delayed in experimental animals by exogenous melatonin administration or by short day exposure [30,31]. Animals kept in constant darkness show a delay in sexual maturation. However, the neuroendocrine pathways, which mediate the effects of blindness upon human sexual development, are not completely understood. Melatonin acts on the gonads indirectly, reducing the secretion of gonatotropines and mainly that of LH. Blind women presented late age at menarche (median age 13 yrs) in this study, as opposed to non-blind individuals (mean age 12,58 years in Greece). In view of these results, it is hypothesized that blindness and the delay sexual maturation might render blind women to longer exposure to the detrimental causative factors of AIS, leading to the increased reported prevalence of the condition.

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Patterns of Extra-Spinal Left-Right Skeletal Asymmetries in Adolescent Girls with Lower Spine Scoliosis: Relative Lengthening of the Ilium on the Curve Concavity & of Right Lower Limb Segments

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Abstract. Extra-spinal skeletal length asymmetry have been reported for the upper limbs and periapical ribs of patients with thoracic adolescent idiopathic scoliosis. This paper reports (1) a third pattern with relative lengthening of the ilium on the concavity of *lower spine scolioses*, and (2) a fourth pattern of relative lengthening of the right total leg and right tibia unrelated statistically to the severity or side of *lower spinal scolioses*. The findings pose the question: are these anomalous extra-spinal left-right skeletal length asymmetries unconnected with the pathogenesis of AIS. Or, are they indicative of what may also be happening to some vertebral physes as an initiating pathogenic mechanism for the scoliosis?

Key words: Scoliosis, etiology, bilateral symmetry, pelvis, legs

1. General introduction

An anomalous feature detected in girls with AIS is extra-spinal left-right skeletal length asymmetries (Figure 1). Upper limb length asymmetry with relative lengthening on the convexity of right thoracic and thoracolumbar AIS curves was reported in clinic patients [1-3], in preoperative patients [4], and very recently in school screening referrals [5]. A second site reported was periapical rib lengthening on the concavity of right thoracic AIS in girls (RT AIS-F)[6]. Together with other clinical as much experimental evidence the periapical rib finding was used to assemble a thoracospinal concept of etiopathogenesis for the initiation of RT AIS-F [7]. Subsequent research using radiological and mathematical techniques did not confirm the rib findings [8,9].

Sevastik [10] responded by stating that neither the techniques employed nor the samples used by these other workers are comparable to the anatomical study of Normelli et al [6].

The present paper reports two further examples of extra-spinal left-right skeletal length asymmetries, namely (1) a third pattern with relative lengthening of the ilium on the concavity of *lower spine scolioses*, and (2) a fourth pattern of relative lengthening in the right leg unrelated statistically to the severity or side of *lower spine scoliosis* (Figure 1). Further studies of skeletal disproportions are presented in a subsequent paper [11]

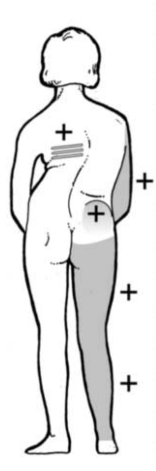

Figure 1. Anomalous extra spinal left/right skeletal length asymmetries detected in girls with AIS. The + signs indicate the relative skeletal overgrowth on that side (see text).

Relative lengthening of the ilium on the scoliosis curve concavity – real increase or innominate rotation/torsion effect?

2. Introduction

Ilium height asymmetry has been observed with each of (1) lumbar scoliosis [12,13], low back pain with leg length inequality [14], and (3) in participants having CT abdominal scans [15]. Ingelmark and Lindström [12] in 370 patients with 'various back disorders' and 215 with lumbar scoliosis observed ilium height asymmetry with ilium shortening more often on the curve convexity. Schwender and Denis [13] observed ilium obliquity in 60% of 50 patients with left lumbar scoliosis exceeding 40 degrees with ilium lengthening on the curve concavity. Pelvic skeletal asymmetry is reported to be associated with altered mechanics in the lumbar spine [16]. Pelvic height is disproportionately increased in AIS girls [17], and pelvic incidence increased [18]

3. Subjects

Seventy of 108 consecutive adolescent patients referred from routine scoliosis school screening during 1996-1999 had *lower spine scoliosis* – lumbar (LS), thoracolumbar (TLS), or pelvic tilt scoliosis (PTS).

4. Methods

4.1 Radiographs - pelvic bones (Figure 2)

On standing full spine anteroposterior radiographs bi-iliac and hip tilt angles [13,19] were both measurable in 60 subjects: after classification [19] the curves were LS 18, TLS 31, and PTS 11 (girls 44, boys 16, mean age 14.6 years). Bi-iliac tilt angle (BITA) and hip tilt angle (HTA) were measured trigonometrically and ilium height asymmetry estimated by a new method as BITA *minus* HTA (corrected BITA=CBITA) and also directly as ilium height asymmetry [12,14,15]. The convention is that tilt angles lower on the right are negative and lower on the left are positive.

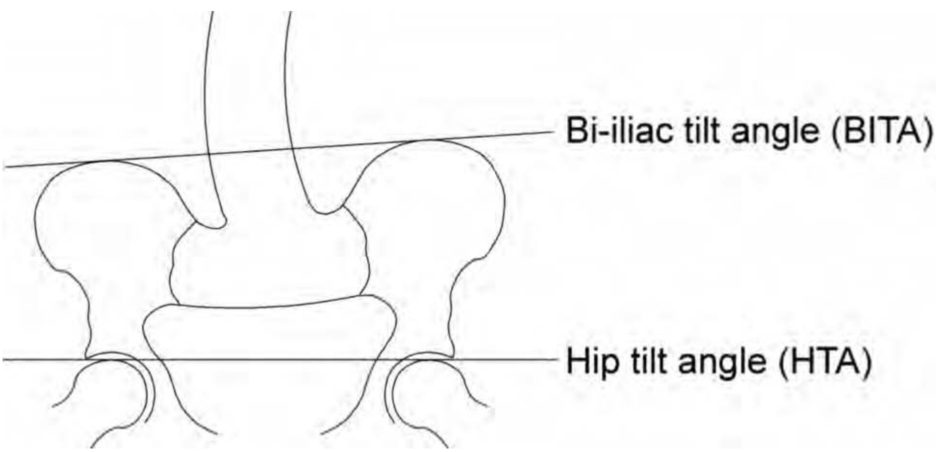

Figure 2. Pelvic datum lines (see text and [11] Figure 3)

4.2 Radiographs - spine

Cobb angle (CA), apical vertebral rotation (AVR) and apical vertebral translation (AVT from the T1-S1 line) were measured on standing full spine radiographs.

The mean Cobb angle is 14 degrees, range 4-38 degrees, 33 left curves, 27 right curves.

4.3 Measurements were made by one observer (RGB)

4.4 Reproducibility

Technical error of the measurement (TEM) and Coefficient of reliability (R) [20] are as follows (10 repeats by RGB):

Bi-iliac tilt angle (BITA): TEM = 0.86 degrees, R=0.83.

Hip tilt angle: (HTA): TEM = 0.45 degrees, R=0.96.

CBITA (BITA *minus* HTA): TEM = 0.75 degrees, R=0.13

Ilium height asymmetry: TEM = 1.76 mm, R = 0.58.

Cobb angle: TEM = 1.2 degrees, R = 0.82.

Apical vertebral rotation: TEM = 3.3 degrees, R = 0.63

5. Results (Figures 3 and 4)

Comparison of CBITA as a measure of ilium height asymmetry for left and right curves shows a statistically significant difference (t= 3.05, p=0.003) (Figure 3). The ilium is relatively taller on the concavity of these curves.

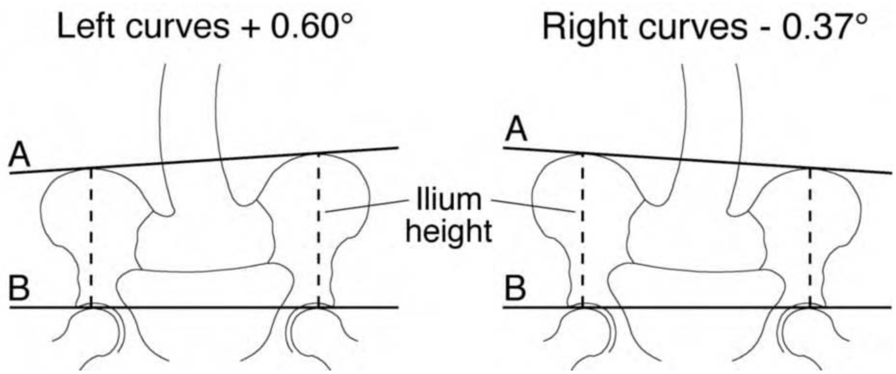

Figure 3. Pelvic datum lines and corrected bi-iliac tilt angles (CBITA) as a measure of ilium height asymmetry. A = BITA, B = HTA, CBITA = BITA *minus* HTA (see [11] Figure 3).

Corrected bi-iliac tilt angle (CBITA) is associated with Cobb angle, AVR and AVT (each p<0.001)(Figure 4).

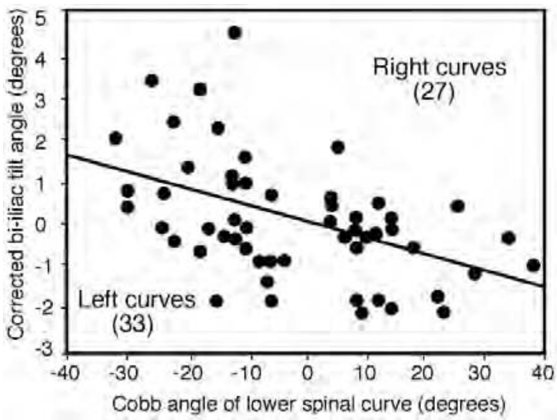

Figure 4. Corrected bi-iliac tilt angle (CBITA) plotted against Cobb angle for left and right lower spinal curves (r= - 0.460, p<0.001).

6. Discussion

6.1 A relatively taller concave ilium is confirmed and an association with curve severity of lower spine scolioses revealed.

6.2 The relatively taller concave ilium may be:

a) real, from primary skeletal changes or asymmetric muscle traction on ilium apophyses [13], or
b) apparent from rotation/torsion at the sacro-iliac joint(s) [21,22] and symphysis pubis.

6.3 The ilium height asymmetry provides another finding of left-right skeletal length asymmetry in AIS girls already reported for the upper limbs [1-5], ribs [6, 7,10], and lower limbs [see next]

Relative lengthening of right lower limb segments unrelated to the lower spinal scoliosis

7. Introduction

Writing before school screenung for scoliosis was introduced Ingelmark and Lindström [12] stated that physiological types of scoliosis are absent in early childhood and begin to form in the 7th-10th years. The cause of these curvatures was difficult to establish and they concluded that the main factor was the usually longer right leg in children before puberty; other workers considered that intrinsic factors were involved.

Ingelmark and Lindström [12] in 370 patients - mainly adult with 'various back disorders' and 215 with lumbar scoliosis - observed in standing radiographs leg length asymmetries in 87% (1 mm threshold). In adults the left leg was usually the longer in good agreement with the findings on skeletons [23].

After school screening for scoliosis almost 40% are reported to have a minor, non-progressive lumbar (87%) or thoracolumbar (13%) scolioses secondary to pelvic tilt [24]. The association of leg length inequality with lumbar scoliosis has been reported by many workers [see 4,12,19,25]; in one study of pelvic tilt scoliosis there were left curves in 55% and right curves in 45% with right curves more common in the leg length inequality group [19]. Manganiello [25] defines three types of pelvic tilt curves associated with leg length inequality distinguished by where the counter deviation occurs, at L5, L4 or L3.

8. Patients and controls

8.1 Patients

Forty-seven girls of 108 consecutive adolescent patients referred from routine scoliosis school screening during 1996-1999 had *lower spine scoliosis* – lumbar (LS) 17, or thoracolumbar (TLS) 30.

The mean Cobb angle is 16 degrees, range 4-38 degrees, mean age 14.8 years, left curves 25, right curves 22.

8.2 Controls

The controls were 278 normal girls (11-18 years, mean age 13.4 years).

9. Methods

9.1 Anthropometry

Anthropometric measurements were made by tape for total leg lengths (LL, pressing into the notch below the anterior superior iliac spine and measuring to the medial malleolus) and Harpenden anthropometer [26] for tibiae (TL) and feet (FL, standing). The readings were made to the nearest 1 mm.

Asymmetries were calculated (left *minus* right) for each of LL, TL and FL, and percentage asymmetries of right/left lengths.

9.2 Spinal radiographs

Cobb angle (CA), apical vertebral rotation (AVR) and apical vertebral translation (AVT from the T1-S1 line) were measured on standing full spine radiographs.

9.3 Measurements were made by one observer (RGB)

9.4 Reproducibility

Technical error of the measurement (TEM) and Coefficient of reliability (R) [20] are as follows:

Left total lower limb length: TEM: = 4.2 mm, R=0.99, n=126 [27]

Left tibial length: TEM: = 3.0 mm, R=0.96, n=126 [27].

Left foot length: TEM: = 1.3 mm, R=0.99, n=126 [27].

Total lower limb length asymmetry: TEM= 4.0 mm, R=0.48, n=126 [27].

Tibial length asymmetry:TEM= 3.7 mm, R=0.38, n=126 [27].

Foot length asymmetry: TEM = 1.5 mm, R = 0.74, n =126 [27].

Apical vertebral rotation (10 repeats by RGB): TEM = 3.3 degrees, R = 0.63.

Cobb angle (10 repeats by RGB): TEM = 1.2 degrees, R = 0.82.

10. Results for asymmetries

10.1 No changes with age. There are no detectable changes of the asymmetries with age for LL, TL or FL in the scoliotic or normal girls.

10.2 Leg length asymmetries (left minus right, mm) are as follows (Figure 1):

Leg asymmetries	Scoliotic	Normal	p
Total leg lengths	-7.9	0.07	***
Tibial lengths	-3.6	0.02	***
Foot lengths	0.09	1.0	NS

*** = p<0.001 NS = Not significant

10.3 Leg length asymmetries (left minus right mm) are unrelated to Cobb angle, AVR or AVT.

10.4 Percentage length asymmetries in scoliotic girls compared with normals show relative lengthening on the right for each of LL (+0.95%, p<0.001) and TL (+0.99%, p<0.001), but not FL (+0.38%, NS).

11. Discussion

11.1 The relative lengthenings in the right total leg and right tibia are unrelated statistically to the severity or side of the lower spine scolioses. A subject with a lower limb length inequality may vault over the longer limb [28].

11.2 The cause of the relative lengthenings is unknown and may be related to –

a) persistence of the pre-pubertal normal pattern of asymmetry favoring the right leg [12].
b) posture – free standing on the right leg [29],
c) neuromuscular mechanisms, or
d) primary skeletal changes in growth plates of femur(s) and tibia(e).

12. Conclusion

The ilium and lower limb asymmetries pose the question: are these anomalous extra-spinal left-right skeletal length asymmetries unconnected with the pathogenesis of AIS? Or, are they indicative of what may also be happening to some vertebral physes [30] as an initiating pathogenic mechanism for the scoliosis? [31].

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Left-right Upper Arm Length Asymmetry Associated with Apical Vertebral Rotation in Subjects with Thoracic Scoliosis: Anomaly of Bilateral Symmetry Affecting Vertebral, Costal and Upper Arm Physes?

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Abstract. Left-right skeletal length asymmetries in upper limbs related to curve side and severity have been detected with adolescent idiopathic scoliosis (AIS). This paper reports upper arm length asymmetry in thoracic scoliosis related significantly to apical vertebral rotation in school screening referrals. The reason(s) for the association of upper arm length asymmetry with apical vertebral rotation is unknown and three factors are considered: (1) neuromuscular mechanisms from primary or secondary causes, (2) relative concave neurocentral synchondrosis overgrowth, and (3) relative concave periapical rib length overgrowth, A putative anomaly of growth plates (physes) of ribs, neurocentral synchondroses and upper arms, would account for the findings. A solution to this dilemma may emerge from the results of surgery should concave periapical rib resections become evaluated further for right thoracic AIS in girls.

Key words. Scoliosis, etiology, bilateral symmetry, synchondroses, vertebrae, ribs

1. Introduction

A relatively longer arm on the scoliosis curve convexity was detected in subjects with idiopathic scoliosis (adolescent, juvenile infantile and adolescent) and congenital scoliosis none of whom had surgery [1,2]. In a subsequent study girls aged 10-18 years with adolescent idiopathic scoliosis (AIS) having right thoracic and right thoracolumbar scoliosis were compared with normals and found to have upper arms

relatively longer on the convexity of the curve, which correlated significantly with the spinal curve angle at the time of measurement [3]. More recently in 57 preoperative girls with right thoracic AIS and all right-handed, Cole et al [4] reported significant lengthening of both upper arm length and forearm-with-hand length on the convexity of the curve. There was no association between upper limb length asymmetries and curve severity (Cobb angle, apical vertebral rotation and apical vertebral translation).
The availability of school screening data provided a further opportunity to evaluate upper limb length asymmetries in relation to a variety of scoliosis curve patterns in idiopathic scoliosis. The findings reported here for thoracic curves show the association of apical vertebral rotation with upper arm length asymmetry and related to curve severity.

2. Subjects and controls

2.1. Patients

Forty-five girls and boys of 173 consecutive adolescent patients referred from routine school screening during 1993-1999 had *idiopathic thoracic scoliosis.* In 43, upper arm lengths and curve severity data were available (girls 25, post-menarcheal 22, boys 18, mean age 14.9 years, range 12-17 years).

The mean values for Cobb angles are 20 degrees (range 4-42 degrees), apical vertebral rotation 14 degrees, right curves 38, left curves 5.

2.2. Controls

The controls were 280 normal girls and 281 normal boys (range 11-18 years, mean age girls 13.4 years, boys 13.6 years) examined in 1973-1981.

3. Methods

3.1. Anthropometry

Bilateral upper limb segments were measured anthropometrically for each of upper arm length (UAL) and forearm-with-hand length using a Harpenden anthropometer [5]. Left-right upper limb length asymmetries were calculated as right *minus* left. Handedness was recorded.

3.2. Radiographs

On standing full spine anteroposterior radiographs measurements were made of Cobb angle and apical vertebral rotation (AVR, Perdriolle)[6].

3.3. Measurements were made by one observer (RGB)

3.4. Reproducibility

Technical error of the measurement (TEM) and Coefficient of reliability (R) [7] are as follows:

Left upper arm length: TEM = 2.9 mm, R = 0.95, n=126 [8].
UAL asymmetry: TEM =3.61 mm, R=0.39, n=126 [8]
AVR (10 repeats by RGB) TEM = 3.3 degrees, R = 0.63
Cobb angle (10 repeats by RGB) TEM = 1.2 degrees, R = 0.82.

4. Results

4.1 Arm length asymmetry, AVR & Cobb angle – all curves

Upper arm length (UAL) asymmetry correlates significantly with each of AVR (Figure 1, r=0.480, p=0.001) and Cobb angle (r= 0.379, p=0.012). Upper arm length asymmetry, AVR and Cobb angle are each independent of age. After correction for sex, curve side, vertebral level and handedness, UAL asymmetry by AVR shows statistical significance (p=0.026) but not UAL asymmetry by Cobb angle (p=0.204, ANOVA).

Forearm-with-hand length asymmetry does not show statistical significance with either AVR or Cobb angle.

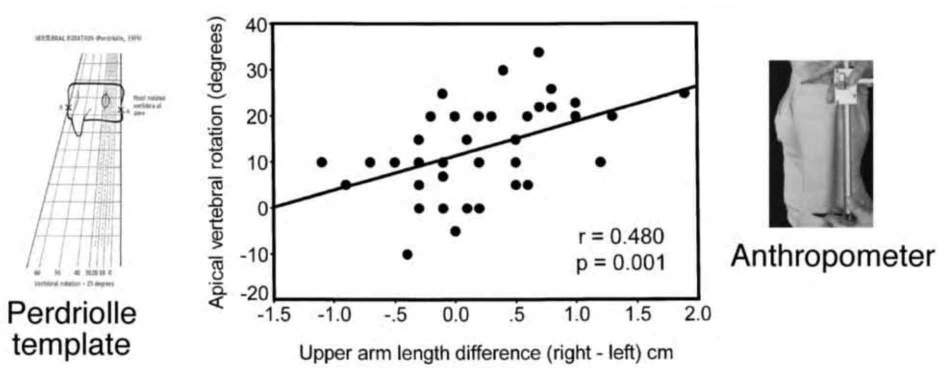

Figure 1 Thoracic AIS: apical vertebral rotation correlation with upper arm length asymmetry (right *minus* left cm, n=43).

4.2 Upper arm length asymmetry (right-left) – scoliotics and normals

In the scoliosis subjects there is no sex difference in upper arm length asymmetry. The normal girls are significantly more asymmetric in the upper arms than the normal boys.

5. Discussion

What may determine the apical vertebral rotation (AVR) in the scoliotics?

Three mechanisms, separately or in combination, that might determine the AVR in the scoliotics are: 1) neuromuscular mechanisms, 2) neurocentral synchondroses, and 3) periapical rib length asymmetry. Putative costo-vertebral pathogenic mechanisms for thoracic AIS are shown in Figure 2.

5.1. *Neuromuscular mechanisms*

There is no evidence that neuromuscular mechanisms may initiate or aggravate apical vertebral rotation in thoracic AIS. Theoretically, such a mechanism could be primary [9], or secondary from muscle activation strategies [10], or other causes [11].

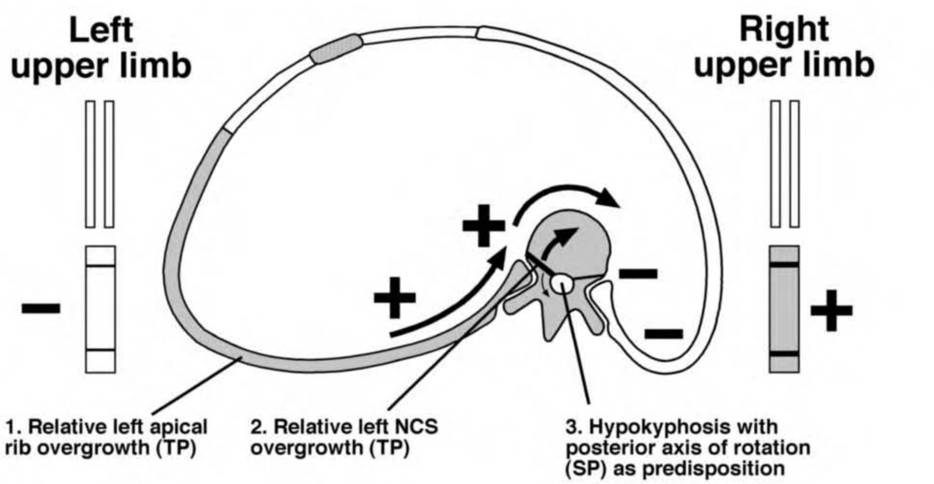

Figure 2. Putative costo-vertebral pathogenic mechanisms for right thoracic AIS in girls: relative physeal overgrowth in rib, vertebra and humerus involving growth conflicts with hypokyphosis (see text, TP=transverse plane, SP=sagittal plane).

5.2 *Neurocentral synchondroses (NCSs)(Figure 2)*

The concept that the greater growth of the concave NCS is pathogenic for AIS is controversial because of lack of agreement on the exact age at which closure occurs [12-15]. Taylor [16] suggested that longer left pedicles about 8 years of age by 'rotating' the vertebral body to the right may predispose a girl to the development of idiopathic scoliosis at a later age. More recently Rajwani et al [17] using MRI in 8 normal subjects age 1-15 years found neural arch asymmetry with the left-sided measurements being greater; Ten AIS patients age 10-16 years also showed neural arch asymmetry but the longer pedicle was not consistently on the convexity or concavity of the curve. In a finite element model of asymmetric growth of neurocentral synchondroses even in combination with other potential pathogenic mechanisms involving the spine – but not the ribcage – did not cause scoliosis [18].

5.3. Periapical rib length asymmetry (Figure 2)

Normelli et al [19] reported that in 5/6 cadaveric women with right convex thoracic idiopathic scoliosis (RT AIS-F) the mean length of three concave ribs was on average 4 mm longer than those on the convexity. These data and other evidence were used by Sevastik [20] to create the thoracospinal concept for RT AIS-F: namely, relative overgrowth of left ribs disturbs the equilibrium of the forces that determine thoracic spinal alignment and triggers RT AIS-F in the three cardinal planes. In radiological studies and using mathematical techniques two groups of workers were unable to confirm relative concave rib overgrowth in RT AIS-F [21,22]. In discussing these latter works Sevastik et al [23] concluded that neither the samples nor the techniques were comparable to the anatomical study of Normelli et al [19].

5.4. A surgical solution to the dilemma?

At present it is not known what may determine the AVR that correlates significantly with the upper arm length asymmetry. We suggest that one or more of the mechanisms outlined above may be involved: a putative anomaly of growth plates (physes) of ribs, neurocentral synchondroses and upper arms would account for the findings. A practical solution to this dilemma may emerge from the results of surgery should concave segmental rib resections advocated by Sevastik [23] become evaluated further [24].

5.5. Preventive surgery

Spine. Betz et al [25] reported experience of convex spine stapling for AIS.
Periapical ribs. Sevastik [20,23] advocates concave periapical rib shortening for right thoracic juvenile and early adolescent idiopathic scoliosis in females.
Periapical ribs and spine. We suggest consideration is given to combining convex spine stapling with concave periapical rib shortening for right thoracic AIS in females.

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Etiologic Theories of Idiopathic Scoliosis: Neurodevelopmental Concept of Maturational Delay of the CNS Body Schema ("Body-in-the-Brain")

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Abstract. Several workers consider that the etiology of adolescent idiopathic scoliosis (AIS) involves undetected neuromuscular dysfunction. During normal development the central nervous system (CNS) has to adapt to the rapidly growing skeleton of adolescence, and in AIS to developing spinal asymmetry from whatever cause. Examination of evidence from (1) anomalous extra-spinal left-right skeletal length asymmetries, (2) growth velocity and curve progression, and (3) the CNS body schema, parietal lobe and temporoparietal junction, led us to propose a new etiologic concept namely of delay in maturation of the CNS body schema during adolescence. In particular, the development of an early AIS deformity at a time of rapid spinal growth the association of CNS maturational delay results in the CNS attempting to balance a lateral spinal deformity in a moving upright trunk that is larger than the information on personal space (self) already established in the brain by that time of development. It is postulated that the CNS maturational delay allows scoliosis curve progression to occur - unless the delay is temporary when curve progression would cease. The putative maturational delay in the CNS body schema may arise (1) from impaired sensory input: (2) primarily in the brain; and/or (3) from impaired motor output. Oxidative stress with lipid peroxidation in the nervous system may be involved in some patients. The concept brings together many findings relating AIS to the nervous and musculo-skeletal systems and suggests brain morphometric studies in subjects with progressive AIS.

Keywords. Scoliosis, etiology, bilateral symmetry, growth, brain, CNS body schema

1. Introduction

In the pathogenesis of adolescent idiopathic scoliosis (AIS) current thinking is that a defect of central control or processing in the central nervous system (CNS) affects a growing spine with a primary pathology involving the hind brain [1]. In the absence of evidence to the contrary there is a view that the spine is normal before it becomes deformed [2]. Evidence questioning the latter view has been gathered very recently by the detection of anomalous extra-spinal left-right skeletal length asymmetries wider than the upper limbs [3-6] and periapical ribs [7-9] and involving the ilium [10] and lower limbs [10,11) in which the arm and ilium asymmetry are associated with curve side and severity (see reference [11] Figure 1). These anomalous extra-spinal left-right skeletal length asymmetries and the proximo-distal leg disproportion [11] led to us to suggest that they may be indicative of what is also happening in immature vertebrae and contributing to the pathogenesis of AIS as a *curve initiation process* [10-14].

An undoubted factor in curve progression of AIS is rapid adolescent growth [15]. The mean age at diagnosis of progressive AIS has been reported to occur in the acceleration phase of the growth spurt [16].

How the CNS may be involved in curve progression is unknown. It is generally considered to result from neuromuscular activity acting on the spine and trunk; but in the absence of evidence either way curve progression may equally result from a failure of the CNS to control a *curve initiating process* at a time of rapid adolescent growth. The failure may result if there is maturational delay of the CNS body schema.

2. The Normal CNS Body Schema, Internal Body Image, or "Body-in-the Brain"

In the last decade knowledge relating to the "body-in-the-brain" - has advanced considerably [17-26]. Ehrsson et al [25] state that the internal body image commonly refers to the perception of spatial dimensions of the body, its size, shape and relative configuration of its parts [26]. The normal CNS body schema provides a postural/locomotor frame of reference acting as a comparator for sensory inputs to adjust to online motor actions. The temporoparietal junction plays a key role in out-of-body experiences, multisensory bodily information, visual perception of the body, perception of biological motion and the distinction between self and other [22,24]. According to Ehrsson et al [21] multisensory integration also occurs in the premotor cortex where activity in a multicentred reference frame is the underlying mechanism for self-attribution. Growth needs continuous, or continual, updating of body size and shape, unique for each individual.

3. The CNS Body Schema Concept for AIS – Four Theoretical Requirements (Figure 1)

At the Athens 2002 IRSSD meeting we speculated that idiopathic scoliosis might result from an abnormality in establishing the CNS body schema during development and growth [27]. The concept is separate from idiopathic (constitutional) delay in growth and puberty [28]. Based on the evidence and argument outlined above we postulate four requirements for the development of AIS as shown in Figure 1.

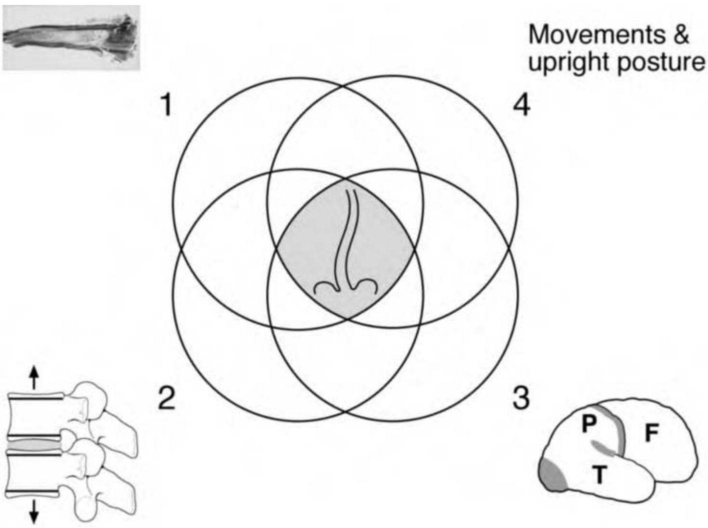

Figure 1. Venn Diagram of the four requirements of the neurodevelopmental concept (1-4, see text).

3.1. First requirement - curve initiation process

This process produces left-right spinal asymmetry. By analogy with the anomalous extra-spinal left-right skeletal length asymmetries that are likely to involve growth plates (physes) we suggest that the process may involve vertebral body growth plates. This suggestion does not exclude the possibility that periapical rib length asymmetry as relative concave rib overgrowth [7,8,9,12,13] or neuromuscular mechanisms may cause the left-right asymmetry and initiate scoliosis in some subjects.

3.2. Second requirement - rapid spinal elongation in adolescent growth spurt

This process results from growth [15,16] principally of vertebral body growth plates under the influence of steroid hormones particularly estrogen [28].

3.3. Third requirement - maturational delay of CNS body schema (Figure 2)

This CNS maturational delay causes impaired neuromuscular adjustments to a deforming and rapidly elongating spine. This requirement predicts that girls with progressive AIS will show focal brain atrophy. Brain morphometric abnormalities have been reported in the prefrontal cortex and thalamus of subjects having low back pain for at least a year [29].

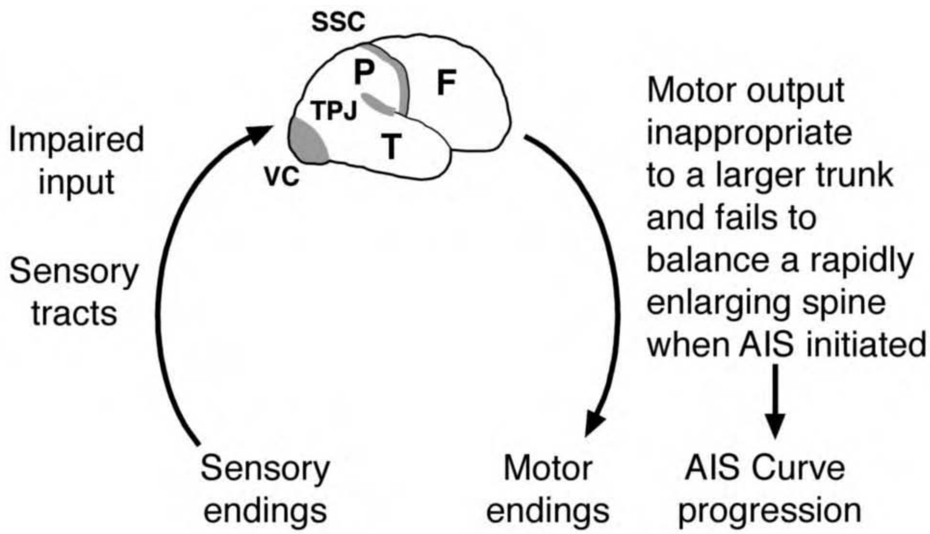

Figure 2. The third requirement – maturational delay of CNS body schema (F,P,T = frontal, parietal, and temporal lobes of the brain, SSC = somatosensory cortex, TPJ = temporoparietal junction, VC = visual cortex).

3.4. Fourth requirement – movements of spine and trunk, upright posture

The neuromuscular adjustment to a deforming and rapidly elongating spine takes place in a spine and trunk that are upright and moving with features unique to humans. Anecdotal evidence suggests that trunk movements and upright posture are important in scoliosis curve progression.

3.4.1. Rest in bed

Rogers [30] noted improvement to the lateral and rotatory elements of scoliosis brought about by prolonged hyperextension on a frame. Arkin [31] stated that rest in bed may halt the progress of idiopathic scoliosis in children. In over 30 patients in which the scoliosis was advancing Cobb kept the children in bed for 22 hours/day. Except for one case, no progress was noted after 3 months.

3.4.2. Unique human upright posture, gait and trunk movements

There is a low or nil prevalence of naturally-occurring idiopathic scoliosis in non-human primates [32]. Human walking [33], unique among animals, involves upright posture, axial pelvi-spinal rotations and counter-rotations. Axial rotations of the trunk are carried out frequently and forcibly that are not performed by quadrupeds [34]. These features were incorporated in the Nottingham concept of the pathogenesis of idiopathic scoliosis [35] of which the present neurodevelopmental concept is a development.

4. The CNS Body Schema Concept for AIS – Where maturational Delay May Arise and a Hypothesis (Figure 2)

Delay in the CNS body schema may arise (1) from impaired sensory input, (2) primarily in the brain, and/or (3) from impaired motor output. Oxidative stress with lipid peroxidation in the nervous system may be involved in some patients [32,36].

4.1. Impaired sensory input

The basic problem may lie in muscle spindles and/or other endings [37-39]. The size-weight illusion (Charpentier test) found in AIS to show a tendency to an infantile response [37] may be due to a cerebral anomaly [Paus, personal communication].

Somatosensory evoked potential latencies of tibial nerves were abnormal after correction for body height in 68% of 100 patients admitted for surgery with idiopathic scoliosis and pathological differences between left and right found in 17% [40]. These changes are interpreted as sub-clinical involvement of the recorded neuronal pathways and we suggest that they may contribute to maturational delay of the CNS body schema in some subjects. Abnormal reflex processing in patients with idiopathic scoliosis demonstrating abnormal central processing [41] may be associated with delay in maturation of the CNS body schema

4.2. Primarily in the brain

Parts of the brain that may contribute to maturational delay of the CNS body schema include in the parietal lobe the somatosensory cortex (personal space or 'self'), temporoparietal junction (TPJ)[22,24], temporal lobes, frontal lobes and visual cortex (extra-personal space). The role of the Nogo receptor in the experience-dependent plasticity of brain maturation [42,43] needs to be examined in relation to the putative maturational delay of the CNS body schema.

4.3. Impaired motor output

Herman et al [44] found that the processing of vestibular signals within the CNS yielded the highest degree of correlation with curve magnitude. They considered that idiopathic scoliosis was a motor control problem. A higher level CNS disturbance was thought to be responsible for visuo-spatial perceptual impairment, motor adaptation and learning deficits; these lead to a recalibration of proprioceptive signals from axial musculature causing idiopathic scoliosis.

The impairment of motor output may also involve motor tracts and central pattern generators [33,35].

4.4. Relation to the NOTOM hypothesis

The CNS body schema concept can be viewed as resulting from an abnormality in neuro-osseous timing of maturation *(NOTOM)* – a hypothesis to explain why girls are more susceptible than boys to scoliosis curve progression [45,46].

4.5. Hypothesis for progressive AIS

We hypothesize that some subjects with progressive AIS will show focal atrophy in one or more areas associated with the CNS body schema.

5. Maturational Brain Processes Continue Through Adolescence

The second decade of life is a period of great activity in brain structure and function [47]. Paus [48] states that non-invasive mapping of brain structure and function with magnetic resonance imaging (MRI) has opened up unprecedented opportunities for studying the neural substrates underlying cognitive development. Paus continues: "There is a consensus of a continuous increase throughout adolescence in the volume of white matter. There is less agreement on the meaning of asynchronous age-related decreases in the volume of gray matter in different cortical regions; these might equally represent loss ("pruning") or gain (intra-cortical myelination) of tissue." Ongoing projects scan healthy and other subjects longitudinally with structural MRI enabling the time-course and anatomical sequence of development to be reconstructed [49].

6. Some Research Techniques and AIS

Brain mapping and other techniques involve phantom limbs [18,19]; visually-guided reaching (involving the posterior parietal cortex [23]; out-of-body experiences at the temporo-parietal junction and failure to integrate multisensory information from own body [22,24]; and the Pinocchio illusion [25,26].

Techniques that may be used to investigate AIS subjects for a CNS body schema focal defect include structural MRI, functional MRI, positron emission tomography, EEG, transcranial magnetic stimulation, somatosensory evoked potentials, central motor conduction time, size-weight illusion, voxel-based morphometry and relation to genetics.

In the University of Nottingham, UK a Brain and Body Centre was established in 2005 with the Launch Event on 29 March 2006 (Director: Tomas Paus MD PhD, Chair in Developmental Cognitive Neuroscience and Professor of Psychology & Mental Health).

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Intervertebral Disc Biomechanics in the Pathogenesis of Idiopathic Scoliosis

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Abstract. The aim of the present study is to investigate whether the deformation of the intervertebral disc contributes to the progression of idiopathic scoliotic curves. In the standing posteroanterior x-rays of 92 scoliotic curves the following readings were obtained: Cobb angle (CA), apical vertebral rotation (AVR), apical vertebral wedging (AVW) and the adjacent to the apical vertebra Upper (UIVDW) and Lower (LIVDW) InterVertebral Discs Wedging. The statistical analyses included inter - intraobserver reliability test, descriptives, monofactorial linear regression and Pearson correlation coefficient, with $p<0.05$ considered statistical significant (SS).
The mean thoracic CA was 13.4º, lumbar CA 13.8º, thoracic AVR 5.3º, lumbar AVR 4.7º, thoracic AVW 1.4º, lumbar AVW 1.5º, thoracic UIVDW 1.6º, thoracic LIVDW 1º, lumbar UIVDW 1.3º and lumbar LIVDW 2º. Both thoracic and lumbar CA regressed SS with lumbar LIVDW, lumbar UIVDW, thoracic LIVDW and thoracic AVW. Lumbar LIVDW correlates SS with thoracic CA, lumbar CA and thoracic LIVDW. An inter and intra-observer error was below 1º.
The eccentric intervertebral disc in the scoliotic spine, through variation in its water concentration produces asymmetrically cyclical load during the 24-hour period and an asymmetrical growth of the vertebral body (Hueter-Volkman's law). The statistical analysis revealed that AVW appears later when already CA increases, the IVDW is more important than AVW and the LIVDW, which is greater than UIVDW, is the most frequent correlated radiographic parameter.
The deformation of the apical intervertebral disc seems to be an important contributory factor in the progression of a scoliotic curve.

Keywords. Idiopathic scoliosis, intervertebral disc, vertebral disc wedging, asymmetrical growth, progression of idiopathic scoliosis

Introduction

The spinal deformity in idiopathic scoliosis (IS) involves not only the vertebrae but also the intevertebral disc (IVD). The IVD becomes significantly and irreversibly wedged although it does not appear to be the primary factor in the aetiology of IS [1] Burwell et al, reporting on the current concepts of the aetiology of IS, summarises on the IVD as being not a primary factor but as a contributing variable to the deformity [2]. The role of the IVD as a contributory factor to the development of the scoliotic curve has been emphasized by many authors [3, 4]. The response of IVD to abnormal stresses imposed on them in scoliosis is essential to the long-term prognosis of untreated lumbar and thoracolumbar curves [5] and it is very likely that the changes in cartilage endplate (vertebral body growth plate) and IVD are key factors in the progression of scoliosis and the manner in which the curve will respond to different therapeutic regimens [6]. A diurnal variation in the water content of lumbar IVD which has been documented on MRI in two young adult subjects, was proposed as a contributory factor to the scoliosis deformity [7]. An increased torsional rigidity of the inter-vertebral discs throughout growth that favors the progression of early scoliotic curves has also been documented [8].

The aim of the present study is to investigate whether the deformation of the intervertebral disc contributes to the progression of IS curves.

Method and Material

The Patients

Seventy children (20 boys with a mean age 12.8 (range 8-15) years and 50 girls with a mean age of 13.5 (range 7-16) years) with a scoliotic curve above 10^{o} according to Cobb method were studied. Twenty seven curves were thoracic, 16 were thoracolumbar and 27 were lumbar. In 22 of the 70 children there was also an upper or a lower compensatory curve, which was also been measured. In total, 92 curves (major and compensative) were measured, 35 thoracic, 27 thoracolumbar and 30 lumbar.

The Radiographic Study

In the standing posteroanterior spinal radiographs of the 92 scoliotic curves the following readings were obtained: Cobb angle (CA), apical vertebral rotation (AVR) according to [Pedriolle], angle of apical vertebral wedging (AVW), the adjacent to the apical vertebra Upper (UIVDW) and Lower (LIVDW) IVD wedging.

The Statistical Analysis

The statistical techniques used were descriptives (mean, Standard Deviation, minimum, maximum values), monofactorial linear regression, Pearson correlation coefficient and inter - intraobserver reliability analysis, with $p<0.05$ considered statistical significant (SS). Data was analyzed using SPSS v.11 statistical package.

Results

The results of the reliability study are shown in **Table 1**.

Table 1: Reliability study

	CA	**AVR**	**AVW**	**UIVDW**	**LIVDW**
Intraobserver error	0,42°	0,73°	0,68°	0,73°	0,68°
Interobserver error	0,8°	0,73°	0,75°	0,89°	0,73°

The mean thoracic CA was 13.4° (min 5°, max 44°, SD 6.8°), the mean lumbar CA was 13.8° (min 6, max 30°, SD 5.18°), the mean thoracic AVR was 5.3° (min 0° , max 15°, SD 3.1°), the mean lumbar AVR was 4.7° (min 0°, max 20°, SD 3.86°), the mean thoracic AVW was 1.4° (min 0°, max 8°, SD 1.73°), and the mean lumbar AVW was 1.5° (min 0°, max 11°, SD 2.25°). The mean thoracic UIVDW was 1.6° (min 0°, max 8°, SD 1.98°), while the mean LIVDW was 1° (min 0°, max 7°, SD 1.6°). The mean lumbar UIVDW was 1.3° (min 0°, max 10°, SD 1.88°) and the mean LIVDW was 2° (min 0°, max 20°, SD 3.46°).

The linear regressions and the resulting polynomial equation to calculate the dependent variable were the following:

Thoracic CA regressed with: 1) lumbar LIVDW ($p<0.000$, thoracic CA= 9.64 + 2.28 X lumbar LIVDW), 2) thoracic LIVDW ($p<0.003$, thoracic CA = 11.02 + 1.89X thoracic LIVDW) and 3) lumbar UIVDW ($p<0.003$, thoracic CA =10.06 + 2.25X lumbar UIVDW)

Lumbar CA regressed with: 1) lumbar LIVDW ($p<0.000$, lumbar CA = 11.85 + 0.97 X lumbar LIVDW), 2) lumbar UIVDW ($p<0.009$, lumbar CA = 12.51 + 1.006 X lumbar UIVDW), 3) thoracic AVW ($p<0.024$, lumbar CA = 11.03 + 1.37 X thoracic AVW) and 4) thoracic LIVDW ($p<0.028$, lumbar CA = 11.45 + 1.52 X thoracic LIVDW). Lumbar AVR regressed with thoracic AVW ($p<0.006$, lumbar AVR = 2.54 + 0.88X thoracic AVW).

Pearson correlation coefficient shows that thoracic LIVDW correlates with thoracic CA ($r^2 = 0.457$, $p<0.07$), lumbar UIVDW correlates with thoracic CA ($r^2 = 0.588$, $p< 0.07$) and with thoracic LIVDW ($r^2 = 0.709$, $p<0.002$), while lumbar LIVDW correlates with thoracic CA ($r^2 = 0.796$, $p<0.0001$), lumbar CA ($r^2 = 0.6512$, $p<0.0000$) and thoracic LIVDW ($r^2 = 0.661$, $p<0.012$).

Discussion

The results from the statistical analysis show that AVW appears later when already CA increases and in small CA readings there is no AVW deformation. The IVDW is more important than AVW in IS pathogenesis and particularly the LIVDW which is found greater than UIVDW, is the most frequently correlated to other radiographic parameters studied, a finding that highlights the importance of the IVD wedging in IS pathogenesis.

In mild scoliotic curves, when the deformity is initiating, the IVD is found wedged, but not the vertebral body. The spine is deformed first at the level of the IVD, due to the increased plasticity of the IVD, in the way of either torsion or wedging as an expression of other initiating factors that may result in IS.

The IVD contains the aggrecans of glycosaminoglycans (GAGs) which imbibe water through the so called Gibbs-Donnan mechanism. The highest concentration of aggrecans is in the nucleus pulposus (NP) where they are entrapped in a type II collagen network [9]. There is an increased collagen content in the NP of AIS IVD, which is maximal at the apex of the curvature. Furthermore, in the scoliotic spine the NP in the IVD is displaced towards the convex side of the wedged interspaces [5]. Differences were also evident in the collagen distribution in the concave and convex sides of the scoliotic annulus fibrosus in AIS with depleted levels in the former compared with the latter [10].

Composing all the above findings, the present study is suggesting that the imbibed water mainly in the apical IVD but also in the above and below adjacent disks of the scoliotic curve must be in a greater amount in the convex side rather that in the concave. This asymmetrical pattern of the water distribution in the scoliotic IVD, in association to the diurnal variation in the water content of lumbar IVD [7], imposes asymmetrically, convex-wise, concentrated cyclical load during the 24 hours period to the IVD and to the adjacent immature vertebrae of the child. The convex side of the wedged IVD sustains greater amount of expansion than the concave side, with all the consequences for an asymmetrical growth of the adjacent vertebrae (Hueter - Volkman law). The strong correlation between lumbar LIVDW and thoracic CA implicates the important role of the lumbar spine and particularly that of the lumbar LIVDW to the progression of the scoliotic curve, as the lumbar IVDs are significantly higher.

The found correlations of this report imply that the apical intervertebral disc wedging through the proposed mechanism seems to be an important contributory factor in the progression of IS curves, emphasizing the role of the apical intervertebral disc in IS pathogenesis.

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Research into Spinal Deformities 5
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Geographic Latitude and Prevalence of Adolescent Idiopathic Scoliosis

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Abstract. Adolescent Idiopathic Scoliosis (AIS) prevalence has been reported to be different in various geographic latitudes and demonstrates higher values in northern countries. A study on epidemiological reports from the literature was conducted to record the prevalence of AIS among the general population of boys and girls, aged 10-16 years old, in different geographic latitudes, in order to test the hypothesis that the prevalence of AIS among boys and girls is different in various geographic latitudes and to examine if there is a possible association between them. Seventeen peer-reviewed published papers reporting AIS prevalence in the general population of boys and girls from most geographic areas of the northern hemisphere were retrieved from the literature. The geographic latitude of each centre where a particular study was originated was documented. The statistical analysis included a linear regression forward modeling procedure of the AIS prevalence by latitude, weighted by sample size.
According to the modelling of the data, a significant positive association between prevalence of AIS and latitude was found for girls ($p<0.001$), following a rather curvilinear trend, but not a significant positive association was found for boys ($p<0.111$).
A positive association between prevalence of AIS and geographic latitude is reported only for girls in the present study. Prevalence of AIS in boys is not associated significantly with geographic latitude. This differing significant association implicates the possible role of environmental factors in the pathogenesis of AIS that may act in a different way between boys and girls.

Keywords. Adolescent idiopathic scoliosis, geographic latitude, prevalence of idiopathic scoliosis, school screening

Introduction

Adolescent Idiopathic Scoliosis (AIS) prevalence has been reported to be different between boys and girls in various geographic latitudes and demonstrates higher values in northern countries [1-17]. The significance of this specific observation may not be obvious but its evaluation is important, because it could be related to possible environmental factors that may contribute to AIS pathogenesis.

The influence of the geography of a specific region on human biology is determined by socioeconomic and environmental factors such as temperature, humidity and lighting that are transferred and expressed in human cells by specific mediators [18].

The aim of this report is to test the hypothesis that the prevalence of AIS among boys and girls is different in various geographic latitudes as it is reported on published papers from different countries and to examine if there is a possible association between them.

Methods and Material

The Scoliosis Prevalence

The inclusion criteria for the epidemiological studies were clearly defined before performing a search of the literature on scoliosis prevalence of boys and girls, by browsing the Medline database. The geographic latitude of each centre where a particular study was originated was documented. The included studies cover the whole spectrum of geographic latitudes in the northern hemisphere.

A paper was considered eligible for inclusion when the study was reporting the prevalence of AIS among boys and girls, was age matched, involving boys and girls between 10 and 14 years old, the curves were detected through screening programs and a cut-off point of 10 degrees of Cobb angle was used for AIS definition. Seventeen peer-reviewed papers met those criteria and were included in the study [1-17].

The Statistical Analysis

The prevalence of idiopathic scoliosis for both boys and girls were treated as the dependent variables in a linear regression forward modeling procedure. The geographic latitude of each location where the study had taken place was the candidate independent variable. Because of the different sample size of each study, frequency weights were used in the regression model, controlling for the impact of each latitude value, according to their sample size. The F-test of significance of overall regression and Type I partial F-test were calculated at a significance level less than 0.05, testing for the significance of overall regression and for each variable added during the modeling. A graphical analysis of the residuals of the regression was performed in order to detect potential problems with the model. Data were analysed using SPSS v.11 statistical package.

Results

The reported prevalence of AIS in the literature increases in the northern geographic latitudes and decreases as the latitude is approaching the equator **(Table 1, Figure 1)**.

Figure 1. The regression curves of AIS prevalence among boys and girls by latitude are following a parallel decrement in northern latitudes

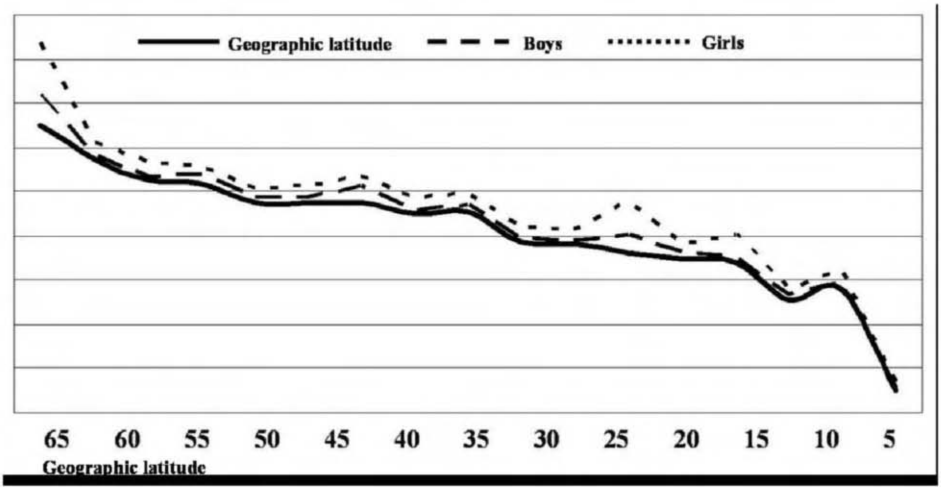

Table 1. Demonstrates data on AIS prevalence (%) according to the city or geographical periphery that the epidemiological study was performed, the size of the sample of the examined boys and girls, the geographic latitude in degrees and the author and the year of publication

City or Geographical Periphery	Geographic Latitude in degrees	Prevalence of AIS (%) Boys	Prevalence of AIS (%) Girls	Author and year of publication
Helsinki (Finland)	65,00	6,80	12,0	Nissinen M et al 1993 [1]
Malmo (Sweden)	57,50	0,63	3,21	Willner S & Uden A 1982 [2]
Oxford (UK)	52,50	1,00	3,20	Dickson RA et al 1983 [3]
Nottingham(UK)	52,00	1,90	1,90	Burwell RG et al 1983 [4]
Quebec (Canada)	47,50	1,14	2,37	Morais Tet al 1985 [5]
Rochester (Minn, USA)	47,50	1,26	2,70	Yawn BP et al 1999 [6]
Wisconsin (USA)	47,50	4,00	2,03	Gore DR et al 1981 [7]
Montreal (Canada)	45,30	1,64	2,70	Rogala EJ et al 1978 [8]
Slovenia	45,00	0,83	2,89	Plenicar-Cucek et al 1995 [9]
Delaware (USA)	38,50	0,93	2,80	Shands AR et al 1955 [10]
Epirus (Greece)	38,00	0,90	2,60	Soucacos PN et al 1997 [11]
California (USA)	36,00	4,20	7,70	Brooks HL et al 1975 [12]
Crete (Greece)	35,00	1,60	1,80	Koukourakis I et al 1997 [13]
Wakayaka (Japan)	34,00	1,38	4,90	Sugita K 2000 [14]
Changsha (China)	28,00	1,76	2,45	Pin LH et al 1985 [15]
Hu Guan (China)	25,30	1,32	1,60	Ma X et al 1995 [16]
Singapoure	5,00	0,25	0,93	Wong HK et al 2005 [17]

The inclusion of the quadratic term of latitude contributed to the explanatory power of the model according to partial *F* test and overall *F* test. According to the modelling of the data, a significant positive association between prevalence of AIS and latitude was found for girls (overall F p-value<0.001), following a rather curvilinear trend but not a significant positive association was found for boys ($p<0.111$) **(Figure 1)**.

Discussion

The regression curves of AIS prevalence among boys and girls by latitude are following a parallel decrement in northern latitudes, as it is shown in **Figure 1**.

The Prevalence of AIS

On reviewing the literature, prevalence figures quoted by various authors, serve to emphasize an apparent divergence in different parts of the world. The figures may be reflecting differences in the definition of a scoliotic curve, the methods of clinical examination, the thresholds for referral, the age group screened and as to whether the studies are based on random sampling or a longitudinal survey of individual children over some years. On the other hand recorded figures may represent real environmental, geographical, genetic or racial influences [18].

In the present study the AIS prevalence for both boys and girls decreases as the geographic latitude approaches the equator, but prevalence of AIS is associated significantly with geographic latitude only in girls. The parallel decrement of their regression curves in northern hemisphere implicates the role of numerous factors related to latitude in the pathogenesis of AIS especially in girls.

AIS and Environmental Factors

A positive association between prevalence of AIS and geographic latitude is reported only for girls in the present study. Prevalence of AIS in boys is not associated significantly with geographic latitude. This differing significant association implicates the possible role of environmental factors in the pathogenesis of AIS that may act in a different way between boys and girls.

AIS is associated with pubertal growth spurt and its progression decelerates after completion of skeletal maturity. The age at onset of menarche is indicative of the remaining growth potential of a child. Goldberg et al [19, 20] have shown that menarcheal status in girls is a more meaningful predictor of curve stability than Risser sign, because at menarche peak growth velocity is already past [21] and although Risser stage 1 is still, on average, 8 months away [22, 23], the possibility for more growth and significant progression, especially for smaller curves is declining rapidly. Furthermore, girls who are pre-menarcheal at diagnosis have a higher prevalence of surgery, as the menarcheal status alone will divide a female patient group into those who are at significant risk of surgery and those who are not [24]. A clear association exists between the deterioration of a scoliotic curve and periods of rapid growth, such those occurring before pubarche. Pubarche appears later in boys when their skeleton has already been at a more mature stage and thus their peak growth velocity does not correspond to age at menarche as in girls.

Numerous environmental factors are acting in a different way between boys and girls, during the pre-menarcheal period in northern countries. These factors are probably influence specific biologic events, such as age at menarche. A small delay in pubarche in girls, which is recorded in northern countries, is associated with increased AIS prevalence [25], as the period of rapid growth and hence the period of spine vulnerability is lengthened, while other pre-existing or aetiological factors are contributing to the development of AIS. A similar delay in age at menarche in boys does not impact on AIS prevalence, as their skeleton is at a more matured stage the period of the rapid growth and thus their spine is not vulnerable to deforming forces that may result in scoliosis.

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Sagittal Configuration of the Spine in Girls with Idiopathic Scoliosis: Progressing rather than Initiating Factor

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Abstract. Thoracic hypokyphosis with increasing axial rotational instability is claimed to be a primary factor for the initiation of Idiopathic Scoliosis (IS) according to some authors. The objective of this study was to compare the sagittal configuration of the spine in two groups of girls with and without scoliosis in order to determine whether thoracic hypokyphosis and/or lumbar hypolordosis are initiating factors for AIS or not. A group of 207 consecutive non-treated girls diagnosed with IS (12.7 y ± 1.8) measured with the Formetric® system were compared to a control group of 45 non-scoliotic girls of the same age (12.4 y ± 2). The Cobb angle for the whole scoliosis sample was 26º ± 13.6 and the angle of axial rotation 12.4º ± 7.7 (Perdriolle). The patient group was divided into subgroups by their Cobb angle ie G1 (5º-19º, n=79), G2 (20º-34º, n=81), G3 (≤ 35º, n=47). The values of the kyphotic angle and lordotic angle were compared. The kyphotic angle was not significantly different in the patients group (48.7º ± 9.4) compared to the control group (51.5º ± 10) while the lordotic angle was slightly but significantly lower in the patient group (39.3º ± 9.4) than in control (42.3º ± 8.8); however, the lordotic angle in G1 (40.5º ± 8.3) was not lower than that of the controls. Non-scoliotic girls and those with a mild scoliotic curve had the same angle of thoracic kyphosis and lumbar lordosis. Both angles tended to decrease in progressive curves. Neither thoracic hypokyphosis or lumbar hypolordosis are considered to be initiating factors for scoliosis but are factors in its progression.

Key words. Idiopathic scoliosis, sagittal configuration, progressing factor

1. Introduction

Idiopathic scoliosis (IS) is a structural 3D deformity: lordoscoliosis [1]. The cause of AIS is still unknown but nowadays it is widely accepted that it is a biphasic process with factor/s for the initiation and factor/s for the progression [2]. Progressive IS is generally attributed to an anterior spinal overgrowth [3]. It has been well established that a segmental structural thoracic lordosis is an essential biomechanical factor, which permits the spine to rotate to the same side of the lateral deviation [4,5]. Dickson et al [4] found that girls and boys tended to reduce their normal postural curvatures after ten years of age. Thoracic hypokyphosis increasing axial rotational instability is claimed to be a primary factor for the initiation of AIS according to the above-cited authors [4,5]. However, whether or not the sagittal plane configuration is a primary factor in curve initiation (etiopathogenesis) is still not fully understood.

2. Material and methods

2.1 Study design

Retrospective analysis of the back and spinal shape using a rasterstereography system (Formetric®) in a group of girls diagnosed with AIS in comparison with an age and sex matched control group.

2.2 Objectives

To compare the sagittal configuration of the spine in two main groups, non-scoliotic and scoliotic girls, in order to determine whether thoracic hypokyphosis and/or lumbar hypolordosis are initiating factors for IS.

2.3 Population

Database: All the patients attending our clinic have been measured using the Formetric® system since June 2002.

Selection criteria:
- Girls.
- Non-treated Idiopathic scoliosis
- Age between 9 and 17 years.

Exclusion criteria:
- Scoliosis associated with a Scheuermann's kyphosis.
- Spondylolisthesis and/or spondylolysis.

A group of 207 consecutive non-treated IS girls (12.7 y $\pm$ 1.8) were compared to a control group of 45 non-scoliotic girls of the same age (12.4 y $\pm$ 2). The Cobb angle for the whole scoliosis group was 26º $\pm$ 13.6 and the angle of rotation 12.4º $\pm$ 7.7 (We used the Perdriolle system but modified it to use intermediate values between the more usual five degrees scale - thus our values are: 2º,3º,5º,7º,8º,10º,12º etc). There were 52 main thoracic curves (single or combined with a minor lumbar curve), 63 double major (thoracic combined with lumbar or thoracolumbar curve), 77 thoracolumbar or lumbar and 15 thoracic double major curves. The scoliosis group was divided into subgroups according the magnitude of the Cobb angle G1(5-19º n=79), G2 (20-34º n=81), G3 ($\geq$ 35º n=47).

2.4 Measurement system

The Formetric® measuring system was used. The Formetric® values used for comparison were trunk length, lateral deviation (rms), surface rotation (rms), kyphotic apex, inflection point, lordotic apex, kyphotic angle (max) and lordotic angle (max). Any other Formetric® values taken were considered irrelevant for this study.

Table 1

	Kyphotic apex	Inflection point	Lordotic apex	Kyphotic angle (rms)	Lordotic angle (rms)
Control group n=45	T7	T12	L3	51.5º ± 10	42.3º± 8.8
Scoliotic girls n=207	T7	T12	L3	48.7º ± 9.4 NS	39.3º± 9.4 p<0.05
G1 (5-19º n=79)	T7	T12	L3	50.1º ± 9 NS	40.5º± 8.3 NS
G2 (20-34º n=81)	T7	T11 NS	L3	48.1º ± 9 p<0.05	39.2º ± 9 p<0.05
G3 (> 35º n=47)	T6 NS	T12	L3	47.5º ± 10 p<0.05	37.7º± 7.4 p<0.005

3. Results

Scoliotic girls had a significantly greater trunk length (408 mm) when compared with non-scoliotic girls (394 mm), p<0.05. Lateral deviation and surface rotation (rms) were both significantly higher in the patient group compared with the control group. Kyphotic apex, inflection point and lordotic apex were located at similar points in both the patient and the control group. The kyphotic angle was not significantly different in the patient group when compared with the control group but the lordotic angle was slightly but significantly lower in patients than in controls. Table 1 shows these results as well as the values observed in the different subgroups.

4. Discussion

Non-scoliotic girls and those with mild curves have the same angles of thoracic kyphosis and lumbar lordosis. Both angles tend to decrease mildly but significantly in progressive curves. The length of the spine has been found to be longer in girls with scoliosis compared to unaffected girls of the same age. It supports the hypothesis that scoliotic girls have longer columns that their peers [3]. Considering the mild differences observed, it appears that in scoliotic patients, the body was compensating to try to keep the total angles of thoracic kyphosis and lumbar lordosis as close to normal as possible, probably due to postural compensation mechanisms. The question whether or not segmental structural lordosis is a primary factor for the initiation of AIS cannot be answered with this study. However it seems evident that neither spinal thoracic hypokyphosis nor lumbar hypolordosis are initiating factors but most probably progression factors or associated geometrical changes occurring in parallel to the progression process. Another explanation could be that different scoliosis groups have different causative factor/s. In such cases, in a particular group, thoracic hypokyphosis and/or lumbar hypolordosis could be an initiating factor, something not clearly identified in this study due to the heterogeneity of the sample.

To our knowledge this is the first study providing Formetric® values for the regional thoracic kyphosis and regional lumbar lordosis in non-scoliotic and scoliotic girls. The kyphotic and lordotic angles both present higher values than expected when compared with other topographic values such as those offered by the Myrin® inclinometer [6]. The observed standard deviations suggest high variability. The angles discussed here do not describe the geometry of the spine in the lateral plane. The spinal shape in the sagittal plane observed in this study ranged from a frank thoracic lordosis to a hyperkyphosis. The latter was not just a paradoxical hyperkyphosis found in long term progressive curves but also seen in milder curves. This finding is in agreement with the high variety of sagittal profiles associated with a particular pattern in the frontal plane found by Legaye et al in a study where the spinal shape was analysed using the ISIS® system [7]. The observations support the concept that the geometry of the spine in the sagittal plane in scoliotic girls is as variable as it is non-scoliotic girls and that the morphology before the initiation, development and progression of the scoliosis determines the final sagittal configuration.

This is a preliminary study reporting the maximum values of regional thoracic kyphosis and regional lumbar lordosis angles as well as the kyphotic apex, the inflection point and the lumbar apex. The Formetric® database offers further data and measures which should be used in further comparisons in future studies in order to validate the results of the present investigation. However, from a practical point of view, we can affirm that when reporting changes in the sagittal profile consequential to any treatment modality, the values discussed above are irrelevant. Segmental analysis of the sagittal shape rather than just thoracic and lumbar regional values should always be undertaken.

5. Conclussion

Regional thoracic kyphosis and lumbar lordosis angles have been found to be similar in non-scoliotic girls and those with mild scoliosis (<20º). In girls with Cobb angles of over 19º both sagittal angles are mildly but significantly lower than in normal girls. These results strongly suggest that regional thoracic hypokyphosis and lumbar hypolordosis are not initiating factors but most probably either simply progression factors or associated geometrical changes occurring in parallel to the process causing progression. The results of the study need to be validated with more data. In order to determine how the shape of the scoliotic spine differs in the sagittal plane when compared to non-scoliotic spines, segmental analysis requires to be undertaken rather than a purely regional analysis using angles which do not fully describe the geometry of the spine.

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Is it Possible to Identify a Population in which the Incidence of Future Development of AIS is Greatly Increased when Compared to the Normal Population?

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Abstract. For future research of predictors of AIS, it would be advantageous to identify a general population in which the development of AIS is greatly increased when compared to the normal population. The probability of predicting future development of AIS among younger relatives of current patients based on the probability of AIS incidence was assessed from the research literature. Although there is considerable literature relating to familial relationships of the probability of developing AIS or having AIS, the probability is relatively low in most cases. Even with the best of predicted probabilities, the identification of patients with a high probability of developing AIS remained low. The identification of people among the general population who have a high probability of developing AIS based on the probabilities expressed in the literature is not possible.

Keywords. Adolescent idiopathic scoliosis, prediction, probability

Introduction

As its name suggests, adolescent idiopathic scoliosis (AIS) develops at the time of puberty and is basically manifested by an abnormal curvature of the spine that has no known cause. While initially it is a cosmetic deformity, the curve can become severe and debilitating, eventually impinging on both the lungs and the heart and significantly reducing their function. Treatment strategies include simple observation with bracing if the curve progresses to 25° (Cobb angle) and eventually extensive surgery involving insertion of metal rods accompanied by spine straightening and fusion if the curve reaches 50°. AIS affects only a small portion of the population (0.5-3%) with approximately 5% of those affected developing curves with sufficient severity to require surgery[1-6].

Despite intensive research, very little is known about the aetiology of AIS. What is known is that progression of the curve is associated with rapid growth of the spine (adolescence and puberty) and most of the patients in the scoliosis clinics (80%) are female. There also appears to be a familial component to AIS. There are also many different variations of the curve (single curves, double curves, curves to the right, curves to the left, different vertebrae involved, different apices) which suggest that there might well be different underlying causes but even this relatively simple question currently remains unanswered.

Specifically hindering the development of appropriate treatment strategies for AIS is the fact that there is no test available that would identify those children who will develop the deformity. If such a test was available then treatment strategies could be developed to prevent the onset of curve development. As it is, children appear at the scoliosis clinic with curves that have already reached 15° and the characteristics of the early, important stages of curve development lie hidden. It is probable that within these early characteristics there lie essential clues for early recognition. In addition, there is also no test available to identify those children whose curve will continue to progress after initial observation especially those who will ultimately require extensive, invasive surgery. If such tests were available and the children identified, then strategies could be developed that would allow aggressive early treatment to prevent further development.

Based on these comments it is clear that a significant step forward in the study of the aetiology of AIS would be to identify a group of apparently normal young children who have not yet developed AIS and follow their progress so that the early characteristics of those that ultimately develop AIS could be determined. However, previous school-screening studies have shown that this is an unfeasible project because the low incidence of AIS and the high number of false positives (children with spinal curves that naturally regress) make it unrewarding, expensive and consequently uneconomical.

In this project, we considered ways to identify a population of young children in which the future incidence of AIS development was naturally increased significantly above the normally reported 0.5-3%% level through a possible familial connection. If such a population could be identified then these children could be closely monitored and much needed data on the early stages of development uncovered with the possibility that progressive indicators could be identified. If the mechanism for identifying such a population could also be determined, then it would be useful in the testing of any progressive indicators that were developed by other means, such as the current melatonin metabolism model being developed in Montreal.

As AIS has a familial component, it was suggested that relatives of children who are attending the scoliosis clinic for the first time might provide a means by which a population in which the incidence of AIS was higher than 0.5-3% might be identified. To achieve this, a questionnaire was created to explore the genealogical background of these children in relation to the incidence of scoliosis. As the population being studies was small, the literature was also searched for studies in which the probability of relatives of affected patients developing AIS could be ascertained.

Methods

The Scoliosis Clinic at the Glenrose Rehabilitation Hospital, Edmonton distributed questionnaires to scoliosis patients throughout Northern Alberta, NWT, Yukon and parts of Saskatchewan and British Columbia. The questionnaire was circulated and offered the patient a voluntary and confidential means of reporting the size of their family, the number of people in their family with scoliosis, their relation to the patient, and a description of the forms of scoliosis seen in themselves and their family members. The descriptions of the disorders included: severity of scoliosis as either mild (10-20 degree Cobb angle as measured from a PA radiograph taken in clinic), moderate (20^0-50^0) and severe (required surgery), age of onset of discovery of scoliosis, method of discovery, treatment undergone, and any possible associated disorders. All reported cases of relatives' scoliosis were considered, regardless of cause.

Data analysis included separating the sample population by the family history of the patient to discover the highest rates of incidence relative to the index patient. Incidence rates were expressed as a percentage of the number of people divided by the total number of relatives. Calculations were performed to locate particular trends in the history of those affected which led to higher than normal incidence rates.

The findings from our sample group were compared with similar data available in the literature which was searched using PubMed.

Results

Fifty-seven questionnaires were returned. The surveys provided information on the 57 (4 male, 53 female) index patients who filled out the survey plus a total of 1257 other family members. Twenty-eight (2 M, 26 F) of the 57 index patients surveyed reported a family history of scoliosis (49.1%). The incidence of scoliosis in the relatives of the index patient was 4.06% (51/1182) with 6 cases seen in the first generation, 32 cases seen in the second and 13 cases seen in the third (table 2). There were 9 cases in which the index patient required surgery and had a relative who also had the disorder. Unfortunately, the data for the size of the sample populations for the first, second and third generation was incomplete. Therefore, no proportions were able to be calculated for all generations. It was simply assumed that the sample sizes grew with each generation.

Eleven index patients reported more than one family member with scoliosis and therefore they might have been recognised as having being related to scoliosis patients with a family history of the disorder prior to their own diagnosis. The proportion of the population in a family that were diagnosed with a family history of scoliosis prior to the discovery of scoliosis in the index patient was 37/312 (11.8%). Five of the 312 were contained within a family with a previously notable history of scoliosis that required surgery (5/312; 1.6%).

Of the 1257 relatives reported in the survey, there were only two cases in which a sister of the index patient was observed as having scoliosis and there were no cases where a brother also suffered from the disorder. Despite questions on the survey regarding a breakdown of the relationship of each family member, there was no recorded number for the total number of brothers or sisters of the patient which had reached an age (10-15 yrs.) at which AIS it may have been assumed that scoliosis had begun to form. Therefore no incident rate could be reported. The totals for each relative seen to have scoliosis in the survey is reported in table 1.

Table 1- The respective relatives with scoliosis and their relation to the index patient.

Brother	*0*
Sister	*2*
Mother	*3*
Father	*4*
Cousins	*16*
Aunt	*19*
Uncle	*3*
Total Relatives	*1298*

Table 2- The severity of scoliosis seen in the index patient and their respective accounts of family histories.

Index Patient	No History	Family History
Mild	6	10
Moderate	13	12
Severe (Surgery)	9	8
TOTAL	28	30

In the literature, familial scoliosis has been reported to occur in 25-97% of cases [8-10]. Wynne-Davies reported an incidence of scoliosis in the relatives of a scoliosis patient as being 6-10 times higher than that of the general population [1]. Later, it was shown that 1% of several thousand first (11.1%), second (2.4%) and third degree (1.4 %) relatives of individuals with scoliosis had a Cobb angle > 10º. However, infantile idiopathic scoliosis patients were also included which probably distorted the numbers [11].

Scoliosis has also been reported in 5% of the brothers and 7% of the sisters of index patients [12]. Filho and Thompson even showed a reduction among siblings in frequency of 6.6%:1.6%:1.0% from first, second and third degree relatives. In a study of 116 index patients diagnosed with AIS, scoliosis occured in 5.2% male and 6.2% female first degree relatives. Yet again, second and third degree occurances were very much less at 1.3% and 0.77% [13]. In contrast, twins have always shown a much higher incidence of the disorder but unfortunately the sample population in this study did not have any twins who suffered from the disorder. Kesling concluded that 76% of monozygous and 36% of dizygous twins shared the disorder, following development in the other [14]. Interestingly, Kesling also noted that there was no significant concordance between the form of scoliosis that affected the twins.

The sample population did not include any data on the proportion of offspring who had scoliosis when the parents were affected. However, the literature revealed values of 42% for affected female offspring and 7% of male offspring from one affected parent. No significant differences were seen in the outcome of the offspring between the mother being affected when compared to the father's status [1]. Unfortunately, these values are in sharp contrast to those reported by DeGeorge and Fisher who found that 17% of affected girls and 29% of affected boys came from affected parents [15].

Discussion

There is already a considerable volume of literature reporting familial relationships of AIS but much of it is confusing and not of much direct use. The sample population of this study remained consistant with the literature with 49.1% of the patient cases having a familial component and the incidence of scoliosis tapering off with each successive generation [12]. The higher incidence (4-8%) of scoliosis seen in the relatives of a person affected by the disorder when compared to the general population (2-3%) provides a population in which the development of AIS is increased when compared to the normal population. Interestingly, there was no difference in the incidence of scoliosis seen by looking at all the relatives of an index patient when compared to looking at all the relatives of an index patient with a previous family history of the disorder. Both methods provided incidence rates of 8%.

These results did not allow the prediction to be made of who will get scoliosis through family histories by predicting which siblings of the index patient would be at highest risk. The sample size was too small for any significant information to be collected and much larger population studies would have to be conducted. However, in the previous literature it has been shown that 7% of siblings can be affected with a slightly higher incidence among females when compared to males [12, 13]. It is problematic to locate high incidence populations because scoliosis has most probably a multifactorial genetic trait.[9, 16-23].

In the current survey, 9 of the 17 individuals that required surgery had a previously affected relative. This might suggest that this is accurate for a global application and might hold some promise for future treatment and research. Currently there is no method of treatment for scoliosis patients in the early stages of the disorder and a clinical application for this population is still not available. From a research perspective, recognizing the relatives of an index patient who are at higher risk for deformity and observing them from before initial signs of scoliosis have begun could provide valuable information to the preliminary stages of the disorder.

Clearly, it is very expensive to screen for potential patients and this is a significant factor [24]. The cost benefits of large-scale screening when compared to selective screening is an important issue and must be weighed against the benefits of increasing the proportion of positive diagnoses obtained by the screening from ~0.5-2% to 4-8%.

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Patterns of Extra-Spinal Left-Right Skeletal Asymmetries and Proximo-distal Disproportion in Adolescent Girls with Lower Spine Scoliosis: Ilio-femoral Length Asymmetry & Bilateral Tibial/Foot Length Disproportion

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Abstract. Anomalous extra-spinal left-right skeletal length asymmetries have been detected in girls with adolescent idiopathic (AIS) in four sites (1) upper limbs, (2) periapical ribs, (3) ilium, and (4) right leg and right tibia. This paper on adolescent girls with lower spine scoliosis reports (1) a fifth pattern of left-right ilio-femoral length asymmetry associated with sacral alar height asymmetry, and (2) bilateral anomalous lengthening of the tibia relative to the foot. The findings are consistent with the hypothesis that at the time of diagnosis of AIS in girls there are anomalies of skeletal proportions associated with a predisposition to curve progression; these proportions are in three dimensions - left-right, cephalo-caudal in the trunk (proximo-distal in the lower limbs), and front-back in the trunk. The origin of these anomalies is unknown but possible causes, and of the associated AIS, are genetic and environmental factors acting in embryonic life not expressed phenotypically until years after birth.

Key words. Scoliosis, etiology, bilateral symmetry, pelvis, legs

1. General introduction

1.1. Extra-spinal left-right skeletal length asymmetries (Figure 1)

Extra-spinal left-right skeletal length asymmetries have been detected in girls with AIS as relative lengthening in four sites: (1) upper limb length asymmetry on the convexity of right thoracic and thoracolumbar curves [1-4], (2) periapical ribs on the concavity of girls with right thoracic AIS [5-7], (3) a taller ilium on the concavity of lower spine scolioses [8]; and (4) right total leg and right tibia unrelated statistically to the severity or side of the *lower spine scolioses* [8].

1.2. The present paper

Two new aspects of skeletal disproportion in girls referred after school screening for scoliosis are revealed here: (1) ilio-femoral length as a fifth type of left-right skeletal length asymmetry (Figure 1), and (2) bilateral proximo-distal tibial/foot length disproportion.

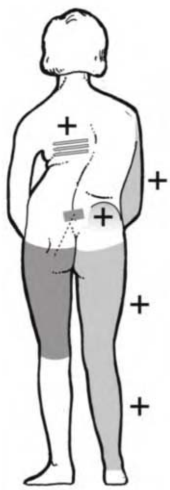

Figure 1. Anomalous extra-spinal left-right skeletal length asymmetries in AIS girls. Ilio-femoral length asymmetry correlates significantly with sacral alar height asymmetry (this paper). The + signs indicate the relative skeletal overgrowth detected on that side (see text).

Ilio-femoral length asymmetry associated with sacral alar height asymmetry and unrelated to ilium height asymmetry and lower spinal scoliosis

2. Introduction

The traditional clinical method for measuring leg length inequality from the anterior superior iliac spines to the medial malleoli [9] includes the ilia [10,11]. Hence, the presence of any ilium asymmetry – the quantum of which is usually unknown, complicates the clinical estimation of total lower limb length inequality [12](Figure 2).

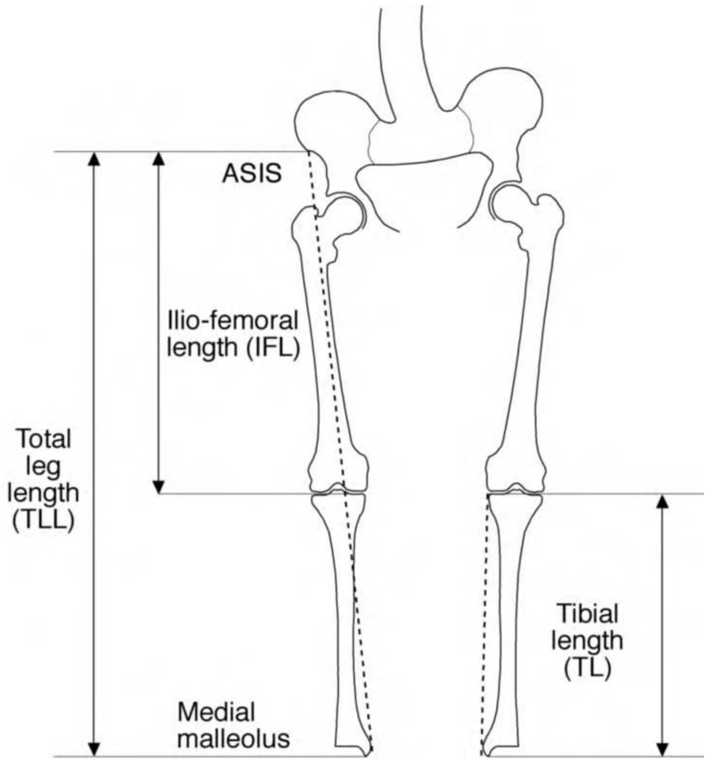

Figure 2. Measured leg lengths and derivatives. IFL=TLL *minus* TL, IFL asymmetry = IFL (left) *minus* IFR (right)

3. Patients and controls

3.1. Patients

Forty-nine of 108 consecutive adolescent patients referred from routine scoliosis school screening during 1996-1999 had *lower spine scoliosis with* measurable radiologic sacral alar and hip tilt angles (Figure 3) – lumbar scoliosis 18, thoracolumbar scoliosis 31 (girls 41, boys 8, mean age 14.7 years).

The mean Cobb angle is 16 degrees, range 4-38 degrees, 27 left curves, 22 right curves.

3.2. Controls

The controls were 278 normal girls (11-18 years, mean age 13.4 years).

4. Methods

4.1. Anthropometry

From anthropometric measurements of total leg lengths and tibiae (Figure 2)[8] derivatives were calculated as ilio-femoral length (total leg length *minus* tibial length) and several length asymmetries, namely: ilio-femoral length asymmetry, total leg length inequality and tibial length asymmetry (all left *minus* right).

4.2. Radiographs – spine and pelvis

On standing full spine anteroposterior radiographs measurements were made of Cobb angle and pelvic asymmetries trigonometrically as ilium height asymmetry [8,13] and a new parameter, sacral alar height asymmetry (left *minus* right, Figure 3). The convention is that tilt angles lower on the right are negative and lower on the left are positive.

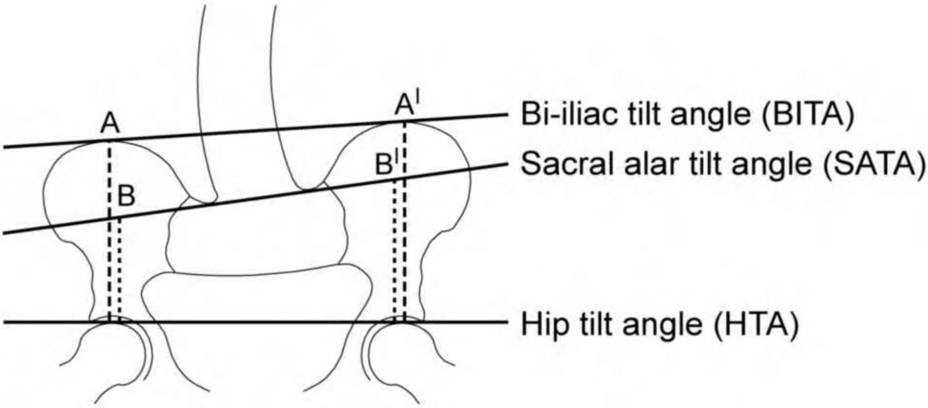

Figure 3. Pelvic measurements as in [8]. AA^1 and BB^1 are lines raised from most prominent part of each femoral head to the BITA and SATA lines to measure ilium height and sacral alar height on left and right; asymmetry of the length of each of AA^1 and BB^1 is calculated as left *minus* right.

4.3. Measurements were made by one observer (RGB)

4.4. Reproducibility, see [8]

Technical error of the measurement (TEM) and Coefficient of reliability (R) [14] are as follows (10 repeats by RGB):

Left ilio-femoral length: TEM = 5.9 mm, R=0.95.
Right ilio-femoral length: TEM = 5.7 mm, R=0.95
Asymmetry of ilio-femoral length: TEM = 3.7 mm, R=0.50
Ilium height asymmetry: TEM = 1.76 mm, R = 0.58.
Sacral alar height asymmetry TEM = 2.7 mm, R = 0.72

5. Results

5.1. Ilio-femoral length asymmetry correlates significantly with sacral alar height asymmetry (girls negatively r= - 0.456, p=0.002, boys positively r=0.726 p=0.041) but not ilium height asymmetry (girls p=0.201)(Figure 4).

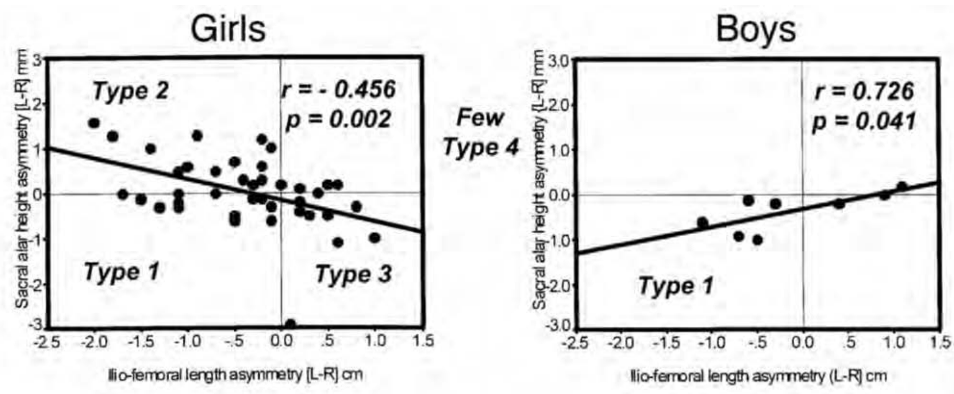

Figure 4. Ilio-femoral length asymmetry plotted against sacral alar height asymmetry for girls and boys. Four types are defined, Types 1 – 4.

5.2 Ilio-femoral length asymmetry for girls is significantly greater in the scoliotics (-4.3 mm) compared with the normal sample (0.42 mm)(p<0.0001)

5.3 Total leg length inequality but not tibial length asymmetry in the girls is associated with sacral alar height asymmetry (respectively r = - 0.367 p=0.017, & r=0.039 p=0.807).

6. Discussion

6.1 Ilio-femoral length asymmetry

6.1.1 The association of ilio-femoral length asymmetry with sacral alar height asymmetry suggests primary changes in the femur(s) and sacrum.
6.1.2 The lack of association of ilio-femoral length asymmetry with ilium height asymmetry suggests that sacral alar height asymmetry is due to factors separate from the ilium, e.g. mechanical modulation of vertebral growth [15].

II. Proximo-distal skeletal length proportions in lower limbs of adolescent girls with scoliosis: tibial length/foot length is greater bilaterally in scoliotics

7. Introduction

There are no reports of proximo-distal skeletal length disproportions (allometry) in the limbs of patients with adolescent idiopathic scoliosis [4].

8. Patients and controls

8.1. Patients

Seventy-one girls of 173 consecutive adolescent patients referred from routine scoliosis school screening during 1993-1999 had *lower spine scoliosis;* after classification [8] there were lumbar (LS) 31, or thoracolumbar (TLS) 40 (mean age 14.7 years, post-menarcheal 56).
The mean Cobb angle is 15 degrees (range 4-38 degrees), apical vertebral rotation 13 degrees, left curves 38, right curves 33,

8.2. Controls

The controls were 278 normal girls (11-18 years, mean age 13.4 years).

9. Methods

Limb segments were measured anthropometrically [8] and proximo-distal proportions calculated for each leg as:
(1) ratio of tibial length/foot length, and
(2) percentage of tibial length/foot length ratios for each of the scoliosis and normal groups.

10. Results

10.1. Ratios

For all ages combined the mean tibial length/foot length ratios are significantly larger in scoliotics than normals, respectively: left leg 1.541 and 1.513 ($p=0.001$, right +1.9%); right leg 1.558 and 1.519 ($p<0.0001$, right +2.6%, Mann-Whitney test).

In the normals but not scoliotics the ratios increase with age for each leg (each $p<0.0001$).

10.2. Tibial length analysed with foot length as co-variate

Tibial length analysed with foot length as co-variate for the right leg but not the left leg shows an effect associated with the presence of scoliosis (right leg p=0.008; left leg p=0.066, ANOVA).

11. Discussion

11.1. Three types of whole body skeletal disproportion in AIS girls

We reported anthropometric evidence for three types of skeletal disproportion in AIS girls – *left-right, cephalo-caudal* and *front-back.* [4,16]. At the time of diagnosis of AIS in girls it was hypothesized that there is a complex and basic disorder of skeletal proportions associated with a predisposition to curve progression [4,16]. The concept that girls with progressive AIS at diagnosis have whole body skeletal disproportions is supported by the finding of disproportionately longer legs relative to arms in AIS girls having spinal fusion compared with brace-treated AIS girls [17].

11.2. Bilateral anomalous lengthening of tibia relative to foot

The proximo-distal disproportion in the lower limbs of these adolescent girls with lower spine scoliosis is in the same dimension as cephalo-caudal disproportion in the trunk of girls with AIS [16].

11.3. The cause of the proximo-distal disproportion in the lower limbs

The findings are consistent with primary skeletal changes in tibial and/or foot physes associated with the scoliosis – similar to the physeal mechanism suggested to explain the tibial length asymmetry in these scoliotic subjects [8].

11.4. An embryonic origin for the tibia/foot disproportion?

The findings of this skeletal disproportions in girls with scoliosis is consistent with primary changes in growth plates that may be determined by the interaction of genetic and environmental factors acting on the developing skeletal primordial in early embryonic life not expressed morphologically until years later [1-4,18].

11.5. Developmental instability

In formulating the concept of developmental instability as the mechanism that leads to scoliosis, Goldberg et al [19] invoked developmental gradients in embryonic life, namely of left-right and cephalo-caudal. Scoliosis is viewed as a whole body phenomenon, as a final common pathway of a variety of destabilizing factors. Our observations on anomalous skeletal proportions, left-right and proximo-distal in the legs, in these girls with scoliosis are consistent with the concept of developmental instability.

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Adolescent Idiopathic Scoliosis: Metric Analysis of the Deformity

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Abstract: In order to explore the concept that scoliosis is fundamentally a loss of left-right symmetry. Surface topography was used to measure asymmetry in three dimensions at three levels on the back surface. Statistical analysis of prospectively collected topographic, radiographic and clinical data, in girls with adolescent idiopathic scoliosis, was carried out and comparisons were made with theoretically perfect symmetry (test value of zero). All scoliosis showed statistically significant differences in coronal dimensions, index points on the convex side of the scoliosis being further from the mid-line than those on the concave side. Primary thoracic scoliosis differed from thoracolumbar and lumbar in that they showed directional asymmetry at all levels and in all directions, the side of the scoliosis convexity being broader, taller and thicker. This asymmetry is not due to posture, spinal balance or trunk rotation, as left and right sides are being compared independently of their orientation in space. The asymmetry is of size in three dimensions and size is determined by growth. Growth is a three dimensional process, but does not necessarily occur equally in all three. Differential growth is both directional and regional, particularly during the pubertal growth spurt, when proportions change substantially, and is controlled by many genes, as well as by hormones and signalling molecules. The implication is that scoliotic deformity is the result of asymmetric growth, not confined to the vertebrae, but affecting the entire trunk. This is a developmental, rather than pathological, phenomenon. It makes questions of aetiology redundant and natural history logical.

Keywords. adolescent idiopathic scoliosis – asymmetry – aetiology – developmental instability

1. Introduction

Scoliosis has been studied by physicians for twenty-five hundred years[1] yet remains an unsolved problem, aetiology unknown, natural history disputed, but treatment agreed. Investigators generally accept the concept of *first* a pathologically curved spine, *secondly*, structural remodelling of vertebrae. This model of a passive and secondary process informs treatment and directs aetiological inquiry. It is supported by studies of scoliosis induced in small animals [2], by the application of external stresses to the spine, although there is no evidence that similar forces are generated in human subjects. Other theories, e.g. the concept of a melatonin deficit [3], of calmodulin disorder[4] or of system maturation[5] have been disputed by neuroendocrinologists[6,7] and scoliosis surgeons [8,9] or are unconfirmed. The paradox is that, while invasive manoeuvres may cause deformity in laboratory animals, scoliosis is more commonly observed[10] in robustly healthy children. One would expect a disease with such visible consequences to leave more traces.

Because scoliosis presents as an obvious asymmetry of the back, there have been reports of associated physical and functional asymmetries: limb length [11], face [12], breast size[13], brainstem[14], teeth[15], paraspinal muscles[16], vibratory sensation[17], cerebral cortex organisation[18], palmar dermatoglyphics [19] and femoral neck angles[20]. These findings are interesting in themselves, and have prompted some investigators [21] to consider an alternative hypothesis based on a biological model of developmental stability [22]. This term refers to the ability of a growing organism to produce the adult phenotype that is specified in the genotype. The end result will depend on its inherent stability and on the severity of the physiological stress encountered. In any bilaterally symmetrical organism, this can be measured by the extent to which that symmetry was achieved. VanValen [23] in 1962 described different patterns of asymmetry (*directional asymmetry*: normal distribution, mean not zero, genetically determined; *antisymmetry*: non-normal distribution, mean zero, genetically determined; *fluctuating asymmetry*: normal distribution, mean zero, resulting from environmental or physiological stresses and quantified by the variance). If scoliosis were to be considered in this category, there would be no aetiology, no unique identifying disease process, only the coexistence of growth, of physiological stress and of deformity.

Reasons to entertain such a paradigm include the reports of asymmetry cited above, the absolute association of the deformity with growth and growth rate [24], its frequent occurrence as a complication of other physical conditions, in particular neuromuscular and genetic disorders, and the persistent absence of a specific disease process. While it is impossible to prove the negative, it is conceivable that such a disease does not exist. If scoliosis were merely an expression of developmental destabilisation, then the deformity itself should fall into one of the categories described above. The Cobb angle [25] of a population can be shown graphically as a skewed normal curve, but studies have not been made relating the back surface deformity to the same principles. This report describes how asymmetry of the back in scoliosis was quantified and analysed, using routine surface topography, and relates the findings to biological standards.

2. Materials and Methods

2.1 Patients

The clinical records of untreated female patients with confirmed adolescent idiopathic scoliosis (age at presentation greater than ten years, Cobb angle [25] equal or greater than 10°, no other significant abnormality) were selected from the spinal deformity database.. Group 1 were classified as primary thoracic, apex at or above the eleventh thoracic vertebra, Figure 1(i), and Group 2 as primary lumbar or thoracolumbar, with apex at or below the twelfth thoracic vertebra Figure 2(i). Only girls were studied, to eliminate any effect from sexual dimorphism.

2.2. Surface Topography

The system, Quantec Image Processing ® (Lathom, Lancashire, UK), has been described before [26,27]. New parameters were requisitioned specifically for the purpose of this study and are described in an accompanying paper in this volume (Goldberg, Groves et al).

2.3. Analysis

All groups were compared individually with perfect symmetry, where all values of left-right differences would be zero (single sample t-test), and with each other (independent samples t-test) using SPSS (Statistical Package for the Social Services Vs. 11).

3. Results

3.1. Group 1. Thoracic scoliosis. Apex at or above eleventh thoracic vertebra. N=105.

There were 105 patients in this group. Mean age was 13.6±1.6 years, range 10.6 to 24.3, mean height 157.2±6.9 centimetres, range 138.1 – 172.5. Mean Cobb angle was 50.1°±19.1, range 11 – 93. The mean topographic spinal angle was 27.9°±13.4, range 5.5 – 59.. Topographic measures show the posterior trunk symmetry index, (POTSI [30], a measure of trunk balance), unsigned was 57.3 ± 27, range 10.74 to 124.88, and signed was 16.77± 18.02, range -20.86 to +51.2. Figure 1(i) shows a the topographic image of a patient in this group.

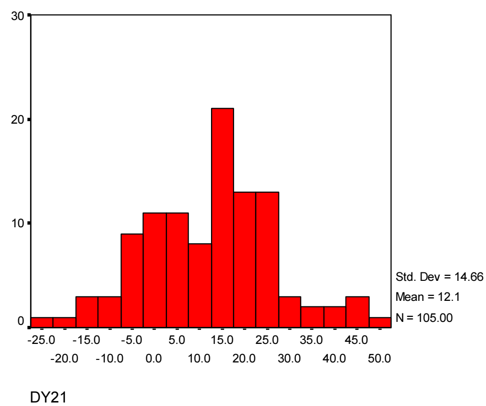

Figure 1(i) **Figure 1(ii)**

Figure 1(i) Patient with a right convex thoracic scoliosis, apex tenth thoracic vertebra, Cobb angle 61°.
Figure 1(ii) Graphic distribution of right left differences in the vertical dimension at the mid thoracic level (dY2 in Table 1 below).

Table 1. Left-right differences in vector- measurements.

	Difference	t	p	Confidence interval
dX1	-11.03±9.09	-12.44	<0.001	-12.79 to -9.27
dY1	8.3581±11.38	7.53	<0.001	6.16 to 10.56
dZ1	-3.02±4.84	-6.44	<0.001	-3.97 to -2.10
dX2	-9.55±7.42	-13.19	<0.001	-10.99 to -8.11
dY2	12.14±14.66	8.48	<0.001	9.30 to 14.98
dZ2	0.403±5.27	0.783	0.435	-.62 to 1.42
dX3	-5.68±7.34	-5.68	<0.001	-7.1 to -4.25
dY3	4.48±6.37	4.48	<0.001	3.25 to 5.72
dZ3	-2.50±3.34	-2.50	<0.001	-3.15 to -1.86

dX1, 2 & 3 = coronal vectors at shoulder, mid thoracic and lumbar index points. dY1, 2 &3 = rostro-caudal or vertical differences. dZ1,2 & 3 = antero-posterior differences. For full discussion see Goldberg et al. This volume.

All vectors are summarised in Table 1. There are statistically significant differences in all directions and at all levels, except the middle Z (dZ2, antero-posterior, lower thoracic level): the right index point is further from the mid-line (X negative), higher (Y positive) and further back at the upper and lowest levels (Z negative) than the left. This is shown graphically for the middle Y vectors in Figures 1(ii), a normal distribution and a mean, 14.7 millimetres, which is statistically different from zero. The mean vertical vectors for this group is positive but in left convex thoracic scoliosis all values are reversed. This group of patients with primary thoracic scoliosis are displaying directional asymmetry, all parameters having a normal distribution about a mean that is not zero (VanValen [23]). The side of scoliosis convexity is taller and broader then the contralateral, more posterior at the shoulder and loin.

3.2. Group 2. Lumbar and thoracolumbar scoliosis. Apex at or below twelfth thoracic vertebra. N=57

There were 57 patients in this group. Figure 2(i) shows an example. The mean age at presentation was 14.1±1.6 years, range 10.4 – 19.36. Mean height was 157.6±8.04 centimetres, range 141.3 – 173.8 Mean Cobb angle was 41.8°±22.6, range 10 – 93, and the mean major spinal angle was 18.5°±12.2, range 0.75 – 44.5. Topographic measures show posterior trunk symmetry index, (POTSI [30]), unsigned was 36.9 ± 19.4, range 10.5 to 93.34, and signed was -4.8± 14.7, range -41.29 to 31.6

Table 2. Left-right differences in vector- measurements

	Difference	t	p	Confidence interval
dX1	-2.22±6.50	-2.577	0.013	-3.94 to -0.49
dY1	-1.76±8.77	-1.514	0.136	-4.08 to 0.57
dZ1	0.17±3.13	0.401	0.690	-0.66 to 0.99
dX2	-2.57±5.05	-3.847	<0.001	-3.91 to -1.23
dY2	-1.81±11.48	-1.189	0.24	-4.85 to 1.24
dZ2	-0.22±6.08	-0.279	0.781	-1.84 to 1.34
dX3	-1.82±5.96	-2.305	0.025	-3.40 to -0.24
dY3	0.42±5.30	0.601	0.55	-0.98 to 1.83
dZ3	-0.82±2.11	-2.932	0.005	-1.38 to -0.26

dX1, 2 & 3 = coronal vectors at shoulder, mid thoracic and lumbar index points. dY1, 2 &3 = rostro-caudal or vertical differences. dZ1,2 & 3 = antero-posterior differences. For full discussion see Goldberg et al. This volume.

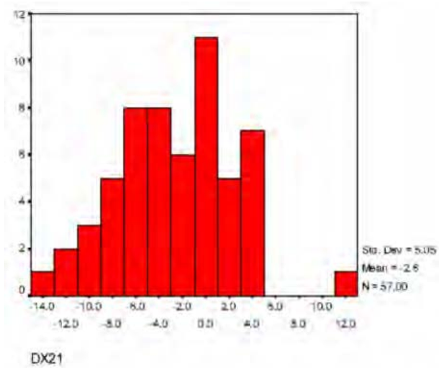

Figure 2(i) **Figure 2(ii)**

Figure 1(i) Patient with a left convex lumbar scoliosis, apex second lumbar vertebra, Cobb angle 72°.
Figure 1(ii) Graphic distribution of right left differences in the coronal dimension at the mid thoracic level (dX2 in Table 2 below).

Table 2 compares right-left asymmetry parameters with zero for group 2, lumbar and thoracolumbar scoliosis. There is a different pattern of asymmetry, which is to be expected, since the deformity is obviously different to the eye. The main feature is that coronal left-right values are statistically significant (convex side is broader than concave) but there is no difference in vertical height. These girls broadened asymmetrically, but otherwise grew more or less equally. Figure 2(ii) shows graphically the distribution of the middle coronal values (dX2, lower thoracic).

Table 3. Comparison by independent t- test of groups 1 & 2

	Group 1 Mean ±SD	Group 2 Mean ±SD	F	Sig.	t	Sig.	c.i.
dX1	-11.03±9.09	-2.22±6.50	4.204	0.042	-7.133	<0.001	-11.26 to -6.37
dY1	8.36±11.38	-1.76±8.77	4.035	0.046	6.296	<0.001	6.39 to 13.29
dZ1	-3.02±4.84	0.17±3.13	2.417	0.122	-5.101	<0.001	-4.45 to -1.96
dX2	-9.55±7.42	-2.57±5.05	5.343	0.022	-7.077	<0.001	-8.92 to -5.03
dY2	12.14±14.6 6	- 1.81±11.48	4.316	0.039	6.680	<0.001	9.82 to 18.07
dZ2	0.403±5.27	-0.22±6.08	0.786	0.377	-.675	0.494	-1.27 to 2.52
dX3	-5.68±7.34	-1.82±5.96	0.764	0.383	-3.614	=0.001	-5.96 to -1.75
dY3	4.48±6.37	0.42±5.30	4.215	0.042	4.328	<0.001	2/20 to 5.92
dZ3	-2.50±3.34	-0.82±2.11	4.565	0.034	-3.922	=0.001	-2.53 to -.84

Key. All measures are in millimetres. SD = standard deviation = t-test statistic. Sig. = p value. 2-tailed significance. c.i. = confidence interval

Table 3 explores these differences between the groups. It shows that thoracic scoliosis causes a measurably greater degree of deformity than lumbar or thoracolumbar. Only at the middle antero-posterior (dZ2) are they equivalent. This approximates just above the waist. The vertical (rostro-caudal, dY1, 2 and 3) is greater on the side of convexity in thoracic curves, while in those with lower apex it does not differ significantly from zero (Table 2(ii)).

4. Discussion

This study analysed the morphology of back surfaces, quantifying left-right asymmetry and comparing it with the theoretical ideal of perfect symmetry. The groups showed different but consistent patterns. When compared with zero, both groups showed directional asymmetry of different degrees and also an increased variance (fluctuating asymmetry). Palmer and Strobeck [32] in 1992 stated that, when directional and fluctuating asymmetry co-exist, analysis of the former is impossible, due to the confounding effect of unquantifiable genetic influences. Graham et al [33] in 1998 disputed this, but the argument is beyond the scope of this paper, which seeks only to establish a biological context for "spinal deformity."

This asymmetry is not due to posture, spinal balance or trunk rotation, as left and right sides are being compared, independently of their orientation in space. The asymmetry is of size in three dimensions and size is determined by growth. Growth is a three dimensional process, but does not necessarily occur equally in all three. If it did, the body would be spherical. Differential growth is both directional and regional [34], particularly during the pubertal growth spurt, when proportions change substantially. This aspect of growth is controlled by many genes, as well as by hormones and other signalling molecules.

Vector parameters in surface topography measure left-right positional differences on the back surface. They are not intended to replace radiography when a Cobb angle is needed. They are self-referential and so unaffected by trunk rotation and balance. What was measured was the asymmetry, on either side of the mid-line, of the surface of the back in scoliosis, and what was shown was a pattern that is generally typical of genetically determined asymmetry in biology. This approach was roundly condemned by Milner and Dickson [35] in 1996, on the basis that left-right asymmetries, for example leg length discrepancies or pelvic tilt, do not constitute or cause scoliosis. This view is not disputed, but it misses the point. Asymmetry does not cause scoliosis. Asymmetry does not cause anything. Asymmetry, and symmetry also, are the results of growth processes that are genetically controlled and environmentally modified (Van Valen [23], 1962). At the cellular level, this is undoubtedly very complex, as the timing of the growth processes must be co-ordinated precisely for the semblance of symmetry to be maintained. Under conditions of physiological stress, this co-ordination can be disrupted. This is not a new or a novel idea. Jones [36] in 1999, p. 123, quotes Darwin and Goethe: " In order to spend on one side, nature is forced to save on the other side." While it is not being suggested that the "side" referred to was, literally, the right or left side, the principle that, in times of stress, a less than perfect outcome will ensue, is universal.

The hypothesis that scoliosis is not a disease but a developmental failure simplifies some matters and explains others: if scoliosis is growth, then of course it will associate with growth rate [24] and cease with the cessation of growth. Because developmental stability is affected by both genetic and environmental factors, then a familial component and an association with other pathological conditions is to be expected. Since it is growth, then any remaining growth after spinal fusion, no matter how good the initial correction, will undo the result to a greater or lesser extent. Because it is a non-specific result of physiological stress, there will be no unique aetiology. This hypothesis is more parsimonious than the current paradigm [37] which requires the concatenation of multiple factors, mostly unidentified and unrecognised by neurologists and physicians, to produce what is a very common morphology in otherwise normal girls. Its disadvantage is its dependence on the absence of evidence for a specific disease process. Its advantage it that it explains the observations and makes testable predictions from existing evidence, without calling in extra unproven entities.

5. Conclusion

The co-existence of so many physical and functional asymmetries in adolescent idiopathic scoliosis has always suggested a developmental model for the deformity. Demonstration of these asymmetries on the back surface also support the hypothesis that scoliosis is not a disease process with a specific aetiology, but an example of developmental instability.

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Abnormal Spread of Junctional Acetylcholine Receptor of Paraspinal Muscles in Scoliosis Associated with Syringomyelia

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Abstract To test the denervation of paraspinal muscles and further investigate the pathogenesis of scoliosis associated with syringomyelia via detecting the spread of acetylcholine receptor (AChR) beyond the confines of the functional neuromuscular junction. Patients were divided into three groups: Group A consisted of 25 patients with scoliosis associated with syringomyelia, Group B included 16 adolescents with idiopathic scoliosis, and Group C comprised 10 cases without scoliosis. Bilateral biopsy of paraspinal muscles was performed during scheduled spinal surgery. Histological evaluation used a double-stain immunofluorescence technique for AchR and acetylcholinesterase. Histological analysis showed that 14 of 25 patients in Group A scored positive for the presence of AchR outside of the neuromuscular junction. There was no significant difference of the positive rate between patients with different degrees of cerebellar tonsillar descent, between patients with distended and non-distended syrinx, with syringx length ≤10 vertebral bodies and >10 vertebral bodies, and with Cobb angle ≤45° and >45° ($p>0.05$). The denervation of paraspinal muscles is present in some patients with scoliosis associated with syringomyelia, suggesting that scoliosis may be caused by a strength imbalance of paraspinal muscles in these patients.

Keywords. Scoliosis; syringomyelia; Immunofluorescence; Acetylcholine

1. Introduction

The development of MRI has led to increased spinal imaging with the resultant increase in the diagnosis of syringomyelia in patients with scoliosis. However, the mechanism by which scoliosis develops secondary to syringomyelia is still unclear. Acetylcholine receptors (AChRs) in the neuromuscular junction (NMJ) play an important role in the innervation of skeletal muscles. Diseases that cause chronic denervation of skeletal muscle will result in an up-regulation of junctional AChRs, which is characterized by a spread of AChRs at extrajunctional sites. This study was to investigate the presence or not of the spread of AChRs by double-immunofluorescence staining, and analyze its association with scoliosis in patients with syringomyelia.

2. Materials and methods

2.1. Subjects

51 children were enrolled in the study and were divided into three groups. Group A consisted of 25 patients with scoliosis associated with syringomyelia and Chiari I malformation (17 males, 8 females; age range, 8–18 years; mean age, 13.1 years). Both Chiari I malformation and syringomyelia were confirmed in all the patients, and none of them had evidence of other intraspinal anomalies. The following observations were recorded from the T1-weighted mid-sagittal MRI scan: degree of cerebellar tonsillar descent, the maximal ratio of syrinx to cord (S/C ratio), and the length of syrinx. The degree of cerebellar tonsillar descent was classified into three grades: Grade 1 in which the tonsil descended over the foramen magnum but did not reach the C1 arch, Grade 2 in which the tonsil reached the C1 arch, and Grade 3 in which the tonsil descended over the C1 arch. In Group A, 13 patients had Grade 1, 12 had Grade 2 and 3. The maximal anteroposterior diameter of any syrinx was determined as S, the diameter of the cord (C) was measured at the same level, and S divided by C gave the maximal S/C ratio. The maximal S/C ratio less than or of 50% was found in 9 patients, and more than 50% in 16. The length of syrinx was defined as vertebral segments spanned by the syrinx. The length of syrinx ranged from 4 to 20 vertebral bodies, including 15 patients having the length less than or of 10 vertebral bodies, and 10 patients more than 10 vertebral bodies. The Cobb angle ranged from 15° to 100° (mean, 51.8°). Ten patients had a Cobb angle less than 45° (average 33.2°), the other 15 patients had large scoliotic curves with Cobb angle more than 45° (average 64.3°).

Group B included 16 adolescents with idiopathic scoliosis. There were 4 males and 12 females with mean age of 14.6 years (range, 12–17 years). The Cobb angle ranged from 42° to 70° (mean, 54.3°). Physical examination and whole-spine MRI were performed to exclude the potential disease or malformation in nerve system in these patients.

Group C comprised 10 cases without scoliosis, including 4 males and 6 females. Their average age was 17.5 years (range, 16-20 years). Group C included lumbar spondylolisthesis in one patient, lumbar intradural neurilemoma in 1, and lumbar disc herniation in 8.

2.2. Specimen Preparation

Biopsy specimens (approximately 1cm^3) were obtained from bilateral erector spinae muscles during posterior spine surgery. In Group A, the biopsy site was located within the spinal innervation region involved by the syrinx and near to the apical vertebral level of the scoliotic curve. In Group B, muscle sample was taken at the apical vertebral level of the curve. The chosen site for biopsy in Group C was cephalic to the spinal innervation region involved in the lumbar lesions.

Muscle biopsy specimens were trimmed for double-immunofluorescence staining and RT-PCR. One portion of each specimen was placed in sterile specimen containers and immersed in ice immediately. The tissue was embedded and cut into 8μm-thick sections at -30°C using a Leica cryomicrotome, then fixed using acetone and stored at -70°C until needed for staining.

2.3. Double-immunofluorescence of NMJ

A double-staining method was undertaken to examine both AChRs and acetylcholinesterase of NMJ. AChRs were stained red using Texas Red-X-conjugated α-bungarotoxin (α-BTX). Because of its well-characterized localization to the NMJ, immunoreactive acetylcholinesterase was chosen to indicate the limits of the NMJ. In contrast to the AChRs dyeing, the acetylcholinesterase was stained green using Alexa Fluor 488-labeled secondary antibody. Therefore, the limits of the NMJ, as defined by the extent of the acetylcholinesterase dyeing, and the distribution of AChRs could be detected separately or simultaneously within a single section of biopsy muscles.

Slides containing biopsy cryosections were placed at room temperature for 10 min and rinsed with phosphate-buffered saline, pH 7.2 (PBS) (three changes), then stained in a solution containing 2ug/ml Texas Red-X-conjugated α-BTX (Molecular Probes, Inc., Eugene, USA). After 1 hr incubation at 37°C, followed by rinsing in PBS (three changes), the sections were incubation at 37°C for 1 hr with an chicken anti-human antibody (0.25ug/ml) to acetylcholinesterase (BD Biosciences, San Jose, USA), then restained using an Alexa Fluor 488-labeled goat anti-chicken IgG (10ug/ml) (Molecular Probes, Inc., Eugene, USA). After 1 hr incubation at 37°C followed by rinsing in PBS (three changes), the sections were fixed using glycerol.

The sections were examined and photographed under a MRC-1024 fluorescence microscope (Bio-Rad, USA). Samples were scored positive for abnormal spread of AChRs if α-BTX dyeing (which appeared red in the microscope) extended beyond this limits of NMJ which were defined by the acetylcholinesterase dyeing (which appeared green in the microscope). Two observers, using a double blinded process, judged the photographs for the presence or absence of abnormal spread of AChRs. Only, if both observers agreed that extrajunctional dyeing of AChRs was present, was the patient scored positive for the presence of abnormal AChRs. In this study, punctate signals were ignored as a possible artifact or nonspecific dyeing.

2.4. Statistical Analysis

Both the presence or absence of abnormal spread of AChRs and the presence or absence of γ-AChR expression in the three groups were analyzed using Fisher's exact test. Statistical analysis was conducted with SPSS 11.5 software. Results were considered statistically significant at $p<0.05$.

3. Results

Histological analysis showed that none of the patients both in Group B and in Group C was judged positive (Fig.1,2), but 14 of 25 (56％) patients in Group A scored positive for the presence of AchRs outside of the neuromuscular junction, including 7 patients having a single convex side positive (Fig.3), 3 having single concave positive, and 4 having bilateral positive (Fig.4). The positive rate was 44％ (11/25) on the convex side of the curve, and 28％(7/25) on the convex side. There was no significant difference in the positive rate between patients with different degrees of cerebellar tonsillar descent, between patients with distended and non-distended syrinx，with syrinx length ≤10 vertebral bodies and ＞10 vertebral bodies，and with Cobb angles ≤45° and ＞45° (P>0.05).

4. Discussion

Abnormal equilibrium, aberrant proprioception have been demonstrated in scoliotic patients. Damage to the posterior column cephalic to the thoracic level in growing children are consistently observed to be associated with scoliosis. Growing children and adolescents with disorders in the somatosensory pathway, particularly those involving the dorsal column of spinal cord, are more susceptible to the development of scoliosis than healthy people. Hence, several theories focusing on the abnormal posterior column pathway of spinal cord have been proposed to explain the pathogenesis of scoliosis associated with syringomyelia. However, proprioceptive aberration has not been detected in many patients, and the incidence of abnormal SEPs is very low. Other authors then hypothesize the scoliosis may be caused by an alteration in the innervation of the trunk musculature, attributed to the syrinx causing damage either to the lower motor neurons or to the dorsomedial and ventromedial nuclei of the anterior horn of the spinal cord.

Expression of junctional AChRs is developmentally controlled[1~3]. Prior to innervation of muscle cells, the receptors are distributed at relatively low density throughout the plasma membrane. Following innervation, the AChRs become highly concentrated in the NMJ at a density of 10,000/μm^2. The distribution of AChRs also change in response to chronic denervation of mature muscle[4]. Neurological conditions, such as amyotrophic lateral sclerosis, peripheral neuropathy, and infantile spinal muscular atrophy, will result in an abnormal spread of receptors at extra-junctional sites. Theroux et al[5] reported that 11 of the 39 children with cerebral palsy showed histologic evidence of AChRs outside the functional NMJ. In the present study, double immunofluorescence analysis showed that 14 of 25 (56％) patients in Group A scored positive for the presence of AchRs outside of the neuromuscular junction, with a positive rate being 44％ on the convex side of the curve and 28％ on the convex side respectively. The findings in the present study revealed that the denervation of paraspinal muscles is present in some patients with scoliosis associated with syringomyelia, suggesting that scoliosis might be caused by the strength imbalance of paraspinal muscles in these patients.

Several studies have reported no relationship between the size of the syrinx and scoliosis. Kontio and co-workers[6] reported on nine cases and noted there was no apparent consistent association between the magnitude of S/C ratio and the curve severity. Similarly, a recent report by Ozerdemoglu et al described the size of the syrinx had no relation to the size of the scoliosis at presentation. Similarly, the present study showed no significant difference of both the positive rate of the spread of AChRs and the positive rate of γ subunit expression between patients with distended and non-distended syrinx，with syrinx length $\leq$10 vertebral bodies and ＞10 vertebral bodies. Furthermore, the results in the present study demonstrated the different degrees of cerebellar tonsillar descent had no relation to both the positive rate of the spread of AChRs and the positive rate of γ subunit expression. However, the study is limited by a small number of cases.

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Quantitative Analysis of Types I and II Collagen in the Disc Annulus in Adolescent Idiopathic Scoliosis

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Abstract. Objective: To find the possible roles of collagen in the pathogenesis of AIS through studies of the distribution of the collagen I and II in the disc annulus fibrous in adolescent idiopathic scoliosis (AIS). **Methods:** The disc annulus fibrous of apex curve were harvested during anterior surgery and divided into concave and convex samples. 25 AIS cases were covered in this study including 6 males and 19 females, with an average age of 14.6 years (range 12-18years). 11 specimens were intervertebral disc from the thoracic region (from T8 to T11) and 14 sample were from lumbar discs (from L1 to L2). RT-PCR was employed to investigate the distribution and content of collagen I (220bp) and collagen II (359bp) in the intervertebral disc specimens. 1% agarose gel electrophoresis and the Gelwork image analysis system was used in the semi-quantitative analysis of the product. **Results**： For the AIS group, type I collagen and type II collagen significantly increased on convex side compared with that of the concave side ($p<0.01$). The same trend was observed in both thoracic and lumber disc annulus fibrosis, but there was no statistical difference expect for the expression of type II collagen in convex side of disc annulus fibrous ($p<0.05$). **Conclusion:** The asymmetric expression of collagen I and II collagen showing that there was degeneration in the intervertebral disc of AIS. The abnormal collagen metabolism may be one of reasons in the development of AIS and probably an important factor in the progression of AIS.

Key Words： Scoliosis; Intervertebral Disc; Type I Collage; Type II Collagen

1. Introduction

Adolescent Idiopathic Scoliosis (AIS) is the most frequent spinal deformity, but its aetiology is still not identified [1,2]. There are many theories about the pathogenesis of AIS[3] , and since the intervertebral disc is an important component of spine and has a significant role in retaining spinal balance and stability，it is considered one of the important factors in the generation and development of scoliosis [4]. Collagen is the important supporting protein of connective tissue and plays an major role in cell structure. It accounts for about 70 to 80% of intervertebral disc dry weight. At present, there is no information relating to collagen metabolism in the intervertebral disc in scoliotic patients [5-7]. This investigation examined the expression of type I and type II collagen of disc annulus fibrosis in different spinal areas.

2. Materials and Methods

25 AIS patients were included in the study. There were 11 cases with a thoracic curve, including 4 males and 7 females, with an average age 14.5 years (range 12-17years). The average pre-operative Cobb angle was 47.1 degrees (range 40-58 degrees). 14 cases with lumbar curves were also studied, including 2 males and 12 females, with an average age of 14.6years (range 12-18years). The average pre-operative Cobb angle was 46.6 degree (range 30-65degree). All patients had an examination and MRI check to exclude any potential disease or malformation of the nervous system.

In thoracic AIS, five intervertebral disc were harvested from T8 to T9, two from T9 to T10, two from T10 to T11, one from T11 to T12 and one from T12 to L1. For lumbar scoliosis, all discs were taken from L1 to L2. The disc annulus fibrosis were then divided into concave and convex components and stored in liquid nitrogen.

Total RNA was extracted from the disc annulus fibrous using an SV Total RNA Isolation System (Promega American). The relative value of OD260/280 and the concentration of RNA were measured using an ultraviolet spectro-machine. To amplify the type I, II collagen and glyceraldehyde-3-phosphate dehydrogenase (GAPDH), a primer of table one and one-step RT-PCR kit was used. Each 50ul tube reaction system uses Rnase-free water (50μl), 5×RNA PCR AMV buffer (10μl),10mM dNTP (1μL), upstream primer (1μL),downstream primer 1 (μL), 25mM $MgCl_2$ (2μL), AMV retroviridase (1μL), DNA pclymerase (1μL), RNA template (YμL).

Y（μL）＝1μg×1000÷the concentration of template（μg/ml），X（μL）＝50（μL）－17（μL）－Y（μL）.

The reaction condition was as follows: 1. One cycle at 48 degrees for about 45 minutes, 2. One cycle at 94 degrees for about 2 minutes 3. 94 degrees for about 30 seconds (degeneration), 60 degrees for about 30 seconds (renaturation) and 68 degrees for about 1 minute (extension). Every step comprised of 30 cycles times 4. One cycle was at under 68 degrees for about 7 minutes (tele-extension), and five kept at 4 degrees.

The PCR amplified product were electrophoresed on the 1% agarose gel under 100mv for about fifteen minutes, to image the gel use ultraviolet photometry (UVP) bio-imaging system. Use of the Gelwork image analysis software scaled the object strap and integrated the gray scale, recorded the proportional score and calculated the relative absorbance value of types I and II collagen and GAPDH.

x±s was usied to indicate the result, and application of SPSS11.5 software gave one-factor analysis of variance, matched-paired ‘t’ test and dependability analysis.

3. Results

For both the convex and concave side of AIS patients, the types I and II collagen and Aggrecan expressions are higher in the lumbar spine than those of the thoracic spine. But, expect for the expression of collagen II which displayed statistic difference ($F=4.89$，$P=0.04$), all others had no statistical difference. The expression of type I and II collagen in AIS in the thoracic spine is statistically significantly higher than in the lumbar spine. The comparison of concave and convex sides in thoracic spine is shown in **Table 1**. There is no co-linearity between the expressions of type I and II collagen and Cobb angle (**Table 2**).

4. Discussion

It has been suggested that an abnormal intervertebral disc is an important factor in inducing the AIS [8]. When the intervertebral disc becomes wedged and degenerates, the content and disposition of matrix metabolin will also change, which in turn would influence spinal stability. Collagen is one of the major components of the extracellular matrix. It forms the skeleton of cells, playing an important supporting role.

Table 1. The expression of Type I, II collagen in disc annulus fibrous in AIS

Substance	Convex in thoracic spine	Concave in thoracic spine	Convex in lumbar spine	Concave in lumbar spine
Type I collagen	1.71±0.35**	1.22±0.27	1.79±0.20**	1.32±0.28
Type II collagen	0.8±0.17**	0.63±0.09#	0.89±0.18**	0.74±0.14

The expressions of the corresponding substances on the concave of the annulus fibrosis in the thoracic spine and lumbar spine, compared convex side with single factor variance analysis: # means P<0.05

The expression of the corresponding substance on convex and concave of the annulus fibrosis are compared with a matched-paired 't' test: * means P<0.05 ** means P<0.01

Table2. The correlation between the expression of Type I, II collagen and the Cobb angle in AIS

	Type I collagen		Type II collagen	
	Convex	Concave	Convex	Concave
P	0.88	0.56	0.62	0.42

Analyzed with regression：*means P <0.05

Type I collagen tolerates stretching and type II collagen tolerates compression; both maintain the mechanical stability of the intervertebral disc. The type and distribution of the collagen contributes to the structural intensity and stability of intervertebral disc. Collagen is the attachment point of cells in the intervertebral disc and provides a tunnel for intercellular message transfer [9]. There are many reports related to this area but the majority did nor compare the concave and convex side. Zhufeng [6] divided the collagen into type I and type II and made an quantitative analysis at the protein level. A changed collagenic type and distribution area were found when compared with congenital scoliosis. This abnormality cannot be explained using orthodox abnormal stress disposition after the scoliosis occurred. Linqi [7] also found there was an abnormal disposition of type I and II collagen in AIS, but it was not considered to be the primarily biological factor for aetiology. Upto now these findings remain questioned.

In present study, a semi-quantitative investigation of type I and II collagen of the intervertebral disc was undertaken in order to analyze the relative amount of collagen present and to compare different parts and change tendency, and any differences between the concave and convex side in the same segment. The results indicate that, not only in the thoracic spine but also in the lumbar spine, the expression of type I and II collagen on the convex side was significantly higher than that on the concave, in agreement with the findings of Zhufen. The expression of type I and II collagen in lumbar discs were all higher than those of the thoracic spine, especially on the concave side for type II collagen, We hypothesis that type II collagen in thoracic spine in AIS probably has is a primarily dyssynthesis, so the thoracic spine degenerates easily leading to spinal instability and scoliosis. Although there was no theory to demonstrate this, it does coincide with the higher disease incidence of thoracic scoliosis. Moreover, the expression of type I and II collagen has no colinearity with Cobb angle, which is difficult to reconcile with a "degeneration theory". Neidlinger [10] 's study showed that when the intervertebral disc was under intermittent strain, type II collagen expression in the annular fibrosis rises when the changes seen in the intervertebral disc is caused exclusively by stress. The concave side would this be more influenced than the convex, and the expression of type II collagen on the concave side would be higher than the convex. According to the Hueter-Volkmann theory [11], under excessive stress, in spines potential of growth and development (ie the cartilage end plate and intervertebral disc of adolescents), the active grade of cell growth and anabolic metabolism will be depressed. As a result, the different pressure load of the concave and convex sides will induce abnormal cytoactivity. The cytoactivity will degrade because of the abnormal pressures on the concave side in scoliotic patients, thus affecting the product of the matrix. By marking the cell in the intervertebral disc with fluorescent labeling Bibby [9] demonstrated the rate of living cells on the concave side to be clearly lower than that on the convex side. This change was in direct proportion to the Cobb angle. The study also confirmed the differences in metabolic activity by testing lactic acid and oxygen disposition in the intervertebral disc. But in present study the expression of type I and II collagen in AIS did not change with the Cobb angle. This may due to the small Cobb angle differences (33°~65°) in our sample.

In conclusion, there is an abnormality of collagen expression in AIS cases and is likely to be a cause of scoliosis. Although we are not sure of the mechanism involved, the change in the content and the distribution of Type I and Type II collagen will surely impair the capacity of the intervertebral disc to withstand stress and increase the likelihood of its being damaged, leading to the change of the intervertebral disc to a wedge shape. Then the long-termed imbalance of standing pressure will restrain the metabolism of the intervertebral disc, changing the content and distribution of the intervertebral disc collagen and thus aggravating the deformity of the interverbral disc. This will lead to a vicious circle, and aggravate the scoliosis. However there are differences between our results and other reports. Further research is needed to establish whether the collagen expression in the nucleic acid directly reflects the condition of the proteins.

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Asymmetric Expression of Melatonin Receptor mRNA in Bilateral Paravertebral Muscles in Adolescent Idiopathic Scoliosis

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Abstract To investigate the change of melatonin receptor mRNA expression in bilateral paravertebral muscles in AIS, congenital scoliosis (CS) and controls in order to analyze its relationship to the pathogenesis of AIS. 20 cases with average age of 15.1±2.2 years and average Cobb angle of 56.2° ±16.1° were included in AIS group. 12 cases with average age of 11.6±3.2 years and average Cobb angle of 59.2° ±33.3° were included in congenital scoliosis (CS) group. 10 cases without scoliosis comprised a control group. The mRNA expression of melatonin receptor subtype MT1 and MT2 were detected by RT-PCR method. The MT2 mRNA expression on the concave side of paravertebral muscle was higher than that on the convex side in AIS and CS groups (p<0.05), but the MT1 mRNA expression showed no significant difference. In the AIS group, the ratio of MT2 mRNA expression on the concave side compared with the convex side in cases with a Cobb angle less than 50° and cases with a Cobb angle greater than 50° showed no significant difference. The melatonin receptor expression in bilateral paravertebral muscles in AIS is asymmetric, which may be a secondary change.

Keywords Melatonin, Receptor, Paravertebral muscle, Scoliosis

1. Introduction

Melatonin is the principal product of the pineal gland and is a focus of studies of the mechanism underlying the development of scoliosis. Melatonin has effects on cell growth and development [6]. Larvosova et al reported that physiological doses of melatonin (100pg to 10ng / ml of medium) stimulated proliferation of chicken skeletal muscle cells and raised DNA and RNA protein contents with incorporation of leucine into cell protein. Melatonin exerts its biological effects primarily through specific high affinity membrane-band receptors. The diversity of melatonin's response within the body may be attributed to the fact that its receptors are expressed in a wide variety of tissues. Human paravertebral muscle is a target organ of melatonin with melatonin receptors within them. Despite many studies on the role of paravertebral muscle in the pathogenesis of scoliosis [2], there is no research on the expression of melatonin receptors in the paraveretebral muscles of patients with AIS.

2. Materials and methods

2.1. Clinical Data of Patients

AIS Group: 20 patients including 3 males and 17 females were included in this group with average age of 15.1±2.2 (range 13-22) years and an average Cobb angle of 56.2°±16.1°(range 40°-108°). The Cobb angle of 10 cases was >50˚ (66.8°±16.8°). The Cobb angle of a further 10 cases was ≤50˚(45.6°±4.3°). 7 cases were Lenke type 1A, 6 were Lenke type 1B, 5 were Lenke type 1C, and 2 were Lenke type 3C. The apical vertebrae were from T_6 to T_{11}.

Congenital scoliosis (CS) Group: 12 cases including 8 males and 4 females were in this group with an average age of 11.6±3.2 （range 8-17） years and an average Cobb angle of 59.2°±33.3°(range 20°-150°). 8 cases had hemivertebrae, 2 displayed an abnormality of segmentation, and 2 had combined defects. The apical vertebrae were from T_7 to T_{12}.

The Control Group: 10 cases without scoliosis (8 males and 2 females) were in this group, including 1 spondylolisthesis, 1 lumbar tumor, 2 Scheuermann's disease, 5 lumbar disc herniation and 1 Ankylosing-Spondylitis. The average age was 19.9±5.3 (range 8-26) years.

Pan spinal cord MRI was performed to exclude potential diseases or malformations of the nervous system in all patients.

2.2. Tissue specimens and experimental material

1cm^3 muscle samples were taken during surgery from the bilateral paravertebral muscles (longissimus) at the apical vertebral level in the AIS and CS groups and at the non-diseased lumbar level for the control group. Muscle samples were stored in liquid nitrogen. The primers of β-actin and melatonin receptor subtype MT1 and MT2 were synthesized by the Biochemistry Institute of the Chinese Academy of Sciences in Shanghai, China. Trizol was purchased from GIBCO Co (USA). TITANIUM^{TM} ONE-STEP RT-PCR KIT was purchased from CLONTECH Co (USA). DNA marker was obtained from MBI Co (USA).

2.3. RT-PCR

Total RNA for the analysis was extracted from snap-frozen tissues. Using the TITANIUM^{TM} ONE-STEP RT-PCR KIT, the cDNA synthesis and amplification were undertaken in a single tube following the manufacture's instructions. PCR using 10μl was run on 2% agarose gel and observed by EB staining under UV light. The images were taken with a Kodak digital camera and analyzed using Molecular Analyst image analysis software. The level of melatonin receptor mRNA was expressed as ratio of melatonin receptor mRNA density compared with β-actin density.

3. Results

AIS Group: The MT1 mRNA expression on the concave side of the paravertebral muscles at the apical vertebral level was 0.401 ± 0.080 (range 0.267-0.546), and on the convex side was 0.381 ± 0.067 (range 0.255-0.522). The MT1 mRNA expression in bilateral paravertebral muscles showed no significant difference ($p>0.05$). The MT2 mRNA expression on the concave side was 0.487 ± 0.118 (range 0.277-0.704), and on the convex side was 0.360 ± 0.120 (range 0.166-0.553). The MT2 mRNA expression on the concave side was higher than that on the convex side ($p<0.05$). The ratio of MT2 mRNA expression on the concave side compared with the convex side in cases with a Cobb angle >50° was 1.45 ± 0.38 (range 0.903-2.359). The ratio of MT2 mRNA expression on the concave side compared with the convex side in cases with a Cobb angle ≤50° was 1.48 ± 0.69 (range 0.963-3.340). The ratio of MT2 mRNA expression on the concave side compared with the convex side in cases with Cobb angle >50° and cases with Cobb angle ≤50° showed no significant difference（$p>0.05$）.

CS Group: The MT1 mRNA expression on the concave side paravertebral muscles at the apical vertebral level was 0.369±0.069 (range 0.271-0.479), and on the convex side was 0.392±0.056 (0.305-0.497). The MT1 mRNA expression in the bilateral paravertebral muscles showed no significant difference ($p>0.05$). The MT2 mRNA expression on the concave side was 0.426±0.133 (range 0.218-0.669), and on the convex side was 0.321±0.116 (range 0.200-0.548). The MT2 mRNA expression on the concave side was higher than that on the convex side ($p<0.05$).

Control Group: The MT1 mRNA expression for the left side paravertebral muscles in the non-disease involved region was 0.395±0.066 (range 0.252-0.464), and the right side was 0.420±0.099 (range 0.227-0.517). The MT2 mRNA expression on left side was 0.403±0.094 (range 0.233-0.517), and on the right side was 0.422±0.105 (range 0.238-0.553). The MT1 and MT2 mRNA expression in bilateral paravertebral muscles showed no significant difference ($p>0.05$).

4. Discussion

In 1959, Thillard first reported that pinealectomy produced scoliosis in chickens, and this was confirmed by Dubousset et al. However, the biological relevance of melatonin in AIS is controversial. It is unlikely that scoliosis results solely from the absence of melatonin. Morcuende et al suggested that if melatonin had a role in the pathogenesis of this disorder, then a more likely mechanism would involve the genetic regulation of melatonin production or its receptors. They performed a genetic study in patients with familial AIS. However, the results demonstrated no evidence of linkage to chromosome 4q and no mutations in the coding region of the gene for human melatonin receptor. Sobajima et al [3] suggested that causes of spinal deformities in the hereditary lordoscoliotic rabbit, the natural animal model for idiopathic scoliosis, may be the result of the contribution of melatonin receptors as well as that of altered serum melatonin levels. However, their study showed no significant quantitative differences in the level of expression of melatonin receptor mRNA in the spinal cord between hereditary lordoscoliotic rabbits and controls. They suggested further studies should be undertaken to investigate melatonin receptor expression in other tissues, such as the spinal column, paravertebral muscle, and the brain. In our study, the expression of melatonin receptor mRNA in bilateral paravertebral muscles in AIS was investigated. The results showed that the expression of MT2 mRNA on the concave side was higher than that on the convex side in AIS group, but the MT1 mRNA expression showed no significant difference. Resemble change of expression of melatonin receptor mRNA was also shown in CS group. The etiology of CS is relatively clear, due to anomalous development of the vertebrae (failure of formation and / or segmentation). So it could be concluded that the asymmetry of melatonin receptor expression in bilateral paravertebral muscles in AIS may be a secondary change. In addition, if it was a primary change, theoretically higher melatonin receptor expression may be on the convex side of paravertebral muscle, which is contrary to our results. In this study, the discrepancy of MT2 mRNA expression in bilateral paravertebral muscles did not correlate with the severity of scoliosis in AIS group. We thought it was because of the influences of age, sex, height, weight, and so on, which were not excluded in this study.

Little is known about the detailed mechanisms underlying melatonin receptor regulation. It was shown that levels of melatonin receptor in the rat suprachiasmatic nucleus (SCN) of the hypothalamus were lower during the night when compared to levels during the day. One hour of light pulse given during the night in pinealectomized rats induced an increase in 2-[^{125}I]-iodomelatonin binding in the SCN compared to rats kept in constant darkness. Estrogen pretreatment in immature female rats was able to down-regulate MT1 expression in the overy [4]. In addition, in both cerebral and caudal arteries, the number of melatonin receptor binding sites correlated inversely with circulating estradiol levels. Savaskan et al [5] reported that MT2 may be involved in mediating the effects of melatonin in the human hippocampus, in Alzheimer's disease its mechanism could be heavily impaired and shown reduced hippocampal MT2 expression. Dillon et al [6] reported that MT1 were detectable in normal and malignant breast epithelium, but receptor levels in tumor cells was higher. It could be inferred from above studies that a change of physiological status or morbid status could affect the melatonin receptor expression in human tissues. That the bilateral paravertebral muscles in AIS locate in different physiological and mechanical states may be the cause of asymmetry of melatonin receptor expression. When scoliosis presents, with the instinct of keeping balance in the spine, load on the convex side of paravertebral muscles is increased. Consequently, the muscle on the convex side shows hypertrophy and relatively higher level of metabolism. In the regulation of the negative feedback mechanism, the MT2 expression on the convex side of the paravertebral muscles is decreased.

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Adolescent Scar Contracture Scoliosis Caused by Back Scalding During the Infantile Period

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Abstract To investigate the pathogenesis, clinical manifestation and treatment of the adolescent scar contracture scoliosis caused by back scalding during infancy. From August 1997 to May 2005, about 1300 patients with scoliosis received surgery in our department. Only four of them were diagnosed with adolescent scar contracture scoliosis. One patient was first treated with skin expansion, back scar excision, and skin flap transfer, followed with anterior correction with TSRH instrumentation. Two patients were first treated with back scar excision and anterior spinal release, then treated with posterior correction with TSRH instrumentation; thoracoplasty was performed after 50 days in halo-wheelchair traction. The other patient was treated with posterior correction with TSRH instrumentation. No management of scalding was performed on the fourth patient. Anterior release and posterior correction were performed at intervals of 3 weeks. The deformities of four patients were well corrected. The trunk balance was restored and the pelvis leveled. The skin incision wounds healed well. Minor loss of correction was recorded during the last follow-up.

Key words scoliosis; scar contracture; scalding; treatment

1. Introduction

Adolescent idiopathic scoliosis (AIS) is the most common type of spinal deformity arising during pubertal growth. AIS etiology and pathogenesis are still largely unknown. However, there are many types of scoliosis caused by known etiological factors. Though the prevalence of these types of scoliosis is much lower than AIS, their physiological characters and treatment principles are different from AIS.

Adolescent scar contracture scoliosis caused by scalding during infancy is uncommon. From August 1997 to May 2005, about 1300 patients had spinal surgery undertaken by the authors. Only four of them were diagnosed with adolescent scar contracture scoliosis. The aim of this study was to investigate its pathogenesis, clinical manifestation, and surgical management.

2. CASES

2.1. Case 1

A fifteen-year-old boy suffered from 25% full thickness scalding by hot water at the age of one month. The scalding was managed with appropriate treatment. Scoliosis was found when he was five years old and developed rapidly after the age of 12, but no management was proposed. On examination a scar contracture was present on the left side of the back, with little muscle tissues felt under the scar. The trunk deviated to the right on the erect view. Curvature of the thoracolumbar spine was right-sided (convex to the side without scar contracture). The pelvis lay oblique, with the left side higher than the right side and leg lengths were equal. There was very limited flexibility on right-sided bending. The curve ranged from T10 to L3 with a Cobb angle of 54°. The side-bending films showed a flexibility of 30%.

Skin expansion, excision of the back scar and flap transfer were performed. Anterior correction of the thoracolumbar scoliosis with TSRH (Medtronic, USA) instrumentation was performed 4 months after the plastic surgery on his back, followed by 3-month post-op cast immobilization. The curvature corrected to 15° immediately after operation with a correction rate of 72%.

2.2. Case 2

This patient was a fifteen-year-old girl who suffered from 35% full thickness scalding by hot water when she was four years old. The scar contracture was on the left side of the back, abdomen, hip, and both thighs. The scoliosis developed at the age of seven years and became severe in the last three years; she never received any bracing or casting to treat her scoliosis. The trunk deviated to the left as the patient stood; the curvature of the thoracic spine was convex to the left side. Leg lengths were equal and the pelvis was found to be oblique, with the right side higher than the left side, on physical examination. The correction of the curve on left side bending was limited. The curve ranged from T6 to L1 with Cobb angle of 103°.

Back scar excision with skin grafting (mainly on the concave side) was undertaken and two months later, an anterior release of the spine was performed. After 50 days in halo-wheelchair traction, posterior instrumentation was done from T5 to L4 using the TSRH system with thoracoplasty performed simultaneously. Three-month's cast immobilization was prescribed after the surgery. The Cobb angle reduced to 46° immediately after the surgery with a correction rate of 55%. At the 3-year-follow up, the total loss of correction was 6%.

2.3. Case 3

This patient was a 23-year-old girl who had 35% full thickness scalding by hot water at the age of 3 years old; her scald was never treated. Scoliosis presented when she was 8 years old and progressed rapidly after age of 13 years old.

A contracture scar was presented on the chest, the whole back, abdomen, both thighs, both glutei and part of the upper extremities. There were little muscular tissue under the contracture scar in the back. The trunk deviated to the right side in the standing position. Curvature of the thoracic spine was to the right side (the convex side of the curve was the side with less scar tissues). The pelvis was oblique to the right side. There was no length discrepancy between her legs. Right-sided bending of the spine was severely limited. The scoliosis involved T2 to L1 with a Cobb angle of 85°. The side-bending films showed a flexibility of 18%.

There was no management of scalding before the correction of scoliosis. Thoracoscopic anterior release was performed. After 20 days in a halo-femoral traction, a posterior correction with TSRH instrumentation was carried out. Three-month cast immobilization followed the surgery. After the correction of the scoliosis, the Cobb angle was 39° with a correction rate of 54%. At the first 12 months follow-up, the loss of correction was 6%.

2.4. Case 4

This patient was an 11-year-old girl who suffered from a 10% full thickness scald due to a hot water burn, aged five years old. There was no treatment for the scalding. The scoliosis presented at the age of 9 and progressed rapidly after age 10.

About 10% contracture scars were found in the left axilla and left hypochondrium. The trunk deviated to the right side in the standing position. Curvature of the thoracic spine was in the right side (The convex side of the curve was the side with the least scar tissue). The pelvis was oblique to the right side. There was no length discrepancy between her legs. Right-sided bending of the spine was severely limited. In the AP films, the curve was convex to the right, involving vertebrae from T7 to L5, with a Cobb angle of 80° . There was a flexibility of 12.5% on the side-bending films.

Scar excision, free skin grafting, and anterior release were performed. Posterior correction with TSRH instrumentation was undertaken two weeks later. With a post-operative Cobb angle of 35, the correction rate was 56%.

3. Discussion

Many studies have confirmed that the mechanical imbalance of the spine could lead to scoliosis [1~3]. To the author's knowledge, adolescent scar contracture scoliosis caused by back scalding during infantile period is ucommon and has not been reported in the current English literature. From August 1997 to May 2005, about 1300 patients received corrective surgery in the author's institution; among them, only four were found with adolescent scar contracture scoliosis. The pathogenesis of scar contracture scoliosis correlates more closely with the so-called pleural scoliosis following extensive pleural scarring from chronic infection.

The symmetric growth and development of bilateral soft tissues is very important for mechanical balance of the spine. The skin, thoracolumbar fascia, intertransverse process ligament, and paraspinal muscles such as the rhomboids, latissimus dorsi, sacrospinalis, and quadratus lumborum, are all involved in the control and balance of the spine. Scalding during the infantile period can lead to contracture of these soft tissues and leave a large area of scar tissue, which can compromise the balance of the spine and lead to scoliosis. Due to the traction of the scar contracture tissue, the spine is convex toward the side without scar contracture or with less scar tissue. During the adolescent growth spurt, the "bow-string effect"[4] of the contracture tissues becomes more apparent, which leads to the rapid progression of scoliosis. With the progression of the scoliosis, a pelvic obliquity develops.

Diagnosis of scar contracture scoliosis is relatively easy. First, the patient has a history of scalding during the infantile period. Secondly, the patient has a rapid progression of scoliosis during the adolescent growth spurt. Physical examination will demonstrate that the curve is convex towards the side without the scar contractures or with less scar tissue, which is different from the right side preference of thoracic AIS. Pelvic obliquity caused by contracture of the soft tissues is another characteristic of scar contracture scoliosis. Due to the traction effects of the scar contracture tissues, the iliac crest on the concave side of scoliosis is higher than that on the convex side, which is different from scoliosis caused by leg-length discrepancy.

The treatment for adolescent scar contracture scoliosis should follow individual and specific principles. The scar contracture tissues should be released sufficiently before any correction of the scoliosis. In the first patient, the back scar excision, skin expansion, and flap transfer were performed first. In the second patient, the preparative release surgery of soft tissue included stripping of paravertebral muscles, interception of contractured thoracolumbar fascia, the iliocostal muscle and the longissimus at different levels, excision of the capsules and ligaments around the costo-transverse joints, the inter-transverse and intercostal muscles, and the posterior section of the corresponding ribs. For the third patient, there is no management of the scalding due to the small amount of contracture scar present for the correction of scoliosis. However, anterior release and halo-femoral traction was mandatory for this patient. With the fourth patient, because of local limited scarring, the scar excision, free skin grafting and anterior release were performed at the same stage.

In these four patients, the scoliosis presented only a short period after scalding and developed rapidly during the adolescent growth spurt. The curve types were either a single thoracic or long thoracolumbar curve, which was convex to the side without scar contracture or with less scar tissue. Pelvic obliquity was found in all patients. The trunk was shifted toward the convex side of the curve.

Pelvic obliquity is one key point in the treatment for scar contracture scoliosis, because a level pelvis is very important for a stable and balanced spine [5]. In the first patient, an anterior approach was used. The anterior approach can shorten the spine and reduce the bow-string effect of the contractured tissues, which is beneficial for the correction of pelvic obliquity. In the other three patients, halo-femoral or wheelchair traction was performed before posterior correction. Huang et al [6] suggested that halo-femoral traction before posterior spinal fusion could straighten the scoliotic spine, level the pelvis, and thereby facilitate posterior instrumentation. The spine may be elongated during posterior surgery, but the contracture scar tissue is not elongated correspondingly. So theoretically the pelvic obliquity could become more progressive after posterior surgery. In this series, shortening the spine, multi-level "V" shape osteotomy, excision of joint capsule and yellow ligament were performed during posterior surgery.

Compared with AIS, the wound of scar contracture scoliosis is more likely to get infected and its healing procedure is more difficult due to poor blood-supply to the scar tissue. Two points should be noticed: 1) Any manipulation during surgery should be gentle and repeated cutting with the electroscalpel should be avoided; 2). Keep the wound clean and dry, avoid compressing the wound and use an antibiotic dressing such as alcohol gauze.

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Classification of Pediatric Lumbosacral Spondylolisthesis

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Abstract. A surgical classification of pediatric lumbosacral spondylolisthesis has been proposed recently. In this classification involving 8 distinct types of spondylolisthesis, the patient is classified according to: 1) the slip grade (low- vs. high-grade), 2) the degree of dysplasia (low- vs. high-dysplastic), and 3) the sagittal spinopelvic balance. The objective of this preliminary study is to assess the reliability of the classification. Two observers classified on two separate occasions 40 subjects with lumbosacral spondylolisthesis, based on standing postero-anterior and lateral radiographs of the spine and pelvis. No direct measurements on the radiographs were performed. All 8 types of spondylolisthesis were identified by the observers. Intra-observer agreement for the first and second observers was respectively 92.5% and 87.5%, while inter-observer agreement was 75.0%. Thirty-nine of 40 subjects had agreement among both observers according to the slip grade. Within these 39 subjects, observers disagreed for 8 subjects with respect to the degree of dysplasia and for only one subject with respect to the spinopelvic balance. The proposed classification could be used to better evaluate and compare available surgical techniques, and to develop a treatment algorithm for spondylolisthesis. This new classification results in good intra- and inter-observer agreement. Further studies with observers not involved in the design of the classification are however needed in order to confirm the relevance of the classification.

Keywords. Classification, dysplasia, sagittal balance, spine, spondylolisthesis

Introduction

Spondylolisthesis has been commonly classified according to the classification developed by Wiltse et al. [1]. In their classification, type I (dysplastic) involves a congenital dysplasia of the sacrum or neural arch of L5. Type II (isthmic) is associated with a defect in the pars interarticularis, described as a lytic separation of the pars (type IIA), a pars elongation (type IIB) or an acute pars fracture (type IIC). Type III corresponds to degenerative spondylolisthesis, while type IV (traumatic) results from an acute fracture of posterior elements other than the pars. Type V (pathologic) spondylolisthesis is caused by destruction of posterior elements due to a systemic or local bone disease.

Marchetti and Bartolozzi [2] have described a classification that separates developmental from acquired spondylolisthesis. In their classification, types I, IIA and IIB spondylolisthesis from the Wiltse et al. classification [1] are all included in the developmental group. Developmental spondylolisthesis is further divided into two major types (low- and high-dysplastic). Although they introduced the concept of low-and high-dysplastic spondylolisthesis, they did not give strict criteria on how to differentiate between the two subgroups. Acquired spondylolisthesis is secondary to trauma, surgery, a pathologic disease or a degenerative process.

Recently, Mac-Thiong and Labelle [3] proposed a new surgical classification of spondylolisthesis based on the following: 1) the slip grade, 2) the degree of dysplasia, and 3) the sagittal spinopelvic balance. Eight distinct types of spondylolisthesis are described in this classification. The classification was specifically developed in order to guide surgical treatment of L5-S1 spondylolisthesis in children and adolescents, and incorporates recent knowledge in the study of sagittal spinopelvic balance and morphology. In their classification, Mac-Thiong and Labelle [3] also clarified the concept of low- and high-dysplasia introduced by Marchetti and Bartolozzi [2] by providing objective criteria to differentiate between these two subtypes.

The current study presents a simplified version of the classification introduced by Mac-Thiong and Labelle [3]. The objective of this preliminary study is to assess the reliability of the classification.

1. Materials and Methods

The radiological files of 40 subjects (18 high-grade and 22 low-grade) with lumbosacral spondylolisthesis were reviewed. The original classification proposed by Mac-Thiong and Labelle [3] involves many qualitative and quantitative criteria to determine the slip grade, the degree of dysplasia and the sagittal spinopelvic balance. In the current study, the classification was simplified (**Figure 1**) and the observers were not allowed to take any direct measurements on the radiographs.

Standing postero-anterior and lateral radiographs of the spine and pelvis showing both femoral heads were available for each subject. Two observers classified twice (at a one week interval) all 40 subjects based on the classification provided in **Figure 1**. Both observers were involved in the design of the original classification [3]. No measurements were taken but brightness/contrast changes of the digital radiographs were allowed.

2. Results

Table 1 presents the results for the 40 subjects classified by the observers. All 8 types of spondylolisthesis were identified by both observers. Intra-observer agreement for Observers 1 and 2 was respectively 92.5% and 87.5%. The inter-observer agreement between the first series of both observers was 75%.

Thirty-nine of all 40 subjects had agreement among observers according to the slip grade. Inter-observer disagreement occurred for a subject with a 43.5% slip. Within the 39 subjects for whom there was inter-observer agreement on the slip grade, observers disagreed for 8 subjects (2 low-grade, 6 high-grade) with respect to the degree of dysplasia and for one subject with respect to the sagittal spinopelvic balance.

Grade	Dysplasia	Spinopelvic balance	Type
Low-grade (< 50% slip)	Low-dysplastic • Minimal lumbosacral kyphosis • Almost rectangular L5 • Minimal sacral doming • Relatively normal sacrum • Minimal posterior elements dysplasia (e.g. spina bifida occulta) • Relatively normal transverse processes	Low PI/low SS (nutcracker type) • Sacral slope ≤ 40°	1
		High PI/high SS (shear type) • Sacral slope > 40°	2
	High-dysplastic • Lumbosacral kyphosis • Trapezoidal L5 • Sacral doming • Sacral dysplasia and kyphosis • Posterior elements dysplasia • Small transverse processes	Low PI/low SS (nutcracker type) • Sacral slope ≤ 40°	3
		High PI/high SS (shear type) • Sacral slope > 40°	4
High-grade (≥ 50% slip)	Low-dysplastic • Minimal lumbosacral kyphosis • Almost rectangular L5 • Minimal sacral doming • Relatively normal sacrum • Minimal posterior elements dysplasia (e.g. spina bifida occulta) • Relatively normal transverse processes	High SS/low PT (balanced pelvis) • Balanced sacrum • Sacral slope ≥ 50° • Pelvic tilt ≤ 35°	5
		Low SS/high PT (retroverted pelvis) • Vertical sacrum • Sacral slope < 50° • Pelvic tilt ≥ 25°	6
	High-dysplastic • Lumbosacral kyphosis • Trapezoidal L5 • Sacral doming • Sacral dysplasia and kyphosis • Posterior elements dysplasia • Small transverse processes	High SS/low PT (balanced pelvis) • Balanced sacrum • Sacral slope ≥ 50° • Pelvic tilt ≤ 35°	7
		Low SS/high PT (retroverted pelvis) • Vertical sacrum • Sacral slope < 50° • Pelvic tilt ≥ 25°	8

Figure 1 – Simplified classification of pediatric lumbosacral spondylolisthesis

Table 1. Classification type of 40 subjects with spondylolisthesis

Subject	Observer 1		Observer 2	
	First series	Second series	First series	Second series
1	1	1	1	1
2	3	3	3	3
3	2	2	2	2
4	6	6	8	8
5	8	8	8	8
6	1	1	1	1
7	5	5	5	4
8	2	2	2	2
9	4	4	4	2
10	8	8	6	8
11	2	2	2	2
12	5	5	7	7
13	7	7	8	8
14	1	1	1	1
15	6	6	8	8
16	5	5	5	7
17	4	4	4	4
18	5	5	3	3
19	6	5	6	6
20	6	8	8	8
21	6	6	6	6
22	5	5	5	5
23	7	7	7	7
24	4	4	4	2
25	3	3	3	3
26	2	2	2	2
27	2	2	4	4
28	1	1	1	1
29	6	6	6	6
30	2	2	2	2
31	4	4	4	4
32	8	8	8	8
33	2	2	2	2
34	1	1	1	1
35	4	4	4	4
36	8	6	6	6
37	8	8	8	8
38	2	2	4	4
39	8	8	8	8
40	1	1	1	1

3. Discussion

The current study shows the relevance of the classification of Mac-Thiong and Labelle [3] to characterize patients with lumbosacral spondylolisthesis since all 8 types were identified. The simplified classification resulted in good intra-observer (92.5% for observer 1 and 87.5% for observer 2) and inter-observer (75.0%) agreement, although the dysplastic criteria originally described [3] were abandoned. In comparison, the intra- and inter-observer agreement for the King classification for adolescent idiopathic scoliosis (AIS) is lower at 83.5% and 68.0%, respectively [4]. The intra-observer agreement with the Lenke classification for AIS is also lower at 65% [4], while inter-observer agreement is between 41% [5] and 55% [4].

Of all 40 subjects, the observers disagree for only one subject with respect to the slip grade and another subject with respect to the sagittal spinopelvic balance. These discrepancies probably could have been avoided if measurements were allowed. As for the degree of dysplasia, there was disagreement among observers for 8 subjects (2 low-grade and 6 high-grade). This finding indicates that objective criteria for determining the degree of dysplasia, such as those proposed in the original classification [3], may increase the overall reliability of the classification.

Because both observers were involved in the design of the original classification [3], another study with additional observers is needed to confirm the relevance of the classification. In addition, statistical analysis using kappa coefficients should be performed in order to provide accurate intra- and inter-observer reliability.

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Hoffmann Reflex in Idiopathic Scoliosis

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Abstract. This study was carried out in order to determine the dependence of selected Hoffmann reflex parameters on type, progression and morphology of idiopathic scoliosis (IS). Data collected from 129 girls with IS (59 progressive and 70 non-progressive cases) aged 7-16 years and 24 healthy subjects were analysed. H-reflex index (IH) and H/M amplitude index (IH/M) were calculated. Progressive left lumbar scoliosis expressed a significant decrease of IH values and a distinct tendency to IH/M depletion compared to non-progressives and controls. Progressive right thoracic scoliosis expressed marked tendency to IH decrease compared to nonprogressive scoliosis. No significant differences in H-reflex parameters were observed between the convex and concave side of the curvature or between types of scoliosis. H-reflex analysis in idiopathic scoliosis supports the hypothesis of a primary neurological disorder in progressive IS.

Key words. Idiopathic scoliosis, aetiology, Hoffmann reflex

Introduction

A central nervous system (CNS) disorder is considered to be an important factor in the onset and development of idiopathic scoliosis (IS) [1,2]. Weak dysfunction of the spinal cord, brain stem, vestibular system, cortical and subcortical associations may be responsible for the IS. Electromyographic studies of reflex activity provide a valuable tool of assessment of CNS function. The Hoffmann reflex (H-reflex) allows an opportunity to determine the function of multiple level elements of the CNS.

Aim of the study

The aim of the study was to determine whether there was a relationship between H-reflex parameters and the type, progression and morphology of idiopathic scoliosis.

Material and Method

Data was collected from 129 girls with IS (59 progressive and 70 non-progressive cases) aged 7-16 years and 24 healthy subjects and analysed. Data included anthropometric (age, height, angle of thoracic kyphosis and lumbar lordosis), radiological (A-P X-ray examination of vertebral column) and electromyographic (H-reflex and unloading reflex) examinations. Cobb angle and apical vertebra rotation were calculated, as well as H-reflex index (IH) and H/M aplitude index (IHM). Essential anthropometric and radiological data are presented in Table 1.

Table 1. Anthropometric and radiological data of assessed girls.

		assessed group n = 129	controls n = 24
age [years]	x	12.26	10.29
	SD	2.50	2.22
height [cm]	x	153.63	139.58
	SD	13.30	14.67
Cobb angle [°]	x	30.0	
	SD	11.24	
axial rotation angle [°]	x	11.58	
	SD	5.43	

x – mean
SD – standard deviation

The progressive nature of the scoliosis was determined on the basis of an unloaded reflex examination, Cobb angle progression, axial rotation and Mehta index [3,4,5].

Results were compared using one-way ANOVA models and linear regression models, the level of $p=0.05$ being considered significant.

Electromyographic assessment of the H-reflex was conducted using standard procedures [6,7,8,9]. The H-reflex was evoked bilaterally using surface electrodes for tibial nerve stimulation with action potential recording from the soleus muscle. For further standardisation in view of related body height difference in length of the reflex arch, a latency dependent H-reflex index (IH) was calculated [10,11]. Amplitude was standardised calculating H/M amplitude index (IH/M) [6,8].

$$IH = 2\left(\frac{patient's\ height\ [cm]}{H\ latency\,[ms] - M\ latency\,[ms]}\right)^2$$

$$IH/M = \frac{H\ amplitude\,[mV]}{M\ amplitude\,[mV]}\,100\%$$

Results

The latencies measured for all sets of examined girls were within a normal range of 35 ms. Mean values of calculated IH and IH/M indexes are presented in Figure 1 and Figure 2, respectively. Resulting differences between convex and concave side in progressive and non-progressive cases were negligible. These results suggest a

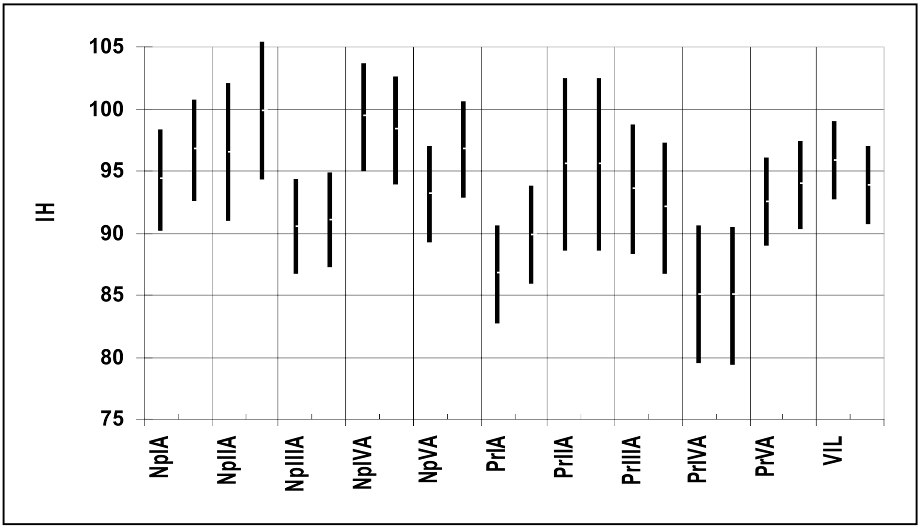

Figure 1. H-reflex index (IH) in assessed groups.

NP – non-progressive; PR – progressive; A – convex side; L – left side
I – right thoracic; II – right thoraco-lumbar; III – left thoraco-lumbar;
IV – left lumbar; V – double major; VI – control group

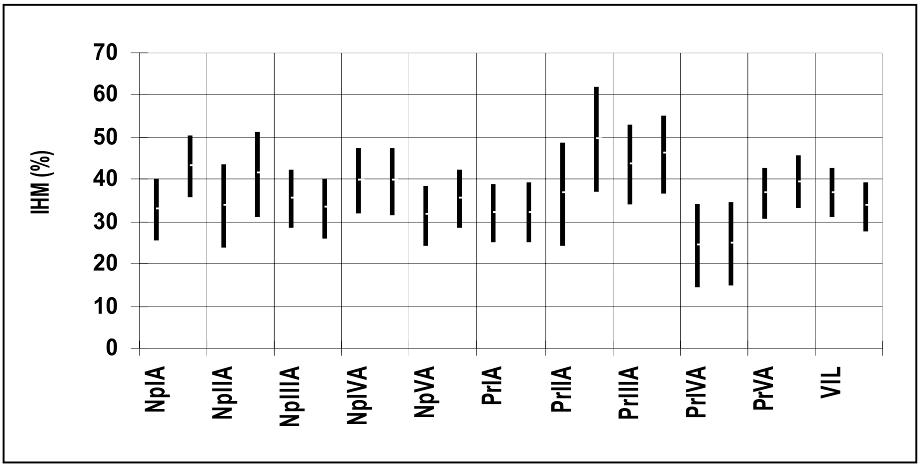

Figure 2. IH/M amplitude ratio in assessed groups.

NP – non-progressive; PR – progressive; A – convex side; L – left side
I – right thoracic; II – right thoraco-lumbar; III – left thoraco-lumbar;
IV – left lumbar; V – double major; VI – control group

tendency for longer H latencies and decreased IH values in the global analysis of progressive scolioses compared to nonprogressive and control subjects.

Progressive left lumbar scoliosis cases expressed a significant decrease of IH values ($p<0.05$) compared to non-progressive and control subjects. A distinct tendency to IH/M depletion in progressive scolioses compared to non-progressive and controls was also observed, although difference did not reach a level of statistical significance.

Progressive right thoracic scoliosis cases expressed a marked tendency to IH decrease compared to nonprogressive scolioses.

No significant differences in H-reflex parameters were observed between the convex and concave side of curvature or between types of scoliosis. No relationship was observed between H-reflex parameters and morphology of the IS.

Discussion

The H-reflex as apossible aetiological cause of IS was examined by Popow and Gajworonskij in the groupt of 32 girls aged 12 to 14 years [12]. They described H/M amplitude index asymmetry between the convex and concave side in 16 cases, including 14 cases of left lumbar IS. The value of the differences exceeded 10%, but did not reach a level of statistical significance. Furthermore, an asymmetry pattern was not consistent: in 6 cases the IH/M was lower at the concave side and in 8 on the convex. The authors did not consider the progressiveness of a scoliosis.

The reflex arch of the H-reflex evoked from the soleus muscle involves L_5 and S_1 segments of the spinal cord, thus lumbar IS appears to be the most adequate to reveal possible pathology. Obtained results in lumbar scoliosis call for existing pathology at the spinal cord level, assuming monosynaptic nature of the H-reflex.

In reality, the majority of researchers consider the H-reflex as monosynaptic, although there is strong evidence suggesting that numerous supraspinal structures of the CNS may influence its activity [6,13,14,15,16]. As a result, the H-reflex may serve as a diagnostic tool capable of multi-level indication of the CNS dysfunction. Any tendency to pathological findings in thoracic scoliosis can be explained only on the basis of the influence of superior levels of the CNS on the H-reflex recordings.

Other publications have emphasized that the measured H-reflex latencies were within accepted normal ranges. Native H-reflex latency and amplitude analysis is of doubtful usefulness. However, after calculating appropriate indexes, latency dependent IH for lumbar progressive scoliosis was set was significantly lower than that for non-progressive and controls, indicating longer relational latencies. Similarly, amplitude-dependent IH/M also was lower for cases of progressive scoliosis, but did not reach a significant level. Amplitude may yet have to be considered as a less impartial parameter.

Conclusion

H-reflex analysis in idiopathic scoliosis supports the hypothesis of a primary neurological disorder in progressive idiopathic scoliosis.

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Indoor Heated Swimming Pools: The Vulnerability of Some Infants to Develop Spinal Asymmetries Years Later

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Abstract. Evidence reported in an earlier paper suggests that infants introduced to indoor heated swimming pools in the first year of life show an association with spinal asymmetries including progressive adolescent idiopathic scoliosis (AIS) and in normal subjects vertical spinous process asymmetry. Indoor heated swimming pools may contain a risk factor that predisposes some infants to develop such spinal asymmetries years later. What the risk factor(s) may be and its possible portal of entry into the infant's body are unknown and possibilities are examined. New teenage controls were obtained after mothers of AIS patients mentioned that they had taken their child to an infant swim class. In a further group of 18 normal teenagers introduced to an indoor heated swimming pool in the first year of life, 15 had vertical spinous process asymmetry. This prevalence of 83% of those at risk confirms our previous observation of vertical spinous process asymmetry in 61% of teenagers who were introduced to indoor heated swimming pools in the first year of life. Subject to confirmation of our observations consideration should be given to chemical risk factors, possible portals of entry, toxicology, environmental epigenomics and disease susceptibility to altered spinal development. If the risk factor is confirmed there may ultimately be a place for the prevention of AIS in some subjects.

Keywords. Scoliosis, etiology, swimming pools, environment, prevention

1. Introduction

There is no generally accepted scientific theory for the etiology of adolescent idiopathic scoliosis (AIS)[1]. Patients with a family history of scoliosis are seen in the AIS clinics but in Scottish parents we find only a small proportion describe a family member with scoliosis. The possibility that environmental factors might influence genetic mechanisms and lead to AIS was raised by Golding [2] who reported an epidemic of idiopathic scoliosis in Jamaica during 1965-83. Nachemson [3] reported anecdotal evidence of salmon fry which developed scoliosis after exposure to water contaminated by the re-painting of a water-regulating dam at a fish farm, and also commented that salmon fry easily get scoliosis when fed deficient diets.

At the 2004 Vancouver IRSSD Meeting we reported evidence that progressive AIS in 79 consecutive patients was positively associated with the early introduction to indoor heated swimming pools in the first year of life (8 or more occasions) [4]. We are not aware of any publication that suggests exposure to indoor heated swimming pools in the first year of life is a risk factor for AIS.

In that study [4,] the 77 normal, healthy Scottish teenagers as controls were examined for spinous process asymmetry using a method developed and used by one of us (MM) for years in the ISIS Clinic of the Scottish National Paediatric Spine Centre. Unexpectedly, vertical spinous process asymmetry was found in 61% of the controls. When the opportunity arose a further group of normal children exposed to indoor heated swimming pools in the first year of life was examined. The evaluation of such teenage children forms the basis of the present paper.

The present work tests the hypothesis that the introduction of infants to indoor heated indoor swimming pools in the first year of life is a risk factor to vertical spinous process asymmetry expressed in adolescence.

2. Material and methods

2.1 Selection criteria

The controls in this study, like the AIS patients in the previous study [4,5], were only included if they met the following six criteria:

Born full term
Fed well as infants
Achieved normal milestones ie walking and talking
Never been to hospital, excluding sports' injuries
No family history of a scoliosis
No back pain (prior to diagnosis in the patient group)

Failure to meet all six resulted in their exclusion.

2.2 Selection

We deliberately sought out mothers of AIS patients who made reference to organized infant swimming classes that their baby had attended. The mothers who mentioned such classes were asked to approach the mothers from those classes in order that we might examine their children's spines and obtain a history. The mothers of AIS patients were given letters to give to those mothers who had attended the swim classes asking for volunteers for our study. The letter stated what AIS is, the importance of finding volunteers and an undertaking not to ask embarrassing questions. This resulted in 21 mothers volunteering with their healthy teenagers (18 girls 3 boys). Their spines were examined by palpation alone and a detailed history obtained of all physical activities from both mother and control. All the children were born within weeks of one another.

2.3 Interviews

The interviews had the same structure as used in our original study [4,].

2.4 Clinical History

A detailed history was obtained from the mother to ensure each control met the above six criteria.

2.5 Physical activity history

The mother was asked to recall all physical activities her child had participated in, starting from the baby's first few months to the age of 4 years. Once the child started school we only recorded after-school and weekend activities carried out at least once each week for a minimum of three terms (one year).

2.6 Physical examination

The spine of each control was examined by palpation whilst standing. The examiner began by placing her left thumb pad on C7 spinous process where it remained. Should any doubt arise in determining C7 the subject was asked to flex their neck when C6 was noted to move. Then, the examiner's right thumb pad palpated each spinous process noting any asymmetry from the vertical. Finally, the examiner placed both hands on the iliac crests and positioned her thumbs just below the sacral dimples in order to locate the posterior superior iliac spines.

2.7 *Controls examined*

We interviewed and examined twenty-one teenager controls with their mothers

3. Results

Three controls failed the six criteria: one had suffered back pain, and two had hospital admissions, leaving 18 controls. Three of these, all girls, had straight spines while 15 had vertical spinous process asymmetry.

All 18 controls (15 girls 3 boys) had been introduced to an indoor heated swimming pools in the first few months of life.

In this specifically chosen group the prevalence of vertical spinous process asymmetry is 83%.

4. Discussion

4.1 Accord with our previous work on controls

The present findings of vertical spinous process asymmetry of 83% accords with our previous finding of 61% amongst the controls. Another group of controls is needed who have not been exposed to indoor heated swimming pools.

4.2 Do chemicals in indoor heated swimming pools through a pulmonary or skin portal of infants affect their spinal development in adolescence?

We ask the question: Do chemicals in indoor heated swimming pools cause the later development in puberty of vertical spinous process asymmetry?

4.3 Indoor-chlorinated swimming pools and respiratory diseases

Bernard et al [6,] evaluating children exposed to the air of indoor-chlorinated pools found a link to asthma and chronic airway inflammation which they suggest may be due to an irritant gas trichloramine (nitrogen trichloride) contaminating the air of indoor-chlorinated pools. Chlorine reacts with bodily proteins to form chloramines; the most volatile and prevalent in the air above swimming pools is nitrogen trichloride [7]. Do the suspected risk factors of indoor heated swimming pools for spinal asymmetries (AIS and vertical spinous process asymmetry) need to be included in such studies?

4.4 Salmon fry and a fish farm

Nachemson [3] reported anecdotal evidence of salmon fry which developed scoliosis after exposure to water contaminated by the re-painting of a water-regulating dam at a fish farm, and also commented that salmon easily get scoliosis when fed deficient diets.

4.5 Infants – skin absorption, relatively large surface area and some chemicals absorbed with deleterious effects

Compared with adults, infants have a large surface area to body weight. Cutaneous permeability to chemicals, as in drug absorption, may not only be increased but cause deleterious effects because several organ systems including the central nervous system are rapidly developing. The problem relates to the potential toxicity of chemicals added to indoor heated swimming pools and the wider issue of the environment in general.

4.6 The Barker hypothesis

Barker et al [8] and others have shown that the origins of important chronic diseases in adult life may lie not only in the intrauterine environment but in early post-natal life. This has led to British and United States medical research projects to gather information on how human genes and the environment interact over the years to cause disease [9,10]. Whether such nature/nurture mechanisms acting in early life can produce left-right asymmetries expressed skeletally in adolescence is unknown [11].

5. Conclusion

The evidence reported in our earlier papers [4,5] shows that the introduction to an indoor heated swimming pool in the first year of life is associated with adolescent idiopathic scoliosis and in normal teenager controls with vertical spinous process asymmetry. The additional group of controls reported here confirms our original findings for normal teenagers. Subject to confirmation, consideration should be given to chemical risk factors, possible portals of entry, toxicology, environmental epigenomics [12] and disease susceptibility to altered spinal development. If the risk factor is confirmed there may ultimately be a place for the prevention of AIS in some subjects.

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Chapter 3

Biomechanics & Imaging

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Effect of Same-Sided and Cross-Body load carriage on 3D Back Shape in Young Adults

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Abstract: Regular carriage of heavy loads such as backpacks, satchels and mailbags results in a variety of acute medical problems and increased potential for back injury. There is a paucity of information about the specific changes in back posture that occur in response to asymmetrical loading. The purpose of this study was to examine the changes in back shape that occurred in response to asymmetrical load carriage, either on one shoulder (same-side) or across the body (cross-body), in healthy young adults. **Methods:** A convenience sample of 21 physiotherapy students randomly performed three trials (unloaded, same-side loaded, cross-body loaded) in standing with a 15% body load. The Microscribe 3DX digitiser (Immersion Group Ltd) recorded the three dimensional coordinates of 15 Key anatomical landmarks on the back in the three conditions. **Results:** A one-way ANOVA with repeated measures and post-hoc tests was implemented to highlight statistical differences in the data collected ($p<0.05$). Significant differences were found in the x, y and z coordinates of the anatomical landmarks in the upper back between unloaded and loaded conditions. Results demonstrated significantly less impact on spinal posture from cross-body loading as compared to same-sided loading. **Conclusion:** This study confirms that there are significant three-dimensional changes in back shape in response to asymmetrical loading. Further work is needed to evaluate the optimal carriage type and maximal body load that results in the least spinal impact and injury potential in young adults.

Keywords: Back shape, Posture, Asymmetrical Loading

1. Background

Regular carriage of backpacks results in numerous musculoskeletal problems such as nerve injury [1] postural abnormalities [2] and low back pain [3, 4, and 5]. Kinoshita, [6], Goh et al. [7], Chansirinukor et al. [8] and Hong & Cheung, [9] have all reported that significant postural adaptations occurred in response to load carriage. Indeed a change in spinal posture due to load carriage is considered to be a plausible intermediary measure for the potential for spinal pain and deformity [9].

In recent years significant concern has also been raised about the potential injury resulting from daily load carriage. Whilst diverse groups of people carry asymmetrical loads, students do so on a daily basis (e.g. a rucksack on one shoulder, a shoulder bag or bags carried across the body), and are further encouraged to do so to follow fashionable trends.

The potential for acute or long-term injury resulting from load carriage using only one strap or straps with uneven weight distribution may be considerable [10]. Little is known about the specific changes that occur in the back following asymmetrical loading.

The purpose of this study was to explore the changes that occurred in the three dimensional back shape of healthy young adults in response to two types of asymmetrical loading, one carried on one shoulder and one carried across the body.

2. Methodology

2.1. Instrumentation

The low cost portable Microscribe 3DX digitizer (Immersion Corporation Ltd.) was utilized to measure back shape [11]. By using a percentage (15%) of the subject's body weight, the load was standardized according to Wang et al [12].

2.1.1. Subjects

A convenience sample of twenty-one "normal" physiotherapy students aged between 23 and 30 participated in the study. Any subjects previously diagnosed with upper limb, lower limb or spinal pathology, proprioceptive or neurological conditions were excluded from the study**.** Ethical approval was obtained from the School Research Ethics committee.

2.1.1.1. Procedure

Subjects were attired so that the whole of the back surface was visible (females in a bra top) and accessible. Fifteen landmark points on the spine were palpated whilst standing and marked with 8mm diameter self-adhesive stickers [11]. The landmarks and procedure were based on previous work by Warren et al [13] who produced a "normal" 3D back profile.

The order of test conditions was randomized across the sample in order to avoid producing a systematic postural change that could have affected the outcome of this study [14]. Following measurement of normal unloaded back shape; each subject was asked to lift the loaded bag and to place it either unilaterally on one shoulder, or asymmetrically across the body, adjusting the strap so that the weight sat at hip level, shown in figures 1a and 1b.

Figure 1a: Same-side Loaded **Figure1b: Cross-body Loaded**

The anatomical landmark positions were then checked and adjusted as appropriate. The subjects were then asked to stand on the footplate in the same relaxed manner. After a four-minute period, the measurements were taken using the Microscribe. The subjects were then given a five-minute rest period to sit down and unload the spine, after which the third test condition was recorded.

3. Data analysis

Data was analyzed using the SPSS 11.5 statistical package. A one-way (within-sample) Analysis of Variance (ANOVA) with repeated measures and post-hoc tests was then used to evaluate overall differences between the parameters being tested in each group. Significance was accepted at a $p < 0.05$.

4. Results

Results demonstrated that that the positions of several of the landmarks between unloaded and the two loaded conditions were significantly different ($P<0.05$). The planes formed by the xz, yz and xy axes correspond to the frontal, sagittal and horizontal planes respectively. Between the unloaded and same-side loaded positions, there were statistically significant differences between the position of the left acromion in all axes, the left scapula in the x and y axes, the right scapula in the y axis only, the right posterior superior iliac spine in the x axis, the cervical apex in the x axis and the vertebral prominence in the x and y axes. Between the unloaded and cross-body loaded conditions the results showed significant differences only at the left acromion in the z-axis, the left scapula in the y and z axes and the vertebra prominence in the x-axis.

5. Discussion

There were both similarities and differences in the postural responses to the different types of asymmetrical loads. In both cases, an overall lean forward was seen combined with a lateral shift to the left away from the load placed on the right hip. The extent of this lateral shift was not as large in the cross-body loaded condition.

In the same-side loaded condition elevation of the loaded shoulder was seen, accompanied by a corresponding counter-balancing depression of the non-loaded shoulder. In the cross-body loaded condition, depression of the loaded shoulder was accompanied by slight elevation of the non-loaded shoulder.

Initial results suggest that cross-body loading results in fewer postural changes than same-side loading. This was shown by the fewer significant changes in axial position of the anatomical landmarks from the unloaded position and the smaller magnitude of postural movements between landmarks in the cross-body loaded position.

The results of this exploratory study confirmed that there are definite postural adaptations in all three planes of movement made in response to both types of asymmetrical loading. This provides clinically relevant information into the potential risk factors and mechanisms of injury that could lead to the variety of musculoskeletal conditions and spinal deformities that have been linked with the carriage of heavy loads.

Alterations of the spinal curvature owing to improper posture can be medically classified as a functional scoliosis [15]. This is only temporary because the spinal column resumes its correct alignment by removing the load, correcting the poor posture. The long-term effects of poor posture are not known, but such alterations of the spine may be responsible for the postural discomfort, muscular pain in the shoulders and perceived back pain associated with heavy load carriage (Pascoe *et al.* 1997; Hong and Cheung 2003).

The understanding of postural displacements that occur in response to asymmetrical carriage of heavy loads can be used by health professionals to make recommendations on appropriate load carriage in a variety of population groups. The results of this initial exploratory study suggest that it may be appropriate to advise against the regular use of heavily-loaded same-side style asymmetrical bags in favour of backpacks or cross-body style asymmetrical bags, with less than 15% body weight load.

6. Conclusions

This study confirms that carrying an asymmetrical load of 15% body weight has a significant impact on the three-dimensional back shape of normal young adults. Same-side asymmetrical loading showed elevation of the loaded shoulder, counterbalanced by depression of the unloaded shoulder. At the trunk there was a lateral shift away from the load and an overall lean forward. There was no significant postural change made at the lower back. In cross-body asymmetrical loading, depression of the loaded shoulder was accompanied by slight elevation of the shoulder at the unloaded side. Again a lateral shift away from the load and forward lean were observed. Results indicated that cross-body loading had less overall impact on posture than same-side loading. Further in-depth analysis is currently being undertaken to understand the mechanisms of potential injuries associated with carrying loads in an asymmetrical manner

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Transverse Plane of Apical Vertebra of Structural Thoracic Curve:Vertebra Displacement versus Vertebral Deformation

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Abstract. CT transversal scans of the trunk provided at the level of Th8 or Th9 (apical vertebra) of 23 patients with structural thoracic scoliosis were reviewed. The following parameters were studied: 1) alpha angle formed by the axis of vertebra and the axis of spinous process, 2) beta concave and beta convex angle between the spinous process and the left and right transverse process respectively, 3) gamma concave and gamma convex angle between the axis of vertebra and the left and right transverse process respectively, 4) rotation angle to the sagittal plane according to Aaro and Dahlborn, 5) Cobb angle. Values of measured parameters demonstrated a common pattern of intravertebral deformity: counter clockwise deviation of the spinous process (alpha angle 15,0 ±8,5°), beta concave (69,8 ±8,5°) significantly greater than beta convex (38,8 ±8,5°), gamma concave (54,3 ±7,8°) not different from gamma convex (56,0 ±8,0°). Strong linear positive correlation between alpha angle and Aaro-Dahlborn angle was observed ($r=0,78$, $p<0,05$). Changes in morphology of apical vertebra due to intravertebral bone remodelling followed the vertebral spatial displacement and there existed a linear correlation in between. The two processes develop in opposite directions.

Introduction

The apical vertebra (AV) of scoliotic curve is most laterally deviated from the central sacral line and presents the most important rotation. In contrast to the end vertebrae, the AV is not tilted but situated in the transverse plane of the body. It can be visualized by computer tomography (CT) transverse scans which pass through vertebral body, pedicles, transverse processes and spinous process (fig.1A.).

Use of pedicle screw fixation brought more interest in the study of anatomy of scoliotic vertebrae [1]. Actually the bone drift, subsequent to the asymmetric loading and growth as well as the tether by posterior soft tissues, result in the presence of intrinsic deformation of the vertebra. Vertebra displacement and vertebral deformation are most expressed inside the apical zone of thoracic structural scoliosis.

The aim of the study was to assess the transverse plane displacement and transverse plane deformation of the apical vertebra of thoracic scoliotic curvature.

Material and methods

Inclusion criteria were: female, diagnosis of idiopathic scoliosis, presence of structural thoracic curve, right convex, CT records available, and anatomic landmarks correctly visualized (pedicles, spinous and transverse processes). Patients' charts were retrospectively reviewed but no CT exam was ordered because of this study. Scans of the trunk of 23 patients were analyzed. The Cobb angle was 60,6 ± 19,3° (28,0 – 101,0°).

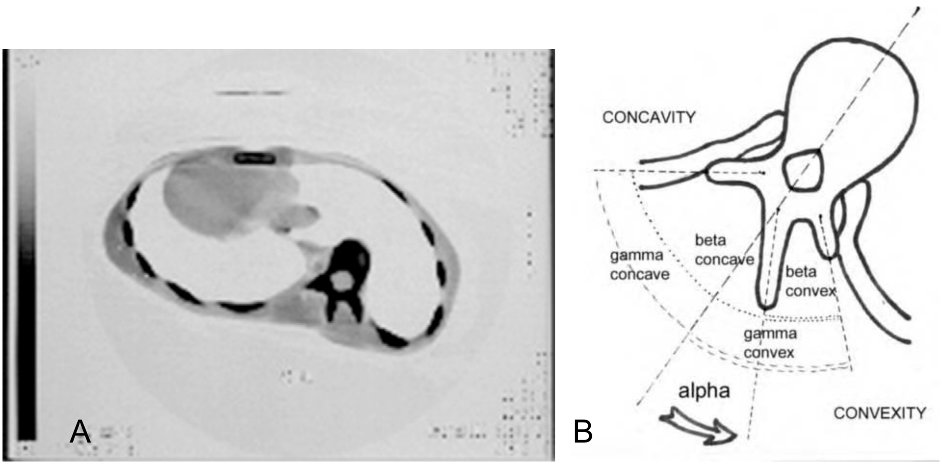

Figure 1. A) CT scan of apical vertebra of right thoracic scoliosis (top view). **B)** Definition of angles.

For each patient the study of intravertebral bone deformation was performed on a single CT transversal scan realized through the apical vertebra (Th8 or Th9) of thoracic curvature (Xv and Yv axis of the local, vertebral axis system) [2]. The study of vertebra displacement was performed on the same CT scan, comprising the section of the whole thoracic cage, and according to the global body axis system (Xg and Yg). Deviation of spinous process (SP) was assessed in the regional axis system (Xr and Yr). The quantification of the SP deviation was done by measuring the angle formed by the axis of the spinous process and the axis of the vertebra (alpha angle, fig. 1B). The direction of SP deviation in the transverse plane was defined as: 1) towards the concave side of the curve ("in opposite direction to the rib hump" or clockwise for the top view) or 2) towards the convex side of the curve ("towards the side of the rib hump" or counter clockwise). Neither Z axis displacement nor deformity was approached in this study.

The axis of vertebra (AV) was drawn through the most anterior and the most posterior points of the vertebral canal (fig.1B.). The axis of spinous or transverse process was drawn through the tip and the mi-distance of the base of each process. The following angles were measured: 1) alpha angle formed by the axis of vertebra and the axis of spinous process, 2) beta concave and beta convex angle between the SP and the left and right transverse process respectively, 3) gamma concave and gamma convex angle between the AV and the left and right transverse process respectively, 4) rotation angle to the sagittal plane according to Aaro and Dahlborn [3], 5) Cobb angle.

Results

Values of measured parameters demonstrated a common pattern of intravertebral deformity, table 1. Beta concave angle was significantly greater than beta convex; gamma concave was not statistically different from gamma convex. Strong linear positive correlation between alpha angle and Aaro-Dahlborn angle was observed ($r=0,78$, $p<0,05$).

In one case the axis of vertebra superposed with the axis of the spinous process. In all the other cases an angle appeared in between (alpha angle). In no case was the spinous process deviated clockwise, to the concavity ("opposite to the rib hump", fig. 2B). In all but one cases the spinous process was deviated counter-clockwise, towards the convexity ("towards the rib hump", fig. 2D).

Table 1. Mean, SD, minimum and maximum for the measured angles, N=23

Parameter	mean ± SD	min – max.
Alpha	15,0 ± 8,5°	0,0 – 32,0°
Beta convex	38,8 ± 11,7°	7,0 – 61,0°
Beta concave	69,8 ± 8,5°	49,0 – 83,0°
Gamma convex	54,3 ± 7,8°	40,0 – 72,0°
Gamma concave	56,0 ± 8,0°	45,0 – 71,0°
Aaro and Dahlborn	18,3 ± 7,7°	10,0 – 38,0°

Discussion

Regular pattern of apical vertebra displacement and deformation, previously reported [4], was confirmed: clockwise vertebra rotation and counter-clockwise intrinsic vertebral deformation. The absolute motion of apical vertebra of thoracic scoliosis in the transverse plane, which is a complex combination of anterior translation, lateral translation and convex rotation, was not studied. We limited to the Aaro and Dahlborn angle of rotation which expresses only one component of vertebra displacement.

Even if anatomic specimens of scoliotics vertebrae are often reproduced in manuals of orthopaedics [5, 6], their morphologic analyse seems insufficient. Parent et al. [7] provided a detailed description of pathologic changes in vertebral bodies based on important series of anatomic specimens. Unfortunately the spinous process of a thoracic vertebra is thin and fragile thus often absent. Moreover in vivo spatial orientation (spinal X and Y axis) of vertebra cannot be revealed if a separate bone specimen is studied. This is why computer tomography may be of interest to analyse either vertebra spatial displacement or vertebral intrinsic deformation.

Forces of tension of ligaments, joint capsules, tendons and muscles cause a prolonged stress and strain on the bony elements of vertebrae [2, 8] and subsequently the bone drift occurs in the transverse plane. Although the whole vertebra is subjected to "distortion" forces, the degree of bony deformation varies in particular anatomic parts of vertebra. The spinous process as well as the anterior part of vertebral body presented higher degree of transverse plane "distortion", while the vertebral canal and transverse processes' deformation was less expressed. The alpha angle between the axis of vertebra and the axis of spinous process was created in order to quantify the "distortion" of spinous process. Strong positive correlation between the marker of vertebra displacement (Aaro and Dahlborn angle) and the marker of spinous process deformation (alpha angle) was noted. Vertebra rotation occurred clockwise but vertebral "distortion" deformation developed counter-clockwise (fig. 2D). Concomitantly to intraoperative findings the paravertebral space - limited by the spinous process and left or right transverse process respectively - was larger at the concave side of scoliosis (beta concave significantly greater than beta convex). As gamma angles were equal for left and right side, the above mentioned difference may be attributed mainly to the spinous process deviation. Surprisingly in some eminent manuals of orthopaedics the figures demonstrating the transverse plane deformation of apical vertebra in thoracic scoliosis seem to reproduce an incorrect image [9, 10, 11, 12, 13, 14], (fig. 2B).

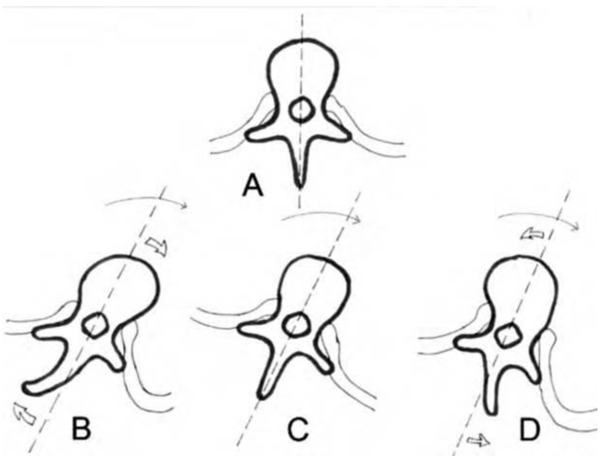

Figure 2. Top view of thoracic vertebra. Convexity at right, concavity at left. Long arrows indicate rotation, short arrows indicate "distortion" (bone drift). **A)** Normal, no rotation, no deformation. **B)** Clockwise rotation and clockwise deformation.; incorrect image. **C)** Clockwise rotation, no deformation; theoretic image. **D)** Clockwise rotation, counter-clockwise deformation; image supported by this study.

In orthopaedic literature the term "torsion" is used in various meanings. Dubousset used this term to describe the total of 3-D displacement of all vertebrae within a scoliotic curve [15]. Kuklo, Potter and Lenke studied "thoracic torsion" by measuring various rib-vertebra related parameters on plane radiographs [16]. In polish orthopaedic literature "torsion" described bony deformation of scoliotic vertebra [17, 18]. These meanings seem substantially different from the "mechanical torsion" defined by Stokes [2] for the local and regional levels; the term bone drift is proposed instead [19].

Conclusions

1. Study of transverse plane of apical vertebra of structural thoracic scoliosis by computer tomography revealed either vertebra displacement or vertebral deformation.
2. The two above mentioned phenomena develop in opposite directions (clockwise rotation, counter-clockwise "distortion") and there exists a linear correlation in between.
3. The spinous process of apical vertebra is deviated towards the convex side of the curve, contrary to the common representation in the literature.

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Correlation of an Induced Rotation Model with the Clinical Categorisation of Scoliotic Deformity – A Possible Platform for Prediction of Scoliosis Progression

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Abstract: *Aim:* The primary aims were to develop a simplified three-dimensional model of the thoracolumbar spine and to predict the influence of axial rotation at different levels of the spine on the resultant scoliotic curve, using King's classification as a comparator.
Materials and Methods: A three-dimensional mathematical model of the simplified thoracolumbar spine (constant size vertebral body without posterior elements) was developed using anatomical data from the published literature. The influence of rotational displacement of the motion segments at various levels of the spine was studied by applying different axial rotations, using a three-dimensional homogeneous transformation matrix method.
Results: The result of the model show the correlation of the deformity in lower regions of the spine (lumbar) with the geometrical changes in upper regions of the spine (thoracic), associated with the continuous alteration in direction of the vertebral axis of rotation along the spine. The final curvature of the scoliotic spine is influenced by both the degree of axial rotation in each region and the spatial deformation of the spine (e.g. kyphotic shape and extent of lateral deformity). Qualitatively, the model is capable of producing different categories of the spinal deformity based on King's classification.
Conclusion: A three-dimensional analysis of spinal shape demonstrates the important relationship between induced vertebral rotation and the resulting deformity. The effect of rotational displacement on the overall configuration of thoracolumbar spine during juvenile growth was assessed and demonstrates close correlation with deformities of the lower regions of spine.

Keywords: Spine, Scoliosis, Mathematical modelling, Axial rotation, Progression

1. Introduction

Adolescent Idiopathic Scoliosis (AIS) is a three-dimensional deformity of the spine, in the lateral, frontal and sagittal planes, that occurs during phases of rapid growth in the juvenile years, for which different aetiological factors have been debated but no aetiology has been proven. A wide range of causal factors and theories for the aetiology of AIS, ranging from neuromuscular conditions [1,2] to structural skeletal abnormalities [3-6], have been proposed and evaluated, among the earliest being the proposal that axial rotation was significant for the initiation and progression of the deformity [7-9]. However, the aetiology and pathogenesis of scoliosis remain unknown [3,4].

Mathematical models are used to study complex biological systems, which are difficult to study using conventional experimental techniques. One advantage of using a mathematical rather a physical model is that modifications to the individual constituents are relatively easy to make in a mathematical model. While there is some information about the scoliosis correction or curve patterns of scoliosis in the literature, and a number of models have also been proposed for scoliotic deformities of the spinal column [5,10-13], there is still the need to investigate and model aetiology related factors of scoliosis, using scientific principles.

Structural changes that occur in idiopathic scoliosis include vertebral wedging, angulation, rotation to the convex side, and changes of position of the vertebrae within the curve [11]. Idiopathic scoliotic deformities are correlated with axial rotation and instability of the spine in the sagittal plane [11,14-16]. However, the regional changes in axial rotation and its correlation with the overall deformity of the spine need to be identified. This can provide clinically valuable information particularly for advanced treatment modalities of scoliosis, such as the use of direct vertebral rotation (compared to simple rod derotation) in order to achieve better three-dimensional result [17].

The specific aim of this study is to develop a simplified three-dimensional model of the thoracolumbar spine in order to investigate the influence of axial rotation at different levels of the spine and its correlation with King's classification [18].

2. Methods

2.1. Model of Normal Spine

A simplified, three-dimensional, mathematical model of the thoracolumbar is developed by the use of published anatomical data of the normal spine [19-23]. In the normal spine, the vertebral bodyline can be regarded as a plane curve in the sagittal plane [20]. In the current model the 'vertebral bodyline', which passes through the 'vertebral centroids' of the lumbar thoracic spine, is considered to be composed of simple arc segments of constant radius [24]. Further simplification of the spinal anatomy include the use of constant size vertebral body and disc structures and the absence of any posterior spinal structures.

The kyhpotic curvature of the thoracic region is about 39° and the lordotic curvature of the lumbar region is 57°. The geometrical data used to build the model is presented in Table 1.

Table 1. Anatomical data of thoracic and lumbar region of spine. (EPW: Average value of upper and lower endplates)

Diameter of vertebral body (EPW)	30.1 mm
Average height of thoracic vertebral body	18 mm
Average height of thoracic disc	4.1 mm
Average value of thoracic kyphosis angle	39°
Radius of equivalent circle used for thoracic kyphosis	397.4 mm
Average height of lumbar vertebral body	22.9 mm
Average height of lumbar disc	13 mm
Average value of lumbar lordosis angle	57°
Radius of equivalent circle used for lumbar lordosis	188.3 mm

There is scattered data bout the normal spine, however, these are mainly related to the variations in the human phenotype rather than pathological condition or deviation from the so-called "normal" form. The frontal, lateral and three-dimensional view of the thoracolumbar model is demonstrated in Figure 1. The present three-dimensional model provides the means to study the effect of induced axial rotation at different levels of spine in the three-dimensional configuration of the thoracolumbar spine, compared with the King's classification [18].

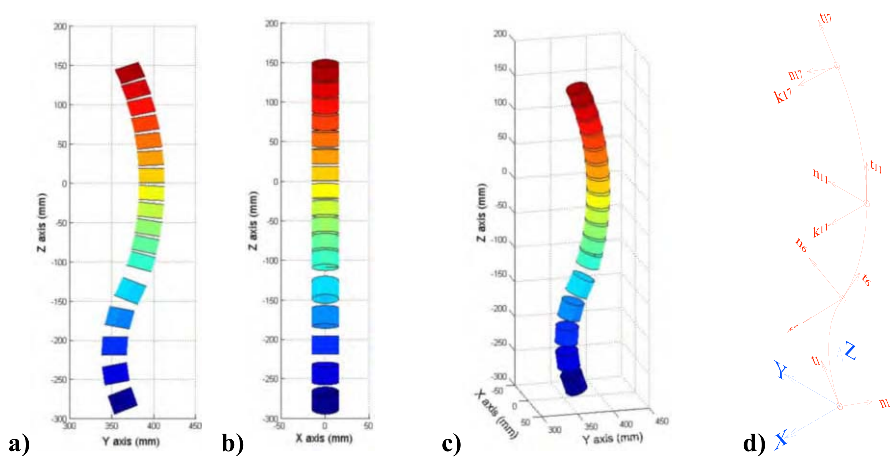

Figure 1. Thoracolumbar model of the normal spine; a) Lateral view, b) Frontal view, c) Three-dimensional view, and d) Three-dimensional view of the global and local coordinate systems along the spine.

2.2. Scoliosis Model

In order to apply the relevant spatial transformations (axial rotation at each vertebral level) and to monitor the resulting deformity, a main reference frame coordinate axis is established and all other axes defined relative to it, with the following convention assumed. X-axis: lateral to the left; Y-axis: posteroanterior and Z-axis: longitudinal (Figure 1-d). The reference origin of the spine is defined to be at the base of thoracolumbar section of the spine (L-5). All other axes (axes belonging to each of the vertebrae, represented by n, t, k) will be defined relative to the axes of reference origin.

The concept used in this model is the transformation of the arbitrary axis, and every thing above it in space, to the reference axis [25]. Therefore, for each transformation iteration a new reference axis is taken and the transformations are applied to all vectors and vertebrae above it leaving all elements preceding it unchanged by the transformation. The direction of the vertebral axis of rotation changes at each level across the spine, influencing the resulting deformation pattern of the remaining segments above it, compared with previous ones. Additionally, the homogeneous transformation matrix is used to apply the rotational and translational operations to the vertebrae [26].

3. Results

In order to simulate the influence of induced axial rotation to the overall configuration of the thoracolumbar spine during juvenile growth, various axial rotations are applied to the model. The patterns adopted in this study are compatible with the observed rotational deformities in the progressive scoliosis, i.e. the rotation above and below the apex has opposite orientations [12-17]. The result in Figure 2-a illustrate the thoracic model with altering axial rotations below and above the apex of the normal spine respectively. The result of the model demonstrates the important relationship between the size of the scoliosis, the size of the kyphosis, the extent of lateral deviation, and the amount of axial rotation.

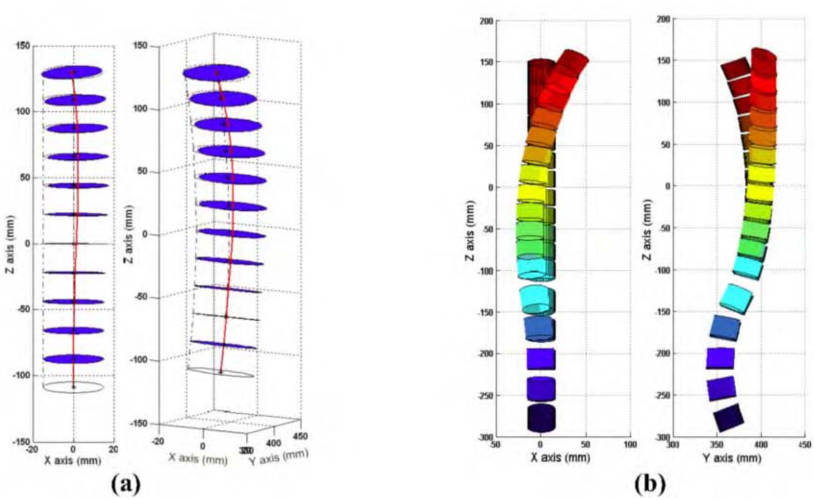

Figure 2. (a) Frontal (left) and three-dimensional (right) views of the thoracic model with altering axial rotations below and above the apex of the curve [intervertebral disc representation]; (b) Frontal (left) and sagittal (right) views of the thoraco-lumbar spine with altering axial rotations below and above the apex of the curve [vertebral body representation].

The result in Figure 2-b demonstrates the characteristic double curve in the coronal plane and flattening of the sagittal plane curvature are present and are due to the rotational interaction between the lumbar and thoracic regions.

Further studies of the model demonstrated that the model has the ability to produce different pattern of scoliosis deformity based on King's classification [18]. **Error! Reference source not found.** Figure 3 demonstrates the correlation of the model with the third and fifth pattern of idiopathic scoliosis categorisation, as an example, compared to King's classification. The results supports and shows that induced axial rotation can create structural changes of the spine, resulting in curvatures similar to the King’s classification, supporting that induced axial rotation can create structural changes of the spine.

4. Conclusion and Discussion

Biomechanical models have been used in the study of scoliosis and have shown the ability to help the physicians, e.g., in pre-surgical evaluation and surgical planning of posterior instrumentation [13]. Frequently, the aim of an analytical model is to provide insight into a problem rather than to generate absolute data, a qualitative rather than quantitative approach. When insight is the aim, then it is usually worthwhile to seek a simple model that can capture the major characteristic of the response of a sophisticated model [27]. In this paper, a mathematical model of the simplified thoracolumbar spine was developed in order to identify how rotational displacement can affect the spatial curvature of spine (i.e., what three-dimensional deformity will be produced as a result of the proposed mechanism), employing the concept of the transformation of the arbitrary axis and a three-dimensional homogeneous transformation matrix method.

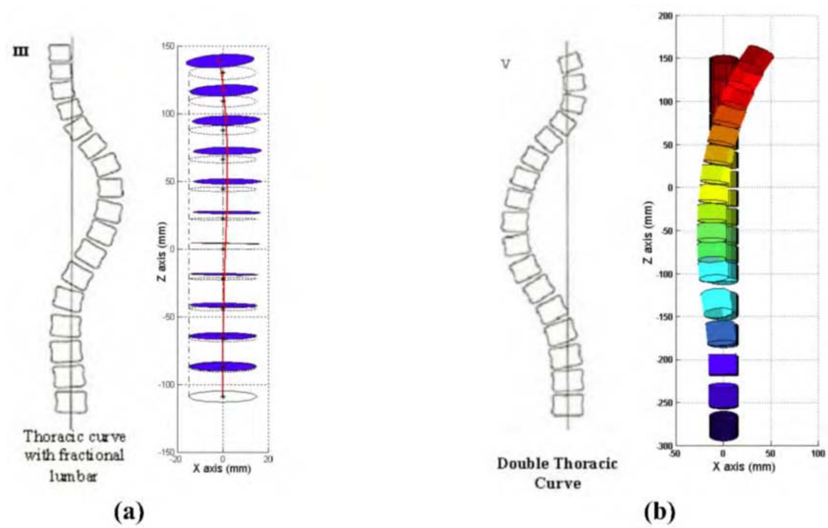

Figure 3. Correlation of the model with clinical categorisation (King's classification); a) Frontal view of the thoracic model with varying axial rotations below and above the apex compared with the third pattern of king's classification, b) Frontal view of the thoraco-lumbar model compared with the fifth pattern of the King's classification [18].

The result of the model demonstrate the correlation of the deformity in lower regions of the spine (lumbar) with the geometrical changes in upper regions of the spine (thoracic), associated with the continuous alteration in direction of the vertebral axis of rotation along the spine (Figure 1 and Figure 2). The final curvature of the scoliotic spine is influenced by both the degree of axial rotation in each region and the spatial deformation of the spine (e.g. kyphotic shape and extent of lateral deformity). Qualitatively, the model is capable of producing different categories of the spinal deformity based on King's classification (Figure 3).

Prediction of the idiopathic scoliotic curve progression is a challenging task, requiring multi-factoral information, such as, rate of growth, level of maturity, connective tissue structure, geometrical data including the rotational displacements, curve location etc. [28-29]. Axial rotation of the motion segments is defined as a key characteristic of idiopathic scoliosis [7,8,9,11], associated with both the Cobb angle and kyphosis, which highlights its role in the development of the scoliotic deformity. Therefore, mathematical modelling being able to implement this effect can be considered as a platform for the prediction of the idiopathic scoliotic deformity.

In this study the role of posterior elements has not been considered, enabling us to better focus on the axial rotation aspect of the scoliotic spine. Also, it is believed that the change in the posterior elements is a secondary adaptation and not primary asymmetrical adaptation of bone [30] and therefore the simplification of the model was a reasonable assumption within the context of proposed study. Moreover, our previous finite element model of the T7-T8 motion segment [31] showed that in the presence of axial rotation the posterior elements cause lateral bending of the motion segment and therefore, enhance the level of deformity.

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A Novel Framework for the 3D Analysis of Spine Deformation Modes

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Abstract. Three-dimensional classification of scoliosis is important. However, analyzing large databases of 3D spine models is a difficult and time consuming task. To facilitate this task a method that automatically extracts the most important deformation modes from a set of 3D spine models is proposed. The 3D spine models are first converted into vertebrae relative positions and orientations. Then, a variability model composed of the Fréchet mean and of a generalized covariance is computed. A principal component analysis is applied to that variability model and the extracted components are converted into deformation modes. Those modes are visualized by animating a 3D spine model where the deformation strength varies (for a given mode). The proposed method was applied to a group of 307 scoliotic patients and meaningful deformation modes were successfully extracted. For example, patients' growth, double curves, simple thoracic curves and lumbar lordosis were extracted in the first four deformation modes. Moreover, the obtained deformation modes are not disconnected from conventional surgical classifications since a logistic regression confirmed that there is a statistically significant relation between King's classification and the first four principal deformation modes. The proposed method successfully extracted important deformation modes from a set of 3D spine models and can be used to refine arbitrary classes (King's or Lenke's classes, for instance), thus helping the design of new clinically relevant 3D classifications.

1. Introduction

Classification is a decisive part of the assessment of adolescent idiopathic scoliosis (AIS). The classification schemes that are currently used such as King's [1] and Lenke's [2] classifications were designed to guide the selection of fusion and instrumentation levels. Those classification systems are based on 2D measures performed on radiographs. However, spine deformations are three-dimensional and there are evidences that, by taking into account the three-dimensional nature of the deformations, sub-classes that are relevant to surgical planning could be found [3].

However, the choice of a method that takes into account the three-dimensional nature of the deformation is far from being trivial. Poncet et al. [4] proposed a classification that was based on spine torsion. Duong et al. [3] used a wavelet transform of the vertebrae centroids and a clustering method to agglomerate similar 3D spine shapes. Both methods are technically elegant and demonstrated that 3D classifications are important and possible. However, those methods are not considered to be very intuitive by physicians.

Thus, instead of the proposing yet another classification, we present a geometric method that can be used to find the most important geometric variation modes in databases of 3D spine models. These modes will indicate what varies the most from a geometric perspective in a given group, thus helping the physician in the task of analyzing large sets of 3D spine models, which is a necessary but tedious task, to define a clinically relevant 3D classification.

The next section will outline the method used to extract those modes. The information that is necessary to understand the results will be explained. However, the mathematical details of the method will not be presented (but can be found in another paper [5] about spine deformation modes). To illustrate the potential of this method, the four most important modes of variations extracted from a database of AIS patient will be presented. Then, the relationship between the extracted modes and the King's classification will be analyzed with a logistic regression. Finally, a discussion of the results and an outline of possible improvements to the method will conclude this paper.

2. Method

In order to analyze the spine deformation modes, a set of geometric descriptors have to be chosen. Then, a statistical model that is based on the chosen geometric descriptors must be computed and the principal modes of deformation can be extracted from this statistical model.

2.1. Intervertebral Rigid Transforms

The spine geometry was described using the rigid transforms that separates local coordinates systems of consecutive vertebrae. Therefore, a single spine model will have a rigid transform associated with every intervertebral space. A rigid transform is the combination of a translation and a rotation. Therefore, this geometric model takes into account not only the relative positions of the vertebrae, but also their relative orientations. The rigid transforms were expressed by a translation vector, a rotation axis and a rotation angle (see Figure 1).

These rigid transforms are computed by triangulating anatomical markers in pairs of calibrated radiographs [6] and by rigidly registering the anatomical markers of a vertebra to those of its first upper neighbour.

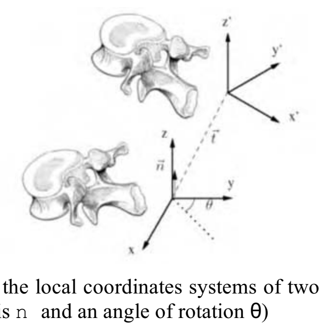

Figure 1. A rigid transform between the local coordinates systems of two consecutive vertebrae (described by a translation vector t, a rotation axis n and an angle of rotation θ)

2.2. Statistical Spine Model and Principal Deformation Modes

The extraction of the principal deformation modes from a database of spine models expressed using rigid transforms requires a statistical model. In the context of our problem a simple statistical model with only a centrality and a directional dispersion measure is enough. This statistical model would usually consist of a mean and a covariance matrix. However, computing the mean of rotations (and thus of rigid transforms) is ambiguous, because rotations cannot be added or multiplied by a scalar (they can only be composed or inverted).

However, the Fréchet mean can be used instead of the conventional definition of the mean since it is defined using the distances between the elements that we would like to average. Moreover, the computation of the Fréchet mean is simple in the case where the exponential and log maps associated with the chosen distance are known. Furthermore, it is possible to define a distance function that is invariant to left (or right) composition (once again technical details can be found in [5]).

The dispersion of the spine models around the Fréchet mean is then captured by a covariance matrix computed in the tangent space of the Fréchet mean. This measure of the dispersion has all the properties of a traditional covariance matrix. Therefore, linear operations can be performed on it. The extraction of the principal deformation modes is then very simple: it consists in computing the eigenvectors of the covariance matrix and sorting those vectors with respect to their corresponding eigenvalues.

The principal deformation modes define an orthonormal basis of the tangent space around the mean. Therefore, it is easy to reconstruct spines models by specifying the amount of deformation associated with one (or many) deformation modes. This property will be used to illustrate the deformation modes.

3. Results

3.1. Deformation Modes

A database of 307 scoliotic patients from the Sainte-Justine hospital was used to compute the principal deformation modes associated with scoliosis. The selection of the patients included in this database was based on the availability of the radiographs needed to compute 3D reconstructions of the spine.

The selection of the subjects did not take into account individual factors such as the age, sex or type of scoliotic curve. Therefore, the statistical model used to extract the principal deformation modes captured many sources of variability such as: the anatomical variability inherent to the pathology but also growth stage, posture, landmarks reconstruction error, *etc*. However, posture during data acquisition was normalized to limit its influence on the results and synthetic experiments suggested that landmarks reconstruction error was associated with a very small proportion of the observed variability.

To illustrate the different deformation modes retrieved using the proposed method, four models were reconstructed for each of the first four principal deformation modes. Those models were reconstructed with deformation strength set to -3,-1,1 and 3 times the standard deviation associated with a deformation mode. The first and second deformation modes are presented at Figure 2. The third and fourth deformation modes are illustrated at Figure 3.

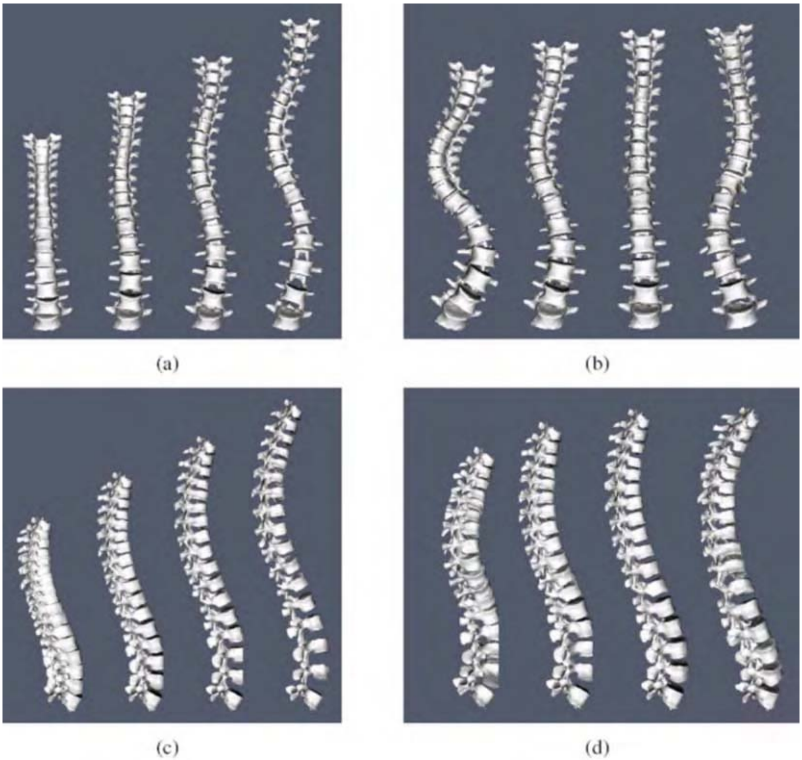

Figure 2. First principal deformation mode (reconstructions for -3,-1,1 and 3 times the standard deviation), posterior-anterior view (a) and lateral view (c). Second principal deformation mode (reconstructions for -3,-1,1 and 3 times the standard deviation), posterior-anterior view (b) and lateral view (d).

The first mode of deformation appears to be associated with the patient growth because it is mainly characterized by an elongation of the spine and it also includes mild thoracic and lumbar curves. The second principal deformation mode could be described as a double thoraco-lumbar curve. The third principal mode of deformation is a simple thoracic curve; this curve is longer than those observed in the first and second principal deformation modes. It is also interesting to note that, in addition to the curves visible on the posterior-anterior view, the second and third principal deformation modes are also associated with the development of a kyphosis on the lateral view. Finally, the fourth component is mainly associated with the development of the lumbar lordosis.

3.2. Relation with existing classification schemes

The curve patterns extracted from the principal deformation modes are connected to the pattern routinely used in different clinical classifications of scoliosis. For instance, the reconstructions built from the first principal deformation mode would be classified as a type I or III (depending on which reconstruction is evaluated) using King's classification [1], the second deformation mode would be associated to King's type I, II and III and the combination of more than one deformation modes could easily create type IV or V curves.

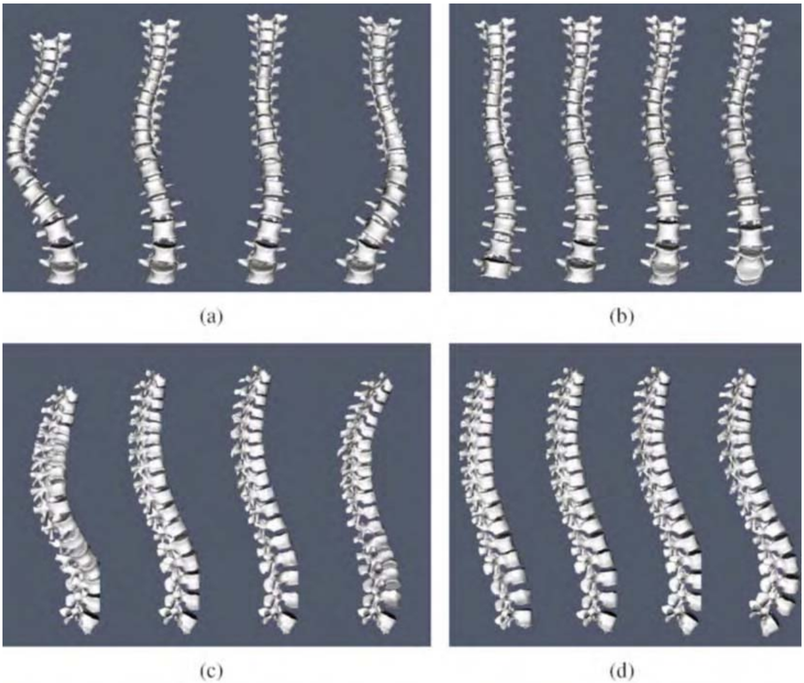

Figure 3. Third principal deformation mode (reconstructions for -3,-1,1 and 3 times the standard deviation), posterior-anterior view (a) and lateral view (c). Fourth principal deformation mode (reconstructions for -3,-1,1 and 3 times the standard deviation), posterior-anterior view (b) and lateral view (d).

King's class	Deformation modes regression coefficients			
	a_1	a_2	a_3	a_4
V	-2.33	-1.18	-8.79	10.23
IV	0.03	2.81	7.29	-
III	1.13	-2.10	-3.87	1.49
II	1.43	-1.94	-0.89	-5.84
I	-0.93	1.38	4.09	-

Table 1. Result of a logistic regression between the first four principal deformation and the King's classes

To demonstrate quantitatively that the principal modes of deformation were linked to clinically used classification, a logistic regression between the King's classes and the first four modes of deformations was performed on 33 subjects. Those subjects were randomly selected and had at least one curve with a Cobb angle of 30 degrees or more. Because of the small number of cases in this analysis, weights were used to balance the numbers of cases in each class during the regression. The results of this analysis are presented in Table 1. Statistically significant effects were found for every classes and it appeared that King's classes are usually not linked with one deformation mode but with a combination of more than one mode. For example, type V membership prediction has large coefficients associated with negative values for the third mode and for positive values of the fourth mode.

These results indicate that there is a strong connection between 2D classifications used for surgical planning and automatically extracted deformations modes. Moreover, the deformations modes are truly three-dimensional, thus frontal deformations of the spine are associated with lateral deformations.

4. Discussion and Conclusion

A method that performs an automatic extraction of the most important modes of deformation on spine models was presented. The method has strong mathematical foundations and was able to extract deformation patterns that were previously derived from surgeons' intuition and experience. Moreover, a statistical link between a more formal surgical classification system (King's classification) and the principal deformation modes was found. The proposed method can also be used to find the principal modes of deformation in more specific groups of patients, for instance, to refine classes in a 3D classification system.

One of the limitations of the proposed framework is that it analyzes inter-patients geometric variability, but it does not incorporate any temporal effect to study intra-patient geometric variability. Therefore, one interesting perspective would be to extend the method to the analysis of temporal progression of spinal deformities to find 3D progression patterns.

Acknowledgement

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Intervertebral Disc Adaptation to Wedging Deformation

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Abstract: Although scoliosis includes wedge deformities of both vertebrae and discs, little is known about the causes of the discal changes, and whether they result from mechanical influences on growth and/or remodelling. Methods and Materials: An external apparatus attached to transvertebral pins applied compression and 15 degrees of angulation to each of two adjacent young rat caudal intervertebral discs for 5 weeks (four animals), or for 10 weeks (four animals). Each week, micro-CT scanning documented the *in vivo* discal wedging. After euthanasia, tail segments (three vertebrae and the 2 angulated discs) were excised and their flexibility was measured over a range of lateral bending. The angle of maximum flexibility was recorded. Then discs were fixed *in situ* (with the external apparatus in place) and sectioned for polarized light microscopy. Results: The disc-wedging deformity averaged 15 degrees initially, it averaged 20 degrees after 5 weeks, and then reduced to 10 degrees (in 10 week animals). The lateral bending flexibility showed a distinct maximum at an average of 1.1 degrees from the *in vivo* position in the 5-week animals, indicating structural remodeling of the discs almost to the deformed geometry. The 10-week animals had maximum flexibility at 1.4 degrees from the in vivo position (no significant difference between 5 and 10-week animals.) Collagen crimp angles [Cassidy *et al.,* Conn Tiss Res 1989, 23:75-88] were not significantly different between convex and concave sides, again suggesting that remodeling had occurred. Conclusions: In a mechanically induced scoliosis deformity in skeletally immature rats, the intervertebral discs underwent remodeling within 5 weeks. This indicates that this animal model is suitable for studying adaptive wedging changes in human scoliosis.

Keywords: Intervertebral_disc, wedging, animal_model, biomechanics

1. Introduction

Scoliosis involves wedging deformity of the discs as well as the vertebrae. Prior to skeletal maturity, the development of vertebral wedging is thought to involve asymmetrical growth in vertebral growth plates, modulated by asymmetrical loading. The cause of the wedging deformity in discs is not known, but may involve asymmetrical remodeling and/degeneration of the disc tissue. Lateral migration of the nucleus has been reported in human scoliosis [1]. During adolescent growth there is minimal vertical height increase in the discs [2]. The purpose of this study was to document morphological, mechanical and annulus structural changes in mechanicaly deformed intervertebral discs in a rapidly growing rat tail model.

2. Methods

2.1. In-vivo study - bent tail model

The tail discs of 8 rats were instrumented for either 5 or 10 weeks. The 8 animals were assigned to one of two groups of 4 animals each: 30 angulation of two disc levels for 5 or 10 weeks, (with the apparatus crossing two discs, each disc angulated nominally 15 , c.f. Mente et al. [3,4]). The apparatus was modified from that used previously [3,4] by use of radiolucent materials (fiberglass rings, nylon rods and nuts). The only radio-opaque materials were the bone-transecting pins and the loading springs, and these produced minimal artifact in the CT images. At weekly intervals (5-week animals) or 2-weekly intervals (10-week animals) *in vivo* micro-CT scans of the tail were performed to measure disc wedging and thickness. *Post-mortem* lateral bending stiffness was measured, followed by *in situ* fixation and histology to measure collagen crimp angles (by polarized light microscopy [5,6]). The objective was to determine whether the discs were structurally altered at 5 weeks, and whether the structural changes were greater after 10 weeks

2.2. Micro-CT of rat tail intervertebral disc

Micro-CT scanning provided a method to monitor precise geometrical measurement of the size and shape of the disc space between vertebrae *in vivo*. Animals were anesthetized at one or two-weekly intervals and imaged in the Explore Locus volumetric conebeam MicroCT scanner (GE Medical Systems, London, Ontario) set at 55 kVp, with 200 views (each taken at 1 degree increments of rotation). Four 150 ms exposures were averaged at each angle, for a total scan time of 9 minutes. Volumes were reconstructed from acquired scan data at a resolution of 94-micron per voxel side. These images (Figure 1) provided excellent resolution of the vertebral bony endplates, permitting precise disc-thickness and wedging measurements. The disc soft-tissue outline of the annulus periphery was visible but indistinct, precluding accurate non-invasive disc volumetric measurements. Disc dimensions (as evidenced by the space between vertebrae) were obtained from a mid-coronal plane section (See Figure 1). The vertebral lateral margins were identified manually, and the disc-bone interface was identified by a custom edge-detection algorithm. The average distance between edges (disc space) was calculated, and the wedge angle was found by fitting lines though the detected edges by linear regression. The angle between these lines provided a measure of disc wedging. Random errors in these measurements were associated with selection of the image plane to be evaluated, and manual identification of the vertebral lateral margins. In an empirical evaluation of measurement variability from these sources, the standard deviation of repeated measures was 8% (disc thickness) and 6% (wedge angle).

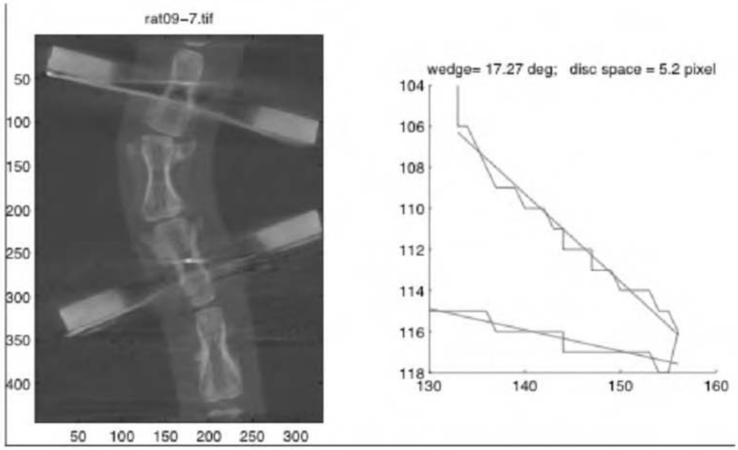

Figure 1. Left: mid-coronal section of rat tail Micro-CT scan, with edge detection of the upper instrumented disc bone-disc interface. Right: disc shape parameters derived from linear regression fit through the interface. (1 pixel=94 μm)

2.3. Mechanical tests of rat tail intervertebral disc stiffnessl

Specimens consisting of three vertebrae with the loaded two intervening discs were dissected from the tails (with loading rings still attached) and embedded in square-section end-fittings for mounting in a four-point bending jig. Two important elements of the design of this jig: were: (1) flexible pieces of shim stock engaged in grooves cut into the end fittings to create the four loading points (Figure 2, left). A fifth piece of flexible shim stock provided a 'hinge' permitting rotation of the upper loading yoke; (2) the end fittings were unbalanced relative to the outer supports, so that they provided an initial 'preload' moment that angulated the specimen in its initial position prior to the start of the test.

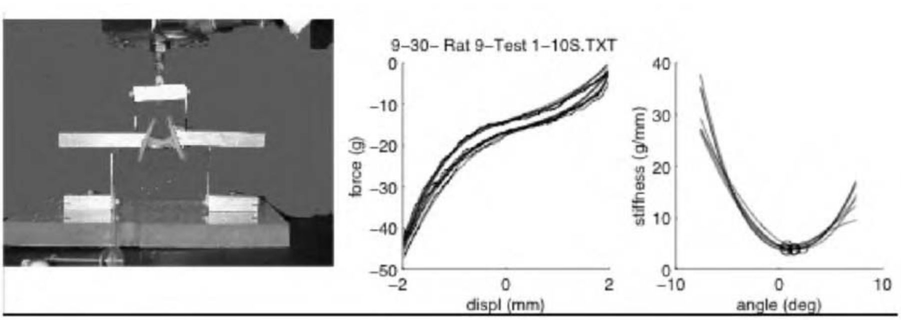

Figure 2. Mechanical stiffness testing of rat tail 3-vertebra preparation with loading rings still attached in testing jig (left), sample load-displacement data (center) and derived stiffness (right).

For testing, the jig was placed in a custom uniaxial micro-mechanical testing machine [7], operated under displacement control with five cycles of the actuator vertical displacement (saw-tooth waveform) that produced angulation or the specimen with a constant moment. Force and displacement were continuously recorded. Each of the ten loading or unloading segments of the load displacement data were fitted by a 4th-order polynomial. Each polynomial was differentiated to obtain a stiffness-angle relationship (Figure 2, right panel) which was corrected for the slightly non-linear geometrical relationship between displacement and angle, and between force and torque.

3. Results

3.1. Micro-CT

Disc wedge angle measurements (two discs per tail) were averaged by Group and Time post-instrumentation. These measurements show (1) that the disc wedge angle varied over time from the nominal 15 per disc intended value, (2) there was a steady loss of disc wedge angle after five weeks, presumably because of steadily increasing vertebral wedging (see Figure 3, left panel). Measurements of disc space (Figure 3, right panel) indicated a loss of disc space over time in these chronically compressed discs.

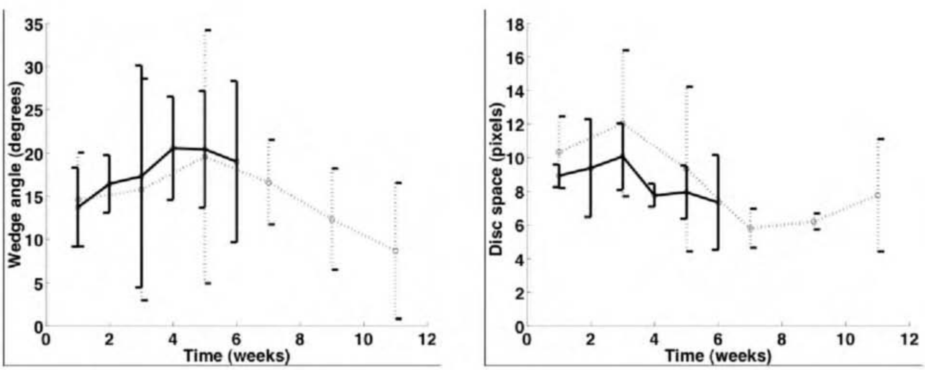

Figure 3. Mean (+/- SD) disc wedge angles (left), and disc space (right) measured from micro-CT scans, averaged for each group of 4 animals. 5-week animals (solid lines) were measured at weekly intervals; 10 week animals (broken lines) at two-weekly intervals.

3.2. Mechanical testing

The minimum stiffness was observed to occur at a distinct point in the angle-stiffness graphs, and occurred at a consistent angle over the multiple (five) loading cycles of each specimen. This minimum of stiffness (Figure 2, right panel) occurred in all tail specimens at a small positive angle, indicating that the discs were almost remodeled to their deformed state. (Acutely, the tails would have minimum stiffness when straight, *i.e.* at an angle of +30° in the stiffness-angle graphs.) There was no significant difference between the mean angle at which minimum stiffness occurred for the 2-disc animals (5-week animals 1.1° ± 0.4°; 10-week animals 1.4° ± 0.7°), indicating that the five week duration was adequate to achieve structural remodeling of the discs. In Figure 2, right panel, an angle of zero (abscissa) corresponds to the angulation of the tail during the *in vivo* experiment (nominally 30° angulation of the tail), as documented by the angle between the loading rings visible in the photograph (left panel, Figure 2).

3.3. Collagen crimp angles

Mean crimp angles were in the range 4.4 to 9.8 degrees. Paired differences averaged 1.1degrees (greater crimp angle on the concave side), but this difference was not statistically significant. Remodeling of the disc tissue was expected to equalize the concave and convex side crimp angles, with the disc fixed in the experimental state (loaded and angulated). The small, non-significant difference in this expected direction suggested that annulus tissue remodeling had occurred.

4. Discussion and conclusions

This study confirmed that the rat tail discs were substantially altered mechanically and structurally after 5 weeks. Mechanical changes were evidenced by the discs adopting a structure whose stiffness was minimum at close to the 15-degree angulated position (the minimum stiffness would normally occur at a straight tail position). Structural changes in the annulus apparently involved a remodeling of the crimped collagen fibers. These fibers have bi-refringent properties, such that alternating limbs of the zig-zag pattern appear bright under polarized light at differing angles when the microscope stage is rotated. This 'crimp angle' varies with the state of tension of the tissue [6]. The crimp angles measured here were lower than those reported for human discs [5], probably because in the present study the tissue was fixed in a loaded condition.

In this animal model, the changes were apparent after five weeks, during which time the recently weaned animals grew to close to their adult size. The changes in human adolescent discs probably occur much more slowly, and further studies are required to determine whether this rat model is an accurate representation of the mechanism of intervertebral disc wedging in the human spine with progressive scoliosis.

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A 3-D Biomechanical Skeleton Model for Posture and Movement Analysis

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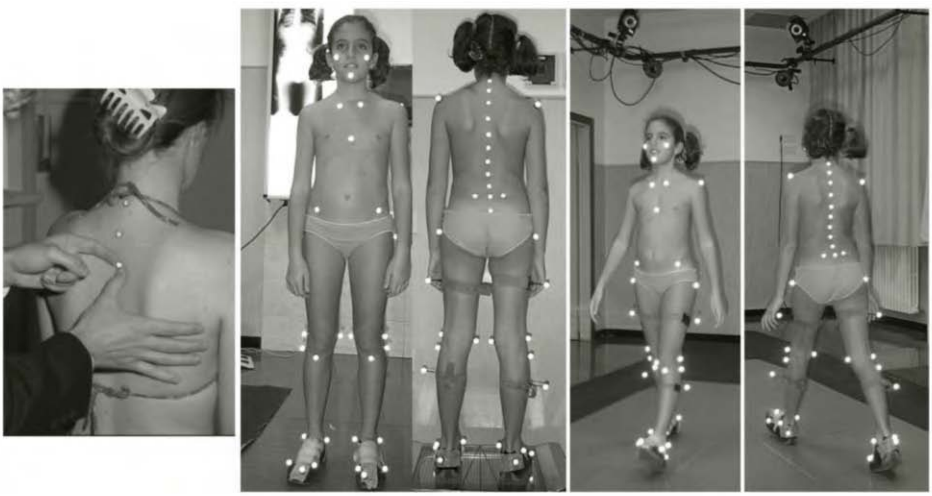
Abstract. A project to merge into a full 3D reliable and detailed human skeleton representation various segmental biomechanical models presented in literature has been undertaken by our group. The obtained 3D skeleton model is fully parametric and can so be fitted to each subject anthropometric characteristics. A non-ionizing approach based on 3D opto-electronic measurements of body landmarks labelled by passive markers has been chosen to build the 3D parametric biomechanical skeleton model. To this aim various protocols involving different body labelling (and so different related anthropometric data) have been established for different analyses. To analyse human posture and spinal related pathologies, a 27 markers protocol has been set for static analysis, while 49 markers protocol has been set for gait and movement analysis. A special focus has been devoted to identify and model the spine with a correct degree of accuracy and reliability. To this aim complex signal processing and optimisation procedures have been tested. The model is able to fully integrate information deriving from other measurements devices as force platform data, surface EMG, foot pressure maps. The presented model is the first proposed in literature, to authors knowledge, able to process such multifactorial information to perform a full kinematic and kinetic analysis with particular focus on the spine.
Several hundreds of patients have been already analysed and followed up with this methodology that proved to be useful for various posture and spine related pathologies (in particular spine deformities, low-back pain etc.).

Introduction

Spine and posture problems are topics of great interest in both biomechanical research and clinical fields. The development of eidology, i.e. of image-processing based diagnostic technologies like digital X-Ray, CAT Scan, MRI, has determined a real improvement in obtaining an ever increasing anatomical delineation of the involved structures in the evaluation of spine related pathologies. Unluckily, except for dynamic X-Ray, no one of these techniques is able to provide information about the functional state of the rachis and the related patient posture. In this case, optoelectronic measurement approach can be very useful to complete the necessary functional information. In fact the use of stereo-photogrammetry-based movement and gait analysis, and their contribution to scientific knowledge, is increasingly being reported in the literature. However its use in clinical environment requires the following three specific necessities to be satisfied: 1) To develop a detailed skeleton model with particular focus on 3D spine morphology, but at the same time keeping as low as possible the number of body landmarks to be used; 2) To extract as many as possible parameters of clinical significance strictly related to anatomical and anthropometrical subject's characteristics; 3) To represent them in an intuitive and clinical compliant fashion maintaining a biomechanical strictness but hiding the burden of complex mathematical approach. With these three goals in mind, our group started a project to transfer into a complete fully 3D reliable and detailed representation different segmental biomechanical models presented in literature. As result, a complete 3D parametric biomechanical human skeleton model has been developed (upper arms not yet included). It has been conceived in a parametric form in order to be scaled according to each subject characteristics by fitting the 3D anthropometric sizes to opto-electronic measurements. Particular care and studies have been devoted to arrange the 3D human skeleton model parameterisation. The accuracy and precision of this model relies both on anatomical findings (cadaver dissections, in vivo, X-ray and gamma ray measurements, parametric regression equations [1,2,3]) reported in literature and on the approach and signal processing procedures and optimization methods we largely described [4,5,6,7]. Given the extraordinary growth of both hardware and software tools, this highly sophisticated computing demanding task can be approached even on relatively low cost powerful PC workstations. To this aim various protocols involving different body labelling (and so different related anthropometric data) have been established for different analyses. To analyse human posture and spinal related pathologies, a 27 markers protocol has been set for static analysis [5,6]. When a more detailed description of lower limb segmental poses is necessary for both static and dynamic condition (such as for gait and movement analysis) an extension up to 49 markers protocol has been set. These models are currently used as clinical tool for diagnostic and therapeutic purposes in different clinical centres. Several hundreds of patients have been already analysed and followed up with this methodology that proved to be useful for various posture and spine related pathologies (in particular scoliosis, low-back pain etc.).

1. Methodology

A non-ionising approach based on 3D opto-electronic measurements of body landmarks labelled by passive markers has been chosen to build the 3D parametric biomechanical skeleton model. The developed model can work at different stages of complexity. That is, depending on different analysis purposes and necessities, the parametric scaling can be detailed with several accurate anthropometric measurements and the dimensions of each skeleton's component are estimated and fitted to match the subject's skeleton. To this aim various protocols involving different body labelling (and so different related anthropometric data) have been established for different analyses. To analyse human posture and spinal related pathologies (scoliosis, back pain etc.), a 27 markers protocol has been set and tested extensively in clinical environment [5,6]. The following anatomical repere points are identified: zygomatic bones, mentum, acromions, sterno-clavicular joints, xyphoid, ASIS, PSIS, knee joints, heels and spinous processes from C7 down to S3 every second vertebra. When a more detailed description of lower limb segmental poses is sought, for instance when gait trials have to be considered, the used number of markers is to be increased. A 7-link chain model of the human pelvis-lower limbs apparatus was developed, with the pelvis, thigh, shank and foot links joined by ball and socket joints representing the hips, the knees and the ankles respectively. At least three markers per each segment have been used, in particular: **Pelvis:** as above described, by using ASIS and PSIS bony landmarks; **Femur:** Great Trocanter middle thigh and Lateral and Medial Femural epicondyles; **Shank:** Head of Fibula, middle shank, Lateral and Medial malleoli; **Foot:** Heel (calcaneous process), 1st and 5th Metatarsal heads, distal big toe end point. Indirect measurements such as joint centres positions are derived from external markers (for instance, hip joints centres are derived from ASIS and PSIS positions and related pelvis dimension, model and regression function [2,3]). The knee joint centre is taken as the mid-point of the segment linking the femur medial and lateral epicondyles, and the ankle joint centre as the mid-point of the segment joining the two malleoli. In this way the full protocol includes 49 markers (fig. 1). Such a protocol is the best trade-off result among three different challenging needs: the proper identification of each segment pose; the necessity to limit the number of used markers; the requirements of marker clusters configurations suitable to apply optimization procedure in order to minimise the problems of soft tissue artefacts and marker misplacement that strongly affect 3D strereo-photogrammetric reconstructions of the musculo-skeletal system and the calculation of its kinematics and kinetics via a markers-based multi-link model. [7,8]. Our experimental recordings are based on the VICON-Mx[1] opto-electronic system (fig. 1); anyway this methodology is a very general one and it can be indifferently applied to any stereo-photogrammetric recording system, provided that this latter would be able to supply all the required landmarks three-dimensional co-ordinates. In addition force platform data, foot pressure maps and surface EMG recordings can be jointly synchronously measured when a full detailed (named also multifactorial) analysis is sought.



Figs.: 1a) Passive markers positioning. 1b) Full protocol set-up for Posture and Gait analysis;

In such a way 3D posture taking into account head, trunk, pelvis and legs postural attitude (upper limbs and ribs are not considered), as well as 3D spine shape at each metameric level can be computed and represented. Also pelvis orientation and scaling and eventual helicoidal deformation can be evaluated from ASIS and PSIS positions. The standard trial session is aimed to completely define subject posture both in

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orthostatic and in simple an complex dynamic conditions. Each static postural attitude is considered correctly recorded when at least 5, one second lasting, acquisitions are performed. Given the 100Hz opto-electronic device data acquisition rate, this means that a minimum of 500 measurements are averaged per each static postural stance [5,6]. Before averaging, an amount of pre-processing is needed on the acquired 3D raw data in order to comply clinical analysis requirements. Namely, the frontal plane of the subject is chosen, in each frame, as the plane containing the PSIS and parallel to the vertical axis, while his sagittal plane is the one orthogonal to this latter and parallel to the vertical axis (SRS recommendations [9]). For all the following computations (averaging, clinical parameters extraction both in static and dynamic conditions, etc.) the measurements are re-aligned in the so defined subject's local co-ordinate system.

From the 3D reconstruction all the 2D clinical parameters claimed for the correct description and biomechanical characterisation of spinal pathology, related to those usually calculated on the radiographic image, are derived (i.e. Cobb and Kypho-Lordotic angles). Moreover, a set of significant biomechanical variables describing the three-dimensional nature of body posture are obtained, such as frontal and sagittal spinal offsets of each marked metamere with respect to the vertical axis passing by S3, frontal and sagittal global offsets of each labelled landmark with respect to the vertical axis passing through the middle point between heels, pelvis frontal and sagittal inclinations, shoulder-to-pelvis, pelvis-to-heels and shoulder-to-heels horizontal rotations, joint forces, joint torques and several more. When the 49 markers set is used the measurements are complemented by the pose of each lower limb chain segment enlightening joint adaptations, anomalies and/or weakness. Our studies as well as our clinical experience led us to identify a set of static attitudes (such as indifferent orthostasis with and/or without an under-foot wedge, self-corrected manoeuvres, ante-retroversion static postural exercises, sitting posture), that can provide a complete documentation of subject postural, balancing and morphological characteristics. Moreover also gait has been included together with the possibility to extract the averaged gait cycle characteristics. The mathematical details of optimization procedure as well as average gait cycle computation are beyond the limits of this paper [10]. Briefly after the proper identification of each valid stride a time normalization of each considered numerical variable is performed before the averaging step. The final outcome is the mean gait cycle in which the average time course and associated standard deviation is defined per each variable of interest. Two main advantages can be enumerated with the possibility to extract the mean characteristics of both static posture or cyclic motor task (gait): first it allows to overcome the single measurements analysis limits by taking into account the ensemble behaviour improving the statistical reliability of the evaluation; second it permits to obtain information about the repeatability and variability of the performed motor task, thus enlightening the subject's motor control capability. Comparisons taking into account spine morphology have been performed between X-Ray films and opto-electronic processed outcomes to assess the clinical significance of the developed algorithms [11] For the graphical representation as well as clinical parameter visualisation and enlightening, a software package based on 3D graphic modelling has been developed.

2. Results and Discussion

With the described methodology several studies have been carried out about spine and posture disorders [12,13]. Given the length limit of this paper only two paradigmatic examples will be illustrated to fully describe the capability of the approach to produce clinically significant outcomes.

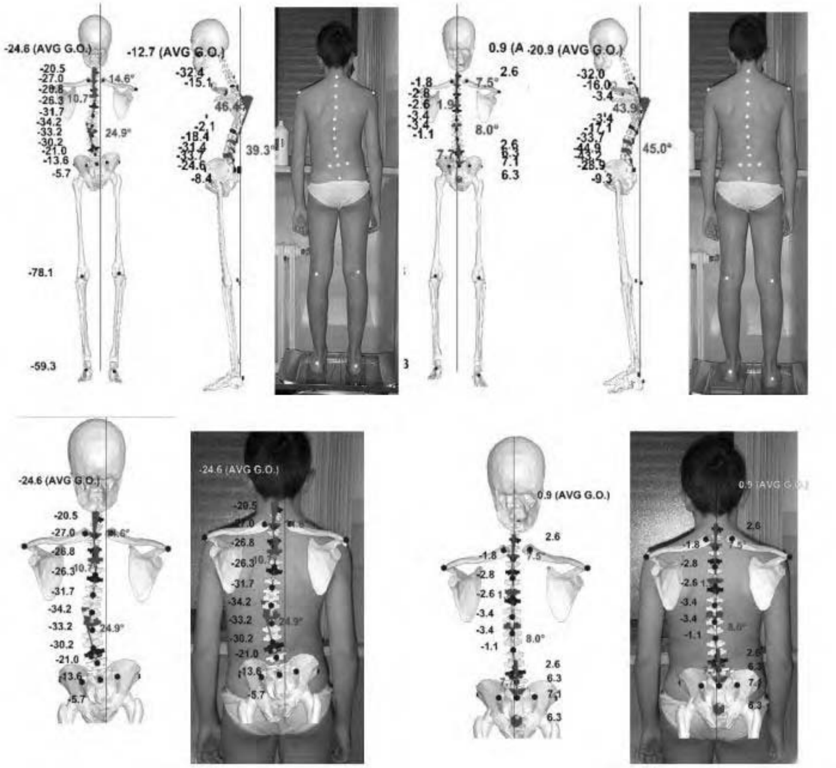

Fig. 2a,b) 3D skeleton representation (frontal and sagittal view) indifferent orthostasis (left panels) compared to corrected orthostasis by the application of a 18mm left underfoot wedge (right panel)

In fig. 2 the averaged posture a scoliotic subject is presented both in indifferent orthostasis and in corrected orthostasis using an underfoot wedge. It is evident how the 3D skeleton reconstruction and report allows the clinician to fully and easily evaluate the postural behaviour and the level of spinal deformity of the analyzed subject. In particular the patient's global and trunk unbalancing as well as his pelvic obliquity associate to leg length discrepancy, with the right leg being longer one.

The peculiarity of the approach is related to its non-ionising nature and its fast response capability. Within a couple of minutes the clinician is allowed to ask the patient to perform various postural tasks and to quantitatively compare the results getting immediate information about patient's posture function and feedbacks on applied corrections. In this case there had been the possibility to apply a series of underfoot wedges of different thicknesses and to determine as the optimal the one which lead to the best posture correction (fig.2b). Fig 3a,b,c,d show an example of the proposed approach when the 49 markers full protocol is applied and mean gait cycle extraction is performed. An analogous case of scoliosis associated to pelvic obliquity has been chosen to show how the approach works when multifactorial analysis is performed. In orthostatic condition beyond the postural differences as described above also disparities in joints loads can be evaluated and comparison can be performed in different conditions (also in this case indifferent orthostasis is compared to wedge orthostasis 23mm right). When gait analysis is performed, mean gait cycle allows to transfer the comparison applied in static condition to a dynamic performance enlightening the different motor task behaviour and repeatability.

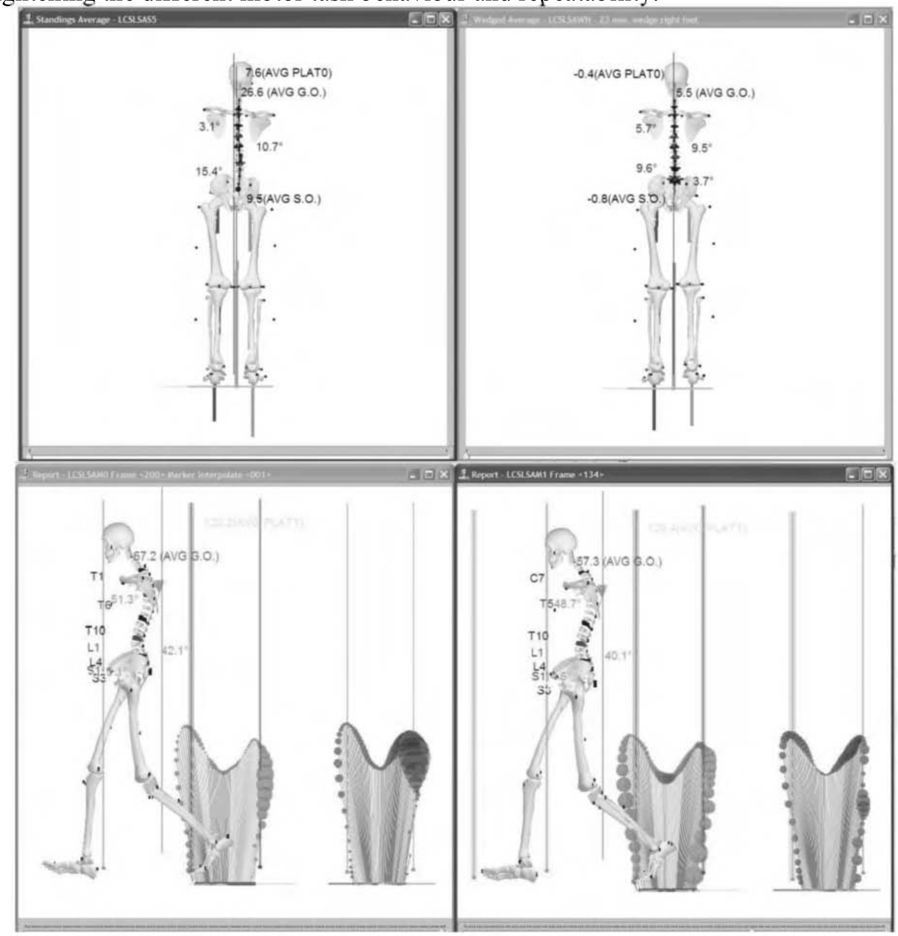

Fig. 3a,b,c,d): Upper panels 3D skeleton representation and joint forces, indifferent orthostasis (left) vs corrected orthostasis by the application of a 23mm right underfoot wedge (right). Lower panels: comparison of the two mean gait cycles corresponding to the previous orthostatic conditions

3. Conclusions

The easy clinical approach of this procedure suggests its use in routinely clinical evaluation for the study of Posture. Several hundreds of patients have been already analysed with this methodology and followed up in our L.A.M.P.O. biomechanics lab as well as in different centres. It proved to be useful for various posture and spine related pathologies. The developed 3D human skeleton model and software package can be used as stable, accurate, reliable and fast tools for the quantitative identification of human body biomechanical characteristics, along with for the understanding of spine posture and gait (movement) related pathologies as well as a guideline to formulate a diagnosis and a therapy plan. A further peculiarity is related to the capability of the developed approach to allow the extraction of the averaged behaviour both for static attitude as well as cyclic motor tasks as gait. In this way the final evaluation of the clinical status of the patient relies on several hundreds of 3D measurements. Such a circumstance improves the statistical reliability of the evaluation allowing to overcome the single measurements analysis limits and permitting to obtain information about the repeatability and variability of the performed motor task. This feature yield the possibility to make robust statistical comparisons both intra-individual and inter-individual to monitor the results of therapy along time and/or the evolution of the pathology. Finally it proved to be a kind of analysis really well accepted both by clinicians and by patients.

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Comparison of Sacropelvic Morphology between Normal Adolescents and Subjects with Adolescent Idiopathic Scoliosis

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Abstract. Previous studies suggest that the pelvic morphology may be abnormal in adolescent idiopathic scoliosis. This study compares the sacropelvic morphology between normal adolescents and subjects with adolescent idiopathic scoliosis (AIS) in both sagittal and coronal planes. The sacropelvic morphology was assessed from the postero-anterior and lateral standing radiographs of 27 normal adolescents and 29 subjects with AIS presenting a major Cobb angle greater than 30°. Sacropelvic morphology was characterized by 19 parameters in the sagittal plane and 26 parameters in the coronal plane. There was no difference in sacropelvic morphology between the two groups in the sagittal plane. In the coronal plane, significant differences were found for right pelvic length, right iliac height, left and right pubic length, left obturator foramen width, bicristal distance, bituberal distance, biacetabular distance, pubic symphysis width, pelvic inlet, and subpubic angle. There was no significant pelvic asymmetry in AIS subjects. This is the first study that specifically evaluates the sagittal and coronal sacropelvic morphology in AIS. The results suggest that the coronal sacropelvic morphology is distorted in AIS. A longitudinal study is required in order to evaluate the influence of sacropelvic morphology in the progression of AIS.

Keywords. Adolescent idiopathic scoliosis, pelvis, sacropelvic morphology

Introduction

Previous studies have demonstrated that there is a significant relationship between sacropelvic morphology and spinal geometry in the sagittal plane in normal subjects [1-10], as well as in subjects with spinal disorders [2,11-19]. Nicolopoulos et al. [20] suggested an abnormal pelvic height as a possible pathogenetic factor in adolescent idiopathic scoliosis (AIS). In that study, they calculated the pelvic height of AIS girls and controls from three measurements: standing height, sitting height and total leg length. The pelvic height was significantly greater in AIS girls, even when these girls were matched with normal girls of similar standing height. They assumed that AIS was associated with abnormal pelvic growth but never did any radiographic study of the pelvis in order to verify their assumption. Legaye et al. [16] investigated the pelvic incidence in normal and scoliotic adults and observed a similar pelvic incidence in both groups. However, they did not specify if the scoliotic patients had either AIS of the adult or *de novo* degenerative scoliosis. Lecoq et al. [15] assessed pelvic incidence in 100 patients of which 67 had idiopathic scoliosis. Their cohort also included patients with congenital scoliosis, hyperkyphosis, isthmic spondylolisthesis, spondylodiscitis and back pain. Since they did not group their patients according to the diagnosis, no definite conclusion can be drawn from their data. Our research group evaluated the sagittal spinopelvic profile of 160 patients with AIS [17]. We found that the lumbar lordosis was significantly related to the pelvic incidence and that the curve pattern was not associated with a specific pattern of sacropelvic geometry in the sagittal plane. The most striking result in our study was that the pelvic incidence in AIS patients (mean: 57.3°) was significantly higher than that reported for normal adolescents of similar age (49.3°) [6].

Although previous studies suggest that the sacropelvic morphology is abnormal in AIS, these studies are based on a limited number of parameters in the sagittal plane that do not take into account the morphology of the whole sacropelvis in both sagittal and coronal planes. Therefore, the objectives of this study are to: 1) introduce parameters that characterize the complete sacropelvis in both sagittal and coronal planes, and 2) compare the sacropelvic morphology between normal adolescents and subjects with AIS.

1. Materials and Methods

The medical and radiological files of all patients seen for the first time at the scoliosis clinic between July 1st 2002 and January 31st 2005 were reviewed. Subjects were included in the study if they had: 1) postero-anterior (PA) and lateral (LAT) standing radiographs of the spine and pelvis showing the complete sacropelvis, 2) a coronal Cobb angle less than 10 degrees (normal group) or greater than 30 degrees (AIS group), and 3) an age between 10 and 18 years. All subjects with a history or clinical signs of hip, pelvic or lower limb disorder, as well as those with previous spine surgery were excluded. There were 27 normal adolescents (normal group) and 29 subjects with AIS (AIS group) included in the study. There were 10 boys and 17 girls in the normal group, while there were 5 boys and 24 girls in the AIS group. The mean age was 13.1±2.0 years and 14.2±1.6 years in the normal and AIS groups, respectively. The mean coronal Cobb angle of the primary curve in the AIS group was 45±12° (range: 30°-73°).

Standing PA and LAT radiographs of the spine and pelvis were analyzed using a software developed by the LIO (Laboratoire de recherché en Imagerie et Orthopédie, École de Technologie Supérieure, Montréal, Canada). Using this software, 26 anatomical landmarks on the PA radiograph (**Figure 1**) and 13 anatomical landmarks on the LAT radiograph (**Figure 2**) were identified for each subject. Based on these anatomical landmarks, 26 coronal (**Figure 3**) and 19 sagittal (**Figure 4**) parameters of the pelvis are computed automatically. These parameters were used to characterize the complete pelvic morphology for each subject. In addition, an asymmetry index was calculated for all parameters measured on the right and left sides of the pelvis from the PA radiograph (asymmetry index = left side minus right side values). Linear parameters were expressed as a percentage of the mean femoral heads diameter. Comparisons between the normal and AIS groups were made using bilateral Student t tests with a level of significance set at 0.05.

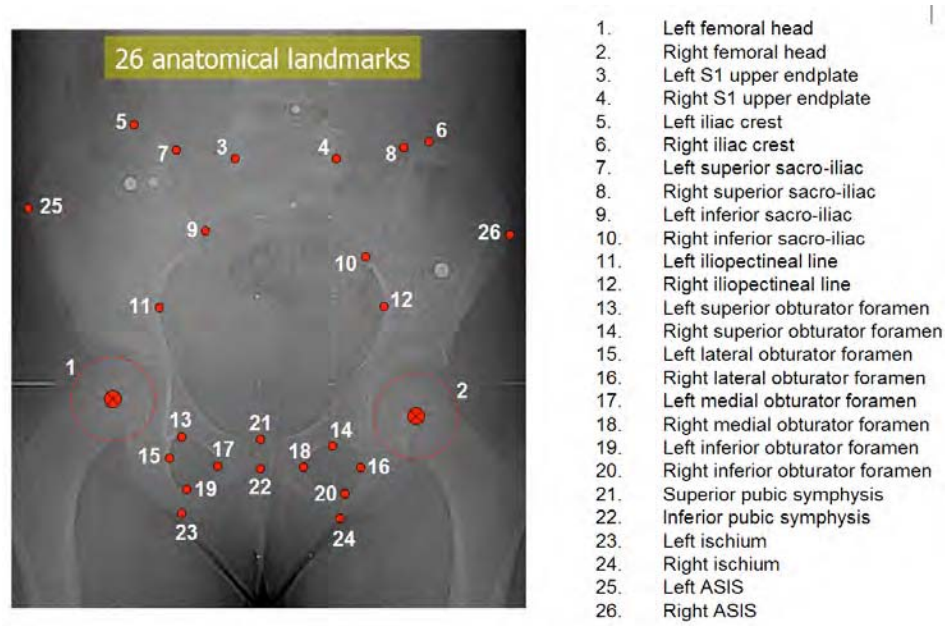

Figure 1 – Anatomical landmarks digitized on the PA radiograph

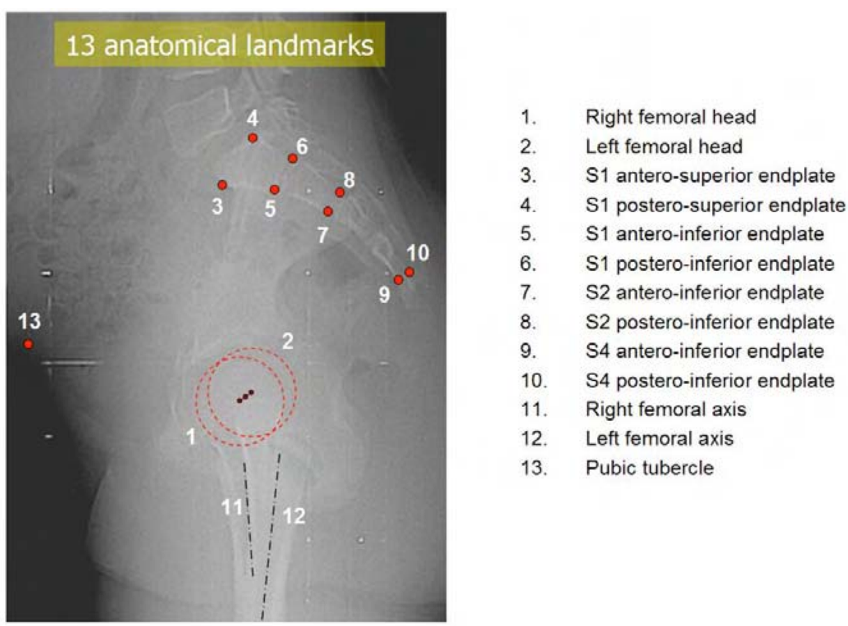

Figure 2 – Anatomical landmarks digitized on the LAT radiograph

Pelvic index	Description
Pelvic length†	Distance from most inferior point of ischial tuberosity to most superior point on iliac crest
Pelvic height†	Vertical distance from most inferior point of ischial tuberosity to most superior point on iliac crest
Iliac height†	Vertical distance from hip center to most superior point on iliac crest
Sacro-iliac height†	Distance from most superior to most inferior point on sacro-iliac joint
Symphysis height	Distance from most superior to most inferior point on pubic symphysis
Obturator foramen height†	Maximal supero-inferior dimension of obturator foramen
Obturator foramen width†	Maximal medio-lateral dimension of obturator foramen
Pelvic inlet	Maximal horizontal width of pelvic inlet
Bicristal distance	Distance between anterior superior iliac spines
Bituberal distance	Distance between ischial tuberosities
Biacetabular distance	Distance between both hip centers
Symphysis width	Distance between most medial points on anterior margins of foramen obturator
Pubic length†	Distance from pubic symphysis to hip center
Ischial length†	Distance from ischial tuberosity to hip center
Sacral width	Maximal transverse width of sacrum
Subpubic angle	Angle between inferior borders of pubis
Femoral head diameter†	Femoral head diameter

† These parameters are measured separately for the right and left sides of the pelvis.

Figure 3 – Coronal parameters of the sacropelvis

Pelvic index	Description
Pelvisacral angle	Angle between upper sacral plate and line joining center of the upper sacral plate to hip axis
Pelvic incidence	Angle between perpendicular to upper sacral plate and line joining center of sacral plate to hip axis
Pelvic lordosis angle	Angle between upper sacral plate and line joining hip axis to posterosuperior corner of S1
Sacro-iliac inclination	Angle between posterior border of S1 and line joining center of sacral plate to hip axis
Sacral table angle	Angle between upper sacral plate and posterior border of S1
Sacral angle	Angle between line joining midpoint of anterior border of S1 and S2 and perpendicular to upper sacral plate
S1 superior angle	Angle between perpendicular to upper sacral plate and line joining midpoint of superior and inferior endplates of S1
S2 inferior angle	Angle between perpendicular to inferior endplate of S2 and line joining midpoint of superior and inferior endplates of S1
Sacral kyphosis (Cobb)	Angle between superior endplate of S1 and inferior endplate of S4
Sacral kyphosis (Ferguson)	Angle between line joining midpoint of superior and inferior borders of S1 and line joining midpoint of inferior borders of S2 and S4
Sacral height	Distance from S1 to S4
Pelvic radius	Distance from hip axis to posterosuperior corner of S1
Pelvic thickness	Distance from hip axis to center of upper sacral plate
Pubo-femoral distance	Distance from pubic symphysis to hip axis
Lateral pelvic inlet	Distance from pubic symphysis to anterior border of upper sacral plate
Sacro-femoral angle†	Angle between upper sacral plate and proximal femoral shaft axis
Femoral head diameter†	Femoral head diameter

† These parameters are measured separately for the right and left sides of the pelvis

Figure 4 – Sagittal parameters of the sacropelvis

2. Results

There was no significant difference in sacropelvic morphology between the two groups in the sagittal plane. Although the pelvic incidence was higher in the AIS group (56.3±11.7° vs. 51.2±14.3°), the difference was not significant (p = 0.14).

Measurement group	Significantly different parameter	P
Height measurements	Right pelvic length	0.045
Height measurements	Right iliac height	0.014
Width measurements	Left pubic length	$<10^{-3}$
Width measurements	Right pubic length	0.010
Width measurements	Left obturator foramen width	0.007
Width measurements	Bicristal distance	0.006
Width measurements	Bituberal distance	0.005
Width measurements	Biacetabular distance	0.001
Width measurements	Pubic symphysis width	0.003
Width measurements	Pelvic inlet	$<10^{-3}$
	Subpubic angle	0.041

Figure 5 – Significant differences in coronal parameters of the sacropelvis

In the coronal plane, significantly increased values were found in the AIS group for 11 parameters (**Figure 5**). There was no significant difference found for the asymmetry assessment (11 asymmetry indices).

3. Discussion

This is the first study to specifically compare the complete sacropelvic morphology between AIS subjects and normal adolescents. The sacropelvic morphology was characterized using 45 parameters (26 coronal, 19 sagittal) of the sacropelvis that can be measured from the PA and LAT radiographs. In addition, these parameters allow for the calculation of asymmetry indices that compares the right and left sides of the sacropelvis.

Significant differences between AIS subjects and controls were found for coronal parameters involving the pelvic height and width (**Figure 5**), while there was no significant asymmetry in the coronal plane. Surprisingly, there was no significant difference in sagittal sacropelvic parameters, although previous data [6,17] suggested that there was an increased pelvic incidence in AIS. It is possible that the absence of significant difference in sagittal parameters be due to the limited number of subjects involved in the current study and a corresponding low statistical power. Accordingly, the statistical power obtained from the comparison of the pelvic incidence was only 0.24, while the mean pelvic incidence was 5° higher in the AIS group. An increased number of subjects is therefore needed in order to draw definite conclusions regarding the sacropelvic morphology in AIS.

The presence of significant differences in sacropelvic morphology raises two hypotheses. The increased values of height and width parameters in the AIS group may be related to the altered growth rate (maturation) reported in AIS [21-22]. Alternatively, the abnormal sacropelvic morphology may be due to an altered sacropelvic formation/development, which could be in association with the process involved in the progression of the spinal deformity. A longitudinal study with subjects presenting non-progressive and progressive AIS is required in order to evaluate the influence of sacropelvic morphology in the progression of AIS.

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Can Posture Analysis Point Towards Curve Progression in Scoliotic Subjects?

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Abstract: Previous research employing biomechanical measurement has demonstrated asymmetries in kinematics and kinetics. Similar asymmetries have been reported from anthropometric studies. These findings suggest that asymmetry may play an important aetiological role in adolescent idiopathic scoliosis (AIS). The present study is a part of a wider comprehensive investigation aimed at identifying asymmetries in lower limb kinematics and pelvic and back movements during level walking in a sample of scoliotic subjects. Such asymmetries may be related to the spinal deformity. While previous studies indicate that force platform measurements provide a good estimation of the static balance of individuals, there remains a paucity of information on dynamic balance during walking. There is published evidence on the use of Centre of Pressure (CoP) and net joint moments in gait assessment. Although these investigations have assessed Centre of Mass (CoM)–CoP distance relationships in clinical conditions, there is a paucity of data relating to the moments about CoM. An objective of the present study was to assess and establish the asymmetry in the CoP pattern and moments about CoM during level walking and its relationship to spinal deformity. Results indicate differences across the subjects depending on the laterality of the major curve. Furthermore, the results indicate that the variables identified in this study could be applied to initial screening and surgical evaluation of scoliosis and other spinal deformities. Further studies are being undertaken to validate these findings.

Keywords: Ground reaction force, scoliosis, centre of pressure, moments, spine

Introduction

Bipedal locomotion creates a major challenge to our balance control system both in walking and running and it is entirely different to the task of maintaining balance during standing. *Posture*, an angular measure from the vertical, is defined as the description of the orientation of any body segment relative to the gravitational vector (line of action of the ground reaction force) and *balance* describes the dynamics of body posture to prevent falling. During the major part of normal walking, an individual's body weight is supported by one limb (stance phase) and this part of gait demonstrates several capabilities such as muscular coordination, balance, strength and joint kinematics [1]. Hence impairment to effective propulsion and balance can be identified by examining this phase. While Centre of Mass (CoM) is a point equivalent of the total body mass in the global reference system, Centre of pressure (CoP) is the point of location of the vertical ground reaction force vector [2]. When both feet are in contact with the ground, the location of CoP under each foot reflects the neural control of the ankle muscles. CoP moves to the anterior with the increased activity of the plantar flexors and it moves laterally with the increase in invertor muscles activity [2]. Although previous investigations indicate that force platforms provide good measurements to calculate the static balance of individuals [3], there is a paucity of information on the dynamic balance during walking. More recently, MacWilliams et al. [4] attempted to document the foot kinematics and kinetics during adolescent gait concentrating on foot joint angles, moment and power using normal subjects Another study investigating the CoP and its relationship to foot pathology, indicated how CoP coordinates can be used to calculate the moments about the joint axis of the foot [5]. More recently, Sloss [6] while studying the effect of foot orthoses on the ground reaction forces indicated the usefulness of the estimation of CoP deviation during walking and showed a difference of approximately 1 cm at both heel strike and push off peaks. While a previous study investigated the asymmetries in kinetic gait parameters in scoliotic subjects [7], one of the purposes of this study is to determine whether or not it is possible to detect changes in the gait cycle in patients with abnormal spinal curvature using centre of pressure pattern.

While comparing various methods of human CoM measurement, Lafond et al. [8] demonstrated the relationship between CoP and CoM. Furthermore, the variable CoP-CoM is reported as the error of the postural control system which provides an important insight into the postural control mechanism. While the position CoM can be estimated through various methods [9,10], it is commonly accepted to be around the S2 vertebra. Studies have indicated that in a static condition the direction of ground reaction force (GRF) vector should point to the location of CoM which in turn projects the CoP. However, in dynamic tasks, since the rate of change of momentum should equal the moment generated by the GRF, the direction of GRF vector points away from CoM. This contrary action helps in achieving balance in dynamic conditions [11]. Although, studies have looked at CoM –CoP distance relationships in clinical conditions [11], there is a paucity of information relating to the moments about CoM. Nault et al. [13], while investigating the relationship between standing stability and body posture parameters in AIS using CoP and CoM, indicated that the scoliotic subjects had a decrease in standing stability indicating greater neuromuscular demand. In a simulated gait experiment, Gefen et al. [13] indicated that the medio lateral stability of the foot was characterised by the medio lateral deviations of the centre of pressure. Significant distortions of the normal pattern of CoP can give evidence of abnormal loads on the foot and of problems in the correct progression of the gait [14]. Therefore as scoliosis affects the physical orientation of various body segments [15], the primary aim of this study was to examine the changes in CoP pattern. Since scoliosis is a deviation from normal curvature, it should be indicated in the CoP pattern. In addition, this investigation will aim to estimate the moments about the CoM and its asymmetries during left and right stance during normal walking.

Method

The present study employed a strain gauge force platform sized 464 x 508 mm (AMTI, MA, USA) to estimate the medio-lateral and anterior-posterior deviations of COP. Kinematic data was collected simultaneously using a six camera motion analysis system along with APAS and APAS Gait (Ariel Dynamics Inc. USA) software to digitise and analyse the data. Nine Adolescent Idiopathic Scoliosis subjects (8 females and 1 male) with an average age of 15.33 (SD 2.54) yrs, mass of 50.22 (SD 4.9) kg and average height of 155.55 (SD 8.3) cm) scheduled for surgery within 2-3 days after data collection, took part in this study. Demographic information including the curve level, amplitude (average Cobb angle 61 (SD 11.68) degrees) and the laterality was recorded as given in table 1. Ethical approval was received from the appropriate local ethics committees. All subjects were supplied with a written explanation of the study and gave a written consent. Subjects were assessed by an experienced clinician for anthropometric measurements. .In order to avoid errors during low vertical forces, the maximum and minimum CoP deviations were estimated for 90 percent of the gait cycle ignoring the first and the last five percent of stance phase. The cameras were calibrated using a standard 1 m^3 aluminium cube with 12 markers and they were synchronised using a light emitting diode (LED) device. Markers were placed on various landmarks including the vertebral prominence of S2. The same researcher positioned the markers every time to avoid inter observer errors and data was collected. The information from S2 marker was used to estimate the moments about CoM as indicated by the following equation:

M = Fx (Perpendicular distance (Z) between CoP and CoM) + Fz (Perpendicular distance (X) between CoP and CoM)

Each participant was then given time to become familiarised with the lab environment and was allowed a number of walking trials prior to data collection. Subjects performed three trials for each foot at the participant's normal walking speed. A valid trial consisted of the participant striking their heel on the force platform without altering their normal gait. The asymmetry (as indicated by symmetry index - SI) was estimated using previously described procedures [16].

Results and Discussion

Table 1 provides demographic information of the subjects.
Table 2 provides the maximum deviations of CoP in the medio-lateral direction and anterio-posterior direction, along with the symmetry index. Results indicate a relationship between the medio lateral direction CoP and the laterality of both the main and compensation curves. This is not evident in the anterior-posterior direction. As shown in the table, a negative SI value indicates deviation to the right.
Table 3 illustrates the moments about CoM (S2 vertebral prominence).

Table 1 Demographic information of the subjects

Subject No.	Age	Height(cm)	Weight(kg)	Cobb Angle (erect) (Degrees)	Cobb Level	Side	Compensation
1	19	177	54	60	T4 –T11	R	Yes, Left Lumbar
2	17	160	56	62	T8 - L2	R	No
3	13	149	49	60	T6 - T12	R	Yes, Min Left Lumbar
4	11	150	40	47	T11 - L3	L	Yes, Min Right thoracic
5	16	159	51	55	T10 - L2	R	No
6	18	155	54	50	T5 –T12	R	Yes, Min Left Lumbar
7	16	155	45	57	T5-T11	R	Yes, Major Left Lumbar
8	14	163	52	85	T6 - T12	R	Yes, Left Lumbar
9	14	159	51	73	T5 - T10	R	Yes, Left Lumbar

Table 2 Maximum deviations of CoP in the medio-lateral direction and anterio-posterior direction

Subject No.	Left Medio-Lateral (X) m	Left Anterio-posterior(Y) m	Right Medio-Lateral (X) m	Right Anterio-posterior(Y) m	SI X m	SI Y m
1	0.016	0.175	0.027	0.172	-53.270	2.057
2	0.015	0.178	0.032	0.165	-70.915	7.712
3	0.034	0.167	0.039	0.160	-14.699	3.984
4	0.020	0.173	0.023	0.173	-12.707	-0.174
5	0.013	0.162	0.017	0.173	-30.490	-6.460
6	0.005	0.132	0.069	0.156	-171.398	-16.289
7	0.027	0.164	0.003	0.167	162.093	-1.993
8	0.023	0.198	0.025	0.201	-7.222	-1.526
9	0.030	0.206	0.035	0.203	-18.058	1.453

Table 3 Moments about CoM (Normalised as % Height*Body mass)

Subject No.	Left Stance Max	Left Stance Min	Right Stance Max	Right Stance Min	SI Max	SI Min
1	5.054	-0.525	5.544	0.008	-9.248	205.815
2	1.090	-1.828	3.259	-0.111	-99.731	177.002
3	0.007	-5.723	1.098	-3.958	-197.579	36.462
4	1.851	-2.461	2.029	-1.478	-9.172	49.927
5	2.369	-1.484	2.600	-0.368	-9.276	120.430
6	1.229	-1.969	1.439	-3.015	-15.741	-41.993
7	3.630	-1.027	1.190	-2.832	101.223	-93.509
8	0.718	-3.928	4.121	-1.402	-140.632	94.792
9	0.549	-4.263	2.934	-0.867	-136.942	132.388

While reported symmetry indices did not exceed the range reported in previous studies [16], there are marked differences between the left and right sides. A previous study indicated that the subjects with a left compensation curve had a greater SI for a left side impulse and subjects with very little or no compensation had a greater right side impulse [7]. This is reflected in the results of CoP deviation reported in the present study amd found for most subjects. Although previous studies indicate lower symmetry for medio-lateral force component [16] and the estimation of CoP deviation takes these values into consideration, results do indicate clear differences. Furthermore as indicated by Chockalingam et al. [17] there might be errors due to low vertical forces during the initial contact and push off phases during gait. However, the results in this study consider only the maximum deviation, which occurs during higher vertical forces. As indicated in previous investigations to achieve balance, the GRF vector points away from the CoM [10] and this is directly reflected in the estimated moments. Higher moment indicates higher deviation from normal to achieve balance during gait. However, due to wide differences in curve magnitude and compensation, this study has not established a clear relationship between estimated moments and curve properties. Further longitudinal studies are warranted. Since, scoliosis is defined as a lateral deviation from the normal frontal axis of the body [18] , centre of pressure is an appropriate measure of the effect of scoliosis. Scoliosis subjects appear to modify their gait in order to compensate for the spinal curvature. As gait is described as an activity that permits an individual to move from position A to position B while maintaining the body in a generally upright and stable posture [19], it is necessary to assess the gait of subjects to detect abnormalities. Furthermore, gait analysis technologies could be applied to the longitudinal study of children allowing an opportunity for research into the effectiveness of footwear modification designed to alleviate any imbalance during walking. As results indicate a clear difference between the medio-lateral CoP deviation between left and right sides, it can be concluded that this is due to the deviation from normal spinal curvature. However, more in depth longitudinal investigation with varying curve types and magnitudes are required to substantiate this claim.

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Validity and Reliability of Active Shape Models for the Estimation of Cobb Angles in Adolescent Idiopathic Scoliosis

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Abstract. Choosing the most suitable treatment for scoliosis relies heavily on accurate and reproducible Cobb angle measurement from successive radiographs. The objective is to reduce variability of Cobb angle measurement by reducing user intervention and bias. Custom software to automate Cobb angle measurement from posteroanterior radiographs was developed using active shape models. Validity and reliability of the automated system against a manual and semi-automated measurement method was conducted by two examiners each performing measurements on 3 occasions from a test set (N=22). A training set (N=47) of radiographs representative of curves seen in a scoliosis clinic was used to train the software to recognize vertebrae from T4 to L4. Images with a maximum Cobb angle between 20° and 50°, excluding surgical cases, were selected for training and test sets. Automated Cobb angles were calculated using best-fit slopes of the detected vertebrae endplates. Intra-class correlation coefficient (ICC) and standard error of measurement (SEM) showed high intra-examiner (ICC > 0.90, SEM 2-3°) and inter-examiner (ICC > 0.82, SEM 2-4°), but poor inter-method reliability (ICC=0.30, SEM 8-9°). The automated method underestimated large curves. The reliability improved (ICC = 0.70, SEM 4-5°) with exclusion of the 4 largest curves (>40°) in the test set. The automated method was reliable for moderate sized curves, but did not properly detect vertebrae in larger curves. Optimization of constraints on scaling, rotation, translation, and iteration may improve reliability with larger curves.

Keywords. Active Shape Models, Cobb angle, scoliosis, measurement reliability

1. Introduction

The Cobb angle can only represent the scoliotic deformity in a single plane, whereas scoliosis is truly a three-dimensional (3D) deformity. In spite of the Cobb angle being limited in describing the 3D nature of scoliosis, it remains the most commonly used method for monitoring scoliotic curves as 3D parameters have not yet been developed that are widely accepted. A variety of individuals (physicians, clinicians, medical students) with different skills and experience measure Cobb angles. Creating an automated method for angle measurement will help reduce intra- and inter-examiner error. Reduced error ultimately leads to better assessment of the patient's need for treatment and allows for improved determination of whether the curve has actually changed over time.

Intra- and inter-examiner measurements have been reported to vary between 3-10° when manually determining the Cobb angle from posteroanterior (PA) radiographs[1-3]. This range is critical to the assessment of curve progression, since a true increase in curvature of ≥5° over a six month period usually warrants further attention. A custom software package was developed to detect vertebrae and calculate the largest curve from PA radiographs with minimal user intervention. To confirm its validity, the automated method was compared to a semi-automated method and the standard manual method. The hypothesis was that the error would be reduced in measuring the severity of the scoliosis by automating the Cobb angle measurement, limiting the amount of error attributed within and between examiners. Individuals then may calculate the Cobb angle with approximately the same amount of validity and reliability, regardless of their skill level or previous experience.

2. Objective

The study goal was to develop a program to allow for a more automated measurement of Cobb angle, and then to test its validity and reliability against both a semi-automated and manual Cobb angle measurement.

3. Methods

Developing and testing the automated measurement of Cobb angles from spine radiographs was achieved in two stages. The first stage used a training set of radiographs to teach the program to recognize vertebrae shape and subsequently calculate superior and inferior endplate slopes. Training was based on the active shape models (ASM) algorithm described by Cootes and Lindley [4-7]. The second stage consisted of estimating and comparing the intra-examiner, inter-examiner, and inter-method reliability of the automated, manual and semi-automated methods.

Active Shape Models were used to detect specific vertebrae. ASM are trained only in the detection and recognition of a specific target object. Since they are only familiar with the variation provided in the training set, ASM will only generate shapes similar to the training set**.** Training creates two models, the object shape model and the object appearance model. After training, by deforming the shape models, and comparing the image with the appearance model, the ASM iteratively converges to the target in the image. The object shape is described by the Point Distribution Model.

During training, the boundary of the object is identified by manually digitizing landmark points around the perimeter. Using Procrustes Analysis, the corresponding landmark points are matched along the training set images, and translated, rotated and scaled for each training set shape. For this study, 40 points per vertebra, for 13 vertebrae (from T4-L4) per radiograph were annotated in the training set. The points were approximately evenly spaced around the vertebra, with ten points per side.

Principle Component Analysis (PCA) was then used to determine the axis along which the majority of the data, and hence the variation among the training set images, lies. Based on the pre-determined level of accuracy, the most common modes of variation that describe the training set can be extracted.

The Point Distribution (shape) model can be represented by the following equation:

$$x = \bar{x} + Pb$$

Where: $\bar{x}$: the mean of the aligned training set images
P: matrix representing the modes of variation
b: shape parameter represented by a vector of weights

The model can be deformed by varying the shape parameter b. The shape parameter b is constrained to ensure implausible shapes are not generated. The ASM varies the shape within the 3 standard deviation limit for each mode of variation.

The second model generated during training is the image appearance, represented by the shade intensity around each landmark point. The program samples a line normal to the intersection of two successive landmark points. The intensity profile is evaluated for all landmark points per vertebra and for all radiographs of the training set. The effects of intensity changes along the normal line are reduced by taking the derivative along the profile. PCA is then used once more to create the statistical model of the intensity profiles.

Once the object shape and appearance statistical models have been created, the ASM locates specific vertebra. In this iterative process, an initial estimate of the vertebra shape is made by selecting initialization points to hasten convergence. Only the region near the initial estimate is examined with the appearance model. Scaling, translation, and rotation are applied to improve the match. This procedure is repeated until either a maximum number of pre-determined iterations occur, in this study set to 50, or convergence to pre-determined threshold is reached.

3.1. Automated Cobb Angles

Cases for the training and test sets were randomly selected from the scoliosis database whose maximum Cobb angle varied between 20-50^o. Excluded were cases that included or showed: congenital deformities, poor imaging clarity, very large curves, major left thoracic curves, or were post-surgical. The excluded cases had a higher likelihood of showing irregularly shaped vertebrae and thus less compatible with the ASM, which are trained to recognize relatively rectangular vertebrae. The training set contained 47 images and the test set had 22 images (Table 1). A 5 mega pixel digital camera was used to digitize the radiographs. Quality was inferior to that attained by digital radiographs, however analogue radiographs are still common.

Table 1: Classification of training and test set radiographs

	Right Thoracic (RT)	Left Lumbar (LL)	RT with LL	Thoracolumbar	Small Curves	Total
# training images	12 (26%)	6 (13%)	15 (31%)	5 (11%)	9 (19%)	47
# test images	7 (32%)	3(14%)	7 (32%)	2 (9%)	3 (14%)	22

The training set was used with test radiographs to measure Cobb angles. Five initialization points placed near the middle of the superior endplate were selected on the test image at every third vertebra, beginning with T4 and ending with L4. These points allowed the program to rapidly converge to an initial estimate of the shape. The angles (in degrees) of the superior and inferior endplates versus the horizontal of each vertebra were displayed and stored after either the threshold accuracy or maximum iterations were reached. The Cobb angle was calculated by adding the absolute maximum and minimum angles.

3.2 Semi-Automated and Manual Cobb Angle Methods

The automated method was validated by comparing it to a semi-automated and manual method. The same 22 test images were used in the semi-automated method. This method requires the selection of four landmark points by the examiner; two points each for the most superior and inferior vertebrae that showed the greatest tilt towards the concavity of the spine. The landmark points are selected by marking positions that best describe the endplate orientation versus the horizontal. For all three methods, two examiners (trained novice and intermediate skill levels) performed the Cobb angle calculation three times for the 22 test images, with trials spaced two to three days apart for a given method.

For the manual method, each examiner was given printed copies of the radiographs (scaled 1:3). They measured the Cobb angles using their choice of end vertebrae and preferred technique and measurement instruments.

3.3 Analysis

$ICC_{(2,1)}$[7] values with 95% intervals (95% CI) were used to estimate the reliability of the intra-examiner, inter-examiner, and inter-method measurements. The ICC can vary between 0 and 1, with 1 indicating perfect reliability, 0.70 recommended for inferences about groups, and between 0.90 and 0.95 recommended to make inferences for an individual [8]. The mean, standard deviation, and standard error of measurement were also calculated for each method and trial. Scatter plots were examined for outliers.

4. Results

Scatter plots of the 3 trials of each method revealed a strong linear correlation between the trials (intra-examiner). ICC values were ≥ 0.9, with 95% CI lower limits ≥ 0.83 and upper limits ≤ 0.98 for the intra-examiner reliability using any of the three methods (Table 2). All 95% CI of intra-examiner reliability estimates overlapped.

Similar results were found for the inter-examiner reliability using any of the 3 methods (ICC values ≥ 0.82 with 95% CI lower limits ≥ 0.62 and upper limits ≤ 0.98, Table 3). The 95% CI of the inter-examiner reliability estimates overlapped.

Table 2: Intra-examiner reliability (ICC), 95% Confidence Interval (CI), Standard Error of Measurement (SEM), mean, and standard deviation (SD)

METHOD	EXAMINER	ICC	95% CI	SEM	MEAN	SD
Manual	1	0.95	(.91,.98)	2.1	26.7	9.5
	2	0.95	(.90,.98)	2.3	29.0	10.3
Semi-Automated	1	0.94	(.88,.97)	3.0	33.4	12.2
	2	0.92	(.85,.96)	3.4	34.4	12.3
Automated	1	0.91	(.84,.96)	2.3	24.7	7.9
	2	0.96	(.92,.98)	1.7	24.1	8.4

Table 3: Inter-examiner reliability (ICC), 95% CI, SEM, mean, and SD

METHOD	TRIAL	ICC	95% CI	SEM	MEAN	SD
Manual	1	0.95	(.88,.98)	2.3	27.0	10.0
	2	0.93	(.83,.97)	3.1	28.3	10.2
	3	0.94	(.86,.97)	4.1	28.3	9.7
Semi-Automated	1	0.89	(.76,.96)	4.0	34.6	12.2
	2	0.93	(.85,.97)	3.1	34.0	12.0
	3	0.90	(.77,.96)	4.1	33.2	12.8
Automated	1	0.96	(.90,98)	1.6	24.5	8.0
	2	0.83	(.63,.92)	3.4	24.7	8.1
	3	0.94	(.85,.97)	2.1	24.0	8.4

Plotting the 3 methods against one another showed near linear correlation between the examiners' results for the manual method versus semi-automated method, but noticeably poorer correlation between the manual versus automated, and semi-automated versus automated method. Four cases with the largest Cobb angles (>40°) as measured by the manual and semi-automated methods were severely underestimated by the automated method. They were eliminated and the inter-method ICC's re-calculated with the remaining 18 test cases. There was a sizable improvement in the ICC values when comparing inter-method coefficients for each examiner (ICC values of approximately 0.70 with 95% CI lower limits ≥0.4 and upper limits ≤0.9, Table 4).

Including the outliers, the SEM for intra-examiner measurements for any method was between 2-3°, and the SEM inter-examiner measurements for each method was between 2-4° (tables 2 and 3). The SEM for inter-method measurements for each examiner was 4-5° with the outliers eliminated (Table 4).

Table 4: Inter-method reliability (ICC), 95% CI, SEM, mean, and SD with 4 largest curves eliminated.

TRIAL	EXAMINER	ICC	95% CI	SEM	MEAN	SD
T1	1	0.71	(.48,.87)	4.3	26.5	7.9
	2	0.69	(.46,.86)	5.1	27.6	9.1
T2	1	0.71	(.48,.87)	4.4	27.4	8.1
	2	0.74	(.53,.88)	4.1	27.2	8.1
T3	1	0.68	(.44,.85)	4.3	25.8	7.7
	2	0.70	(.47,.86)	4.5	27.6	8.2

5. Conclusions

Intra-examiner and inter-examiner ICCs showed high reliability. Inter-method ICC values improved with removal of curves > 40^{o}. The automated method is limited to the content of the training set and by the apparent shape of vertebrae becoming more irregularly shaped with increased severity. The high reliability demonstrated by the intra-examiner ICCs suggests that the automated method is reliable regardless of the experience of the examiner. Since one examiner was a trained novice, the automated method could produce similar results in a clinical environment where those using the automated measurement program have little experience. Inter-examiner ICCs were similar to the intra-examiner ICCs, which supports the idea that the semi-automated and automated methods are useful, since the trained novice's results compared quite well to the intermediate examiner.

Possible sources of intrinsic error such as selection of the vertebrae used and the measurement technique were not controlled by standardized guidelines. While this adds to variability, it is a more realistic assessment of a clinical scenario in which different examiners evaluate a patient's successive radiographs with various instruments. The automated method worked best for test images of moderate curve size (up to 40^{o}) and may be of greater value with refinement of the shape parameter*s* influencing the scaling, translation, and rotation, thereby improving matching to the shape of a larger curve. Sensitivity to the shape parameters and speed/accuracy trade-off with the number of iterations will be explored. The automated method is more efficient with initiation points and may become more automated with easily detected radio-opaque control points on specific landmarks. Higher quality digital radiographs with more distinct vertebrae may produce even better results for all methods.

6. Acknowledgments

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Surface Alignment to Unmask Scoliotic Deformity in Surface Topography

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Abstract: Comparisons of back surface topography to monitor scoliosis are hampered by shape change due to other causes, primarily stance variations. The aim is to extract changes due only to the scoliosis from the observed changes. Surface (back) topography data were derived from 2 patients measured repeatedly (10x) at a single visit and from 45 patients measured at routine clinical visits. The measured back shapes were aligned to obtain the position of closest fit using a mathematical technique. The shape similarities were then quantified with a closeness-of-fit index. The similarity indices from the alignments were used to estimate noise factors due to postural variation, relative to typical patient change. Surface alignment has also been trialled using models with predictable topographic changes to determine whether the noise sources can be modelled. The values of the root-mean-square of the residual surface differences at all measured points after mathematical back shape alignment were used as a surface similarity index. The magnitude of this index for the repeatedly measured back shapes indicates the back shape variation due to stance, and has been compared with the variation found in normal patients. The similarity index has also been examined for cases both with and without modelled changes to estimate the effectiveness of stance modelling. The noise due to stance change was indicated by a surface similarity index which averaged 2.0 mm; the index for backs measured at routine visits averaged 3.5 mm. It was concluded that noise due to stance is significant and deserves to be recognised, in the comparison of back surfaces in three-dimensions. There is evidence that changes due to noise can be modelled.

Keywords. Surface topography; stance effects

1. Introduction

Comparisons of measured back surface topographies, when used to monitor the external manifestation of scoliosis, can be complicated by the existence of sources of apparent shape change other than scoliosis. These may include natural changes in the patient due to growth or body weight variation between successive visits, and the influence of the patient's chosen instantaneous stance. The long-term goal of the work-in-progress being reported here is to enable changes due the scoliosis to be identified from observed back surface topographies using the tool of automated surface-to-surface alignment. The technique is being enhanced by additional mathematical modelling described below. However, the study recognises that, despite the extensive use of surface topographies to monitor scoliosis, any confusion created by the patient's adopted stance has never been satisfactorily resolved. To implement automated surface alignment, it is important that firstly the contribution of the "noise" caused by stance variations is evaluated. Accordingly, the immediate aim is to evaluate the influence of stance on surface topographies.

2. Method:

2.1 Surface-to-surface Alignment

The crucial element of the study is a mathematical surface-to-surface alignment (or surface registration) algorithm, which is used to obtain the position of closest fit for pairs of measured back shapes, and which is based on a least squares solution for the closest surface fit, as described by Mitchell *et al.* [1], [2]. The mathematical procedure is regarded as being more rigorous and freer from the human judgment which can be involved in the manual surface topography comparison which involves manipulation of graphical images of the measured backs, as discussed by Berg *et al.* [3].

The surface alignment process removes the general separation which occurs because of the differences in the position of the patient at the times of measurement. The software "moves", mathematically, one back shape surface towards its position of best fit with the other, an outcome defined as occurring when the total of the squares of the separations is minimised. (The separations between the two surfaces are calculated from each point on one surface to a corresponding interpolated point on the other surface. Extreme and/or abnormal differences between the surfaces can be excluded from influencing the procedure).

Currently, differences between the two surfaces caused by any change in shape will remain when the position of closest fit is found, because the algorithm assumes that the shapes remain the same, and only their average position change is sought. The surface alignment programme ascertains the overall shifts and rotations to move one surface into "contact" with the other (representing the general change in patient position), and the final relative positions of the two surfaces can be used to create difference maps of various formats, such as shown in Figure 1.

The residual surface separations can be studied in order to decide on the patient's scoliotic change. However, one of the principal goals of the work-in-progress which is being reported here is to extend the surface-to-surface alignment beyond conformal matching, by incorporating models which represent the anticipated changes. Modelling the various patterns of change, presumably scoliotic but perhaps others also, may enable them to be separately identified, and thus distinguished from one another, during the match solution. It is crucial to recognise that the goal of this development is to model the causes of the differences such as those seen in Figure 1. Two models which have been used are simple scale change to represent patient growth, and a shear effect, in the form of a lateral movement of the patient's shoulders relative to the waist. The latter was chosen, not because it was necessarily a typical scoliotic change, but rather as a simple shape change which could be easily implemented for trials. Successful modelling of all causes of change, would reduce all differences to zero.

A single quantity which is derived from the alignment and which has been used here to indicate the closeness of any two surfaces is the root-mean-square (r.m.s.) of all surface separations (other than outliers) and the mean of absolute values of the residuals (again excluding outliers), the latter result being designated a difference index or closeness-of-fit index as a gauge of the similarity between the two surfaces.

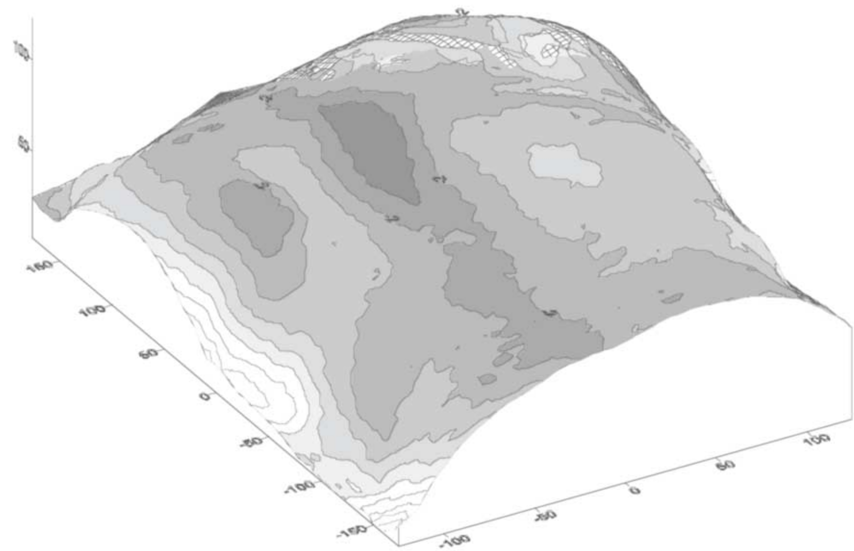

Figure 1. Back surface depicted in three dimensions with surface differences after alignment with another surface being indicated by shading. Figure created using Surfer software version 7.0, (Golden Software, Golden, Colorado, USA).

In summary, the work reported here has two components, both related to automated surface topography alignment:

1. To assess the impact of stance on the apparent surface differences. Although this had been looked at before by Berg *et al.* [3], it had not been done using an automated method which is seen as being unbiased.
2. To assess whether differences could be modelled, recognising that two changed surfaces cannot be expected to be simple conformal replicas of each other.

2.2 Data:

Data for these analyses comprised three distinct sets, all obtained by measurements on human patients with a Minolta Vivid 700 laser scanner, and all comprising at least 10,000 (x,y,z) coordinates:

1. Data comprised the measurements of 45 patients at successive clinical visits, at a typical interval of six months.
2. To evaluate stance effects, data was derived from two patients measured repeatedly (10x) at a single visit. Berg *et al.*[3] explain that "*The patients were given the opportunity to move freely between scans, and repositioned in the frame for each surface topography capture*".
3. To examine the effectiveness of modelling, three additional data sets similar to that at 1, representing three patients who were expected to exhibit large shape change, were utilised.

All back surfaces were cropped if necessary to eliminate any extraneous points which may have been scanned on background surfaces beyond the back, and which could influence the match unacceptably.

2.3 *Computations*

Matches were carried out in order to assess the following:

a) Differences due to normal patient change: This was assessed by simply matching the pairs of surface shapes from all patients in data set number 1. This indicated the variations of closeness-of-fit indices that may be recorded under standard surface matching circumstances using the algorithm in question.

b) Noise due to system: There may be apparent changes at the "noise" level, caused by the means of measuring and comparing the surface topographies. To evaluate the "base-level" noise in the algorithm, in case it was at a significant level compared to stance or scoliosis, a single surface data was aligned with itself. However, to avoid simply getting a perfect match with identical point distributions, the data points from the ten back shapes of one of the patients in data set number 2, were divided into two sub-sets, to create two surfaces, at half normal density, but representing the same surface.

c) Noise due to stance change: This was_assessed by matching the backs from both patients in data set number 2. For each patient, all ten data sets were matched which each other, providing 45 matches for each patient.

d) Modelling of change: Test surfaces were used, in which data had certain amounts of scale changes and shear artificially introduced. As well, the program which sought shear was tested with data set number 3.

3. Results

a) Differences due to normal patient change: the closeness-of-fit index for 43 valid back alignments obtained from patients measured at routine visits averaged 3.6 mm, but ranged from 0.5 mm to 8.7 mm, with a standard deviation of 1.3 mm.

b) Noise due to system: the r.m.s. value from 10 matches from the ten backs obtained on just one of the repeat measurement patients, was 0.7 mm.

c) Noise due to stance change: The r.m.s. of residuals from the 45 matches of the repeated measurements of one patient was 2.3 m with standard deviation 0.7 mm; the figures for the other patient were 1.8 mm with standard deviation 0.6 mm. Although more tests are deserved, it seems that the "stance noise" is given by an r.m.s. surface difference of order 2 mm. It should be noted that the use of a single closeness-of-fit index has the disadvantage that it does not reveal the spatial distribution of the differences between the surfaces, so at this stage it is not indicated whether the stance changes are different from scoliotic or indeed any other cause of change.

d) Modelling of change: Using back surfaces in which data had certain amounts of scale changes and shear artificially introduced, the program returned the input values of the introduced parameters of scale and shear, so that it could be accepted that the concept was valid and that the algorithm and program had been verified. When used with pairs of backs from data set 3, the algorithm which sought change shear parameters, returned r.m.s. values which were improved by small amounts for two patients, as in Table 1. It must be noted that, if the causes of differences could be completely modelled, the r.m.s. difference index would tend towards a value of zero. It is crucial to appreciate that these outcomes only show that the non-conformal modelling concept is valid, by improving the closeness of fit index, but not that the chosen models are necessarily appropriate. This study will be continued.

Table 1. Changes in surface alignment results when seeking shear parameters, (expressed as a movement of the shoulders divided by the waist-to-shoulder distance).

Patient	r.m.s. for conformal match	r.m.s. when shear parameter sought
1	6.68 mm	6.68 mm
2	5.11 mm	4.88 mm
3	6.11 mm	5.99 mm

4. Conclusion

Changes in surface topography due to stance have a magnitude which is significant relative to the magnitude normal patient change, and they may thus constitute a significant component of the apparent change observed in typical patients. For some patients, the change due to stance can cause surface differences which are larger than those seen from one clinical visit to another. Stance effects deserve to be allowed for, in the automated comparison of back surfaces in three-dimensions.

The evidence from artificially introduced changes is that the shape alterations, including growth, can be recovered by an automated non-conformal surface-to-surface alignment algorithm.

In this work, the characteristics of the stance changes have not been distinguished from scoliotic changes. Appropriate models of scoliotic change, stance, growth and so on have yet to be determined.

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Automatic Matching of Spine Images to Assess Changes in Scoliosis

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Abstract. This paper presents an image matching approach that can be used to measure changes in scoliotic curves. The proposed approach uses a novel fuzzy logic controller to estimate all open parameters. Using fluoroscopy images of a spine phantom, it was found that, with minimal user interaction, the matching of spine images could be achieved with high accuracy (the average errors were around 0.03 mm) and high computational efficiency (requiring less than 1 minute for matching each vertebra).

1. Introduction

Scoliosis is a condition that involves a lateral curvature and rotation of the spine that could cause noticeable trunk deformities. This condition affects between 2% and 4% of adolescents [1] and between 70% and 80% of the cases have an unknown cause [2]. The management of patients with scoliosis relies on subjective identification and measurement of a set of features on spine radiographs. These include: the Cobb angle [3], vertebral endplate tilt angles, and the apical and end vertebrae of the scoliotic curve. Because these features are assessed manually, they are prone to high inter- and intra-observer variability [4]. For instance, the typical inter- and intra-observer variability of the Cobb angle is accepted to be +/- 5 degrees, which is comparable to the threshold of change that is considered when making treatment decisions. In this paper, rigid image matching approach that can be used to automatically measure changes in scoliotic curves is presented. Because the measurement process is automated, it is expected that the variability in the measurements will be reduced.

Medical image matching [5]-[7] aligns anatomical structures of interest in one image with corresponding anatomical structures in another image. The components of an image matching algorithm are illustrated in Fig. 1. A moving image is aligned with a fixed image. The comparison quantifies the goodness of the alignment. The optimization computes the optimal transformation parameters as a function of the comparison output. The transformation finds the mapping that relates structures in the moving image to structures in the fixed image. Finally, the interpolation evaluates the image intensity at the mapped positions. For the image matching to succeed, it is necessary to properly set the parameters associated with the optimization. This task is usually done by experimentation. Unfortunately, this approach is difficult and time consuming [8], complicating the adoption of image matching methods in clinical practice. The goal of this paper is to evaluate a methodology for estimating the optimization parameters. This methodology reduces user interaction and facilitates the adoption of image registration methods in clinical practice.

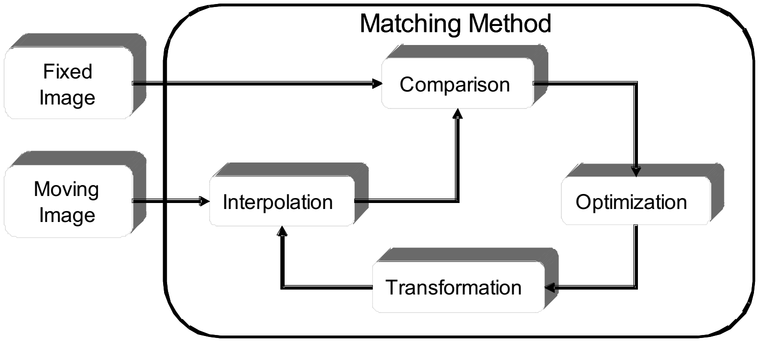

Fig. 1 Components of an image matching approach.

2. Methods

One frontal fluoroscopic image of a three vertebrae spine phantom [9] (see Fig. 2) was used as a fixed image. Fifty moving images were created by applying a known set of transforms to the fixed image. The input transforms were as follow: the translations in the "x" axis were 1.66 mm +/- 7.47 mm (range -13.48 mm to 15.17 mm); the translations in the "y" axis were -1.30 mm +/- 6.36 mm (range -14.28 mm to 11.24 mm); the rotations were -0.16° +/- 17.09° (range -28.6° to 35.5°). The image matching algorithm is based on fuzzy logic as described in [10]. The algorithm was implemented using the C++ programming language and the Insight Toolkit (ITK, www.itk.org) [11], a set of open-source set of libraries for medical image processing, registration, and segmentation. The key component of the proposed image matching algorithm is a fuzzy controller that uses information related to the fixed and moving images and information related to the goodness of the alignment to automatically set and adjust the optimization's parameters. The matching was computed for one vertebra at a time. Each vertebra was selected using regions of interest (see Fig. 2). The image matching process is illustrated in Fig. 3. On the top row, the images misalignment is large, causing the distance between the left eyes of each image (d_1) to be large. The middle row represents an intermediate step in the matching process. In this step the misalignment is smaller than the initial one, causing the distance between the left eyes of each image (d_2) to be smaller than the initial distance (d_1). The bottom row, shows the case when the two images are aligned. In this case the distance between the left eyes in each image (d_3) is close to zero. To evaluate the proposed approach, the quality of the resulting matching was obtained quantitatively by computing the distance (in mm) of a point moved using the known transform and a point moved using the computed transform. Smaller distances between the two points imply higher quality. The computational complexity was obtained as the number of iterations required to match a moving image to a fixed image.

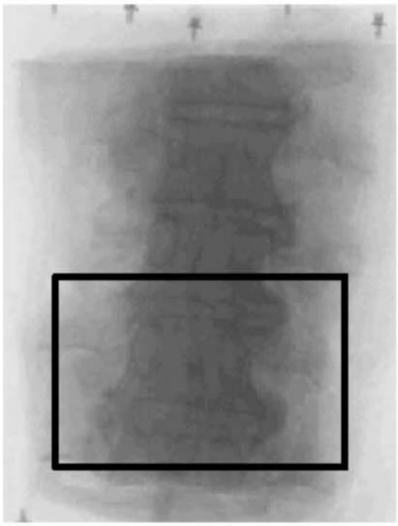

Fig. 2 Frontal fluoroscopy image of a spine phantom with the region of interest for the Vertebral Body 1 indicated with a solid square.

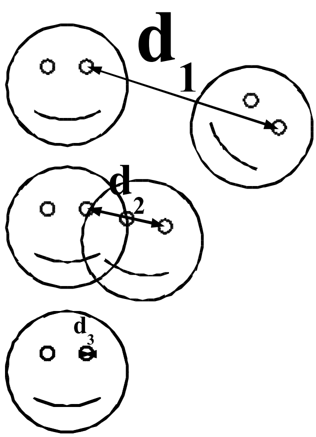

Fig. 3 Image matching process: On the top row the misalignment between the moving and fixed image is large. On the middle row, the misalignment between the moving and fixed images is smaller than the one in the top row. On the bottom row, the two images are aligned.

3. Results

Table 1 summarizes the stats for the distance between a point moved using the known transform and a point moved using the estimated transform. The maximum distance was 0.11 mm with the average distance being 0.03 ± 0.02 mm. Tables 2 and 3 summarize the computational cost required for implementing the proposed approach. All, but one, of the experiments were completed in less than 2 minutes in a 3.07 GHz Pentium 4 Laptop with 1 GB of RAM.

TABLE 1. Statistics for Distance between a point moved using the given transform and a point moved using the estimated transform (50 experiments)

Stats.	Distance		
	Vertebral Body 1	Vertebral Body 2	Vertebral Body 3
mean	0.032 mm	0.025 mm	0.025 mm
standard deviation	0.018 mm	0.015 mm	0.021 mm
minimum	0.006 mm	0.004 mm	0.001 mm
maximum	0.079 mm	0.065 mm	0.111 mm

TABLE 2. Statistics for Computational Cost as Number of Iterations (50 experiments)

Stats.	Number of Iterations		
	Vertebral Body 1	Vertebral Body 2	Vertebral Body 3
mean	126.76	79.64	150.56
standard deviation	40.22	19.40	48.51
minimum	67	48	88
maximum	222	123	307

TABLE 3. Statistics for Computational Cost as Time Required for Alignment (50 experiments). The experiments were run on a Laptop with a 3.07 GHz Pentium 4 processor and 1 GB of RAM

Stats.	Time Required for Alignment		
	Vertebral Body 1	Vertebral Body 2	Vertebral Body 3
mean	53.04 sec	33.18 sec	60.71 sec
standard deviation	16.83 sec	8.08 sec	19.56 sec
minimum	28.03 sec	20.00 sec	35.48 sec
maximum	92.89 sec	51.25 sec	123.79 sec

4. Discussion

In this study, an effective and novel methodology for automatically setting the optimization's parameters of a medical image matching application was validated. The key component of said methodology is a fuzzy controller that automatically sets the optimization's parameters to guarantee the high quality of the matching of the moving image to the fixed image.

The results presented in Tables 1, 2, and 3 suggest that the proposed application can be used to accurately match fluoroscopy spine images without extensive user interaction. Moreover, because of the high quality of the results and the low computational cost incurred, the proposed approach is a promising option for clinical practice. Although this recommendation is based on the study of fluoroscopy images, we expect it to be applicable to the matching of radiographies of patients with scoliosis.

The next issue worth pursuing is the development of a tool, using the proposed methodology, for automatically measuring changes in scoliotic curves. This could be achieved by performing the matching of each individual vertebra and then analyzing the results with the help of a computerized tool.

5. Acknowledgements

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This work benefited from the use of the Insight Segmentation and Registration Toolkit (ITK), an open source software developed as an initiative of the U.S. National Library of Medicine and available at www.itk.org.

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Chapter 4

Conservative Treatment

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A Comparison of the Clinical Effectiveness of Spinal Orthoses Manufactured Using the Conventional Manual Method and CAD/CAM Method in the Management of AIS

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Abstract. Spinal orthoses are commonly prescribed to patients with moderate AIS for prevention of further deterioration. In a conventional manufacturing method, plaster bandages are used to get patient's body contour and plaster cast is rectified manually. With the introduction of CAD/CAM system, a series of automated processes from body scanning to digital rectification and milling of positive model can be performed in a fast and accurate fashion. This project is to study the impact of CAD/CAM method as compared with the conventional method. In assessing the 147 recruited subjects fitted with spinal orthoses (43 subjects using conventional method and 104 subjects using CAD/CAM method), significant decreases ($p<0.05$) were found in the Cobb angles when comparing the pre-intervention data with that of the first year of intervention. Regarding the learning curve, Orthotists are getting more competent with the CAD/CAM technique in four years time. The mean productivity of the CAD/CAM method is 2.75 times higher than that of the conventional method. The CAD/CAM method could achieve similar clinical outcomes and with its high efficiency, could be considered as substitute for conventional methods in fabricating spinal orthoses for patients with AIS.

Keyword. AIS, Spinal Orthosis, CAD/CAM

Introduction

Patients with moderate Adolescent Idiopathic Scoliosis, AIS are generally prescribed with spinal orthosis for prevention of further deterioration. The conventional method of making spinal orthosis is by manually creating a negative plaster cast of the patient (Figure 1). A positive cast is then prepared by filling the negative cast with plaster. Rectification of the positive cast is done by removing and adding plaster to certain specific areas according to the patient's spinal deformity. A spinal orthosis is formed by moulding a plastic sheet onto the rectified positive cast. The required trim line is then cut and straps are secured into the orthosis. Adjustments to the orthosis are undertaken during the final fitting process.

Figure 1.
A plaster cast is taken from a patient with AIS using conventional manual method.

Figure 2.
A 3-D body image is taken from a patient with AIS using CAD/CAM method (Laser Imaging).

A computer-aided design and computer-aided manufacture (CAD/CAM) system normally comprises of 3 components namely, a digitizer, a computer workstation and a mill. The digitizer captures and converts the 3-D information of the body (Figure 2) or limbs (positive or negative cast) into a digital file. The computer workstation is used to manipulate the image on the screen and design via inputting data and/or using a computer mouse. The mill (carver) receives the rectified file from the computer station and produces a 3-D foam/plaster model according to the directives of the rectified file.

CAD/CAM system has been widely used in the industry since 1970s [1]. In 1979, the first CAD/CAM system for Prosthetics and Orthotics was developed by James Foort's team in the University of British Columbia. The system was for below-knee socket design. Afterwards, other researchers began to develop differential parts of the CAD/CAM system with him. The system was demonstrated at the International Society of Prosthetics and Orthotics in London in 1983. Great interest was generated at this time and lead to a race to develop commercial CAD/CAM systems. There are now close on ten different CAD/CAM systems on the market such as BioSculptor [2], CAPOD systems [3], Clynch Technologies Inc. [4], IPOS [5], Orten [6], Seattle Limb Systems [7], TracerCAD system [8], CANFIT-PLUS^{TM} [9] and Prosthetics Design Inc. Most of them can serve not only for upper and lower limb prostheses and orthoses but also for spinal orthoses. However, research studies about the application of CAD/CAM systems to spinal orthotics are very few.

Drawbacks are present in the conventional manufacture of the spinal orthoses, such as it is time consuming in cast taking and rectification, there is high plaster consumption, it has relatively low accuracy and there is no data storage for future reference. An introduction of a CAD/CAM system into spinal orthotic fitting could benefit by not only saving time but also in standardizing the fabrication process, improving accuracy and allowing the Orthotists to spend more time with patient activities such as assessment, education and training. Apart from technical considerations, the clinical effectiveness of CAD/CAM method and the learning curve are major concerns. A CAPOD CAD/CAM system has been applied extensively in the Prince of Wales Hospital, Hong Kong since 1998. The aim of this study is to evaluate the impact of CAD/CAM method as compared with the conventional method. There are two objectives: 1) to compare the effectiveness of spinal orthoses fabricated using the conventional method and the CAD/CAM method for managing patients with AIS; and 2) to evaluate the learning curve of Orthotists in applying the CAD/CAM method.

1. Material & Method

1.1. Subject Selection Criteria

- female with progressive adolescent idiopathic scoliosis;
- Cobb angle: 20° - 45°;
- age: 10 - 15 years;
- Risser's sign ≤ 3; &
- treated with thoraco-lumbo-sacral orthoses for curve apex at T8 or below.

In this study, subjects were selected from the Scoliosis Clinic of the Prince of Wales Hospital, Hong Kong. The subjects were divided into two groups – one group of subjects were managed using the conventional method from Year 1995 to 1998 (retrospective data) while the other group of subjects were handled using a CAPOD CAD/CAM method from Year 1999 to 2002 (prospective data).

1.2. Parameter and Method of Measurement

The patient's maturity was measured in terms of chronological age and Risser's sign [10]. In consideration of the clinical effectiveness, the following three clinical assessment parameters were included and all measurements were taken from standing PA radiographs by the same investigator in the visits of pre-brace, the 4th, the 8th and the 12th month of orthotic treatment:

- PA Cobb angle measured using the Cobb's method [11];
- apical vertebral rotation (AVR) measured using the Perdriolle method [12]; &
- trunk listing (cervico-sacral lateral offset).

A standard form was used to record the amount of time taken by Orthotists in accomplishing different processes of the CAD/CAM method from Year 1999 to 2002. The information collected would be used to study the Orthotists' learning progress. The productivity of the conventional method and the CAD/CAM method in fabricating spinal orthoses were also compared.

1.3. Method of Data Analysis

One-way repeated measures ANOVA was used in the three clinical assessment parameters at the four visits and in the learning curve analysis from Year 1999 to 2002. If the results were significant ($p < 0.05$), post-hoc multiple comparison test was applied.

1.4. Ethical Considerations

Informed consent was obtained from subjects undergoing the prospective study. The ethical approval from The Hong Kong Polytechnic University and the Prince of Wales Hospital was granted.

2. Results

In this study, 147 subjects were recruited (43 subjects using the conventional method and 104 using the CAD/CAM method). The mean, standard deviation and range of patient's age and Risser sign at the 1st visit are shown in Table 1 while the curve patterns are shown in Table 2.

Table 1. Assessment of the subjects' maturity.

Maturity	Conventional Method (n = 43)	CAD/CAM Method (n = 104)
Age (year) mean ± 1SD (range)	12.7 ± 1.0 (10.5 - 14.5)	12.7 ± 1.1 (10.0 -15.3)
Risser's sign (grade) mean ± 1SD (range)	0.9 ± 1.0 (0 - 3)	0.7 ± 1.0 (0 - 3)

Table 2. Curve pattern distribution.

Curve Pattern	Conventional Method (n = 43)	CAD/CAM Method (n = 104)
Thoracic	19	39
Thoraco-lumbar	4	5
Lumbar	8	45
Double Major	12	15

2.1. Cobb's Angle

The mean, standard deviation and range of Cobb's angle of the two subject groups are shown in Table 3. Both methods had significant reduction in Cobb's angle ($p < 0.05$) between the pre-brace visit and the following three visits.

Table 3. The mean, standard deviation and range of Cobb's angles in the first 4 visits.

Visit	Cobb's Angle (degree) mean ± 1SD (range)	
	Conventional Method (n = 43)	CAD/CAM Method (n = 104)
Pre-brace	30.3 ± 6.1 (20 - 45)	30.0 ± 5.8 (20 - 43)
4th month	22.3 ± 6.9 (10 - 35)	20.2 ± 7.7 (3 - 44)
8th month	23.2 ± 6.4 (8 - 41)	23.5 ± 7.6 (8 - 40)
12th month	24.0 ± 7.4 (3 - 44)	23.2 ± 7.7 (2 - 44)

2.2. Apical Vertebral Rotation

The mean, standard deviation and range of AVR of the two subject groups are shown in Table 4. For the conventional method, significant decreases ($p < 0.05$) were found between the pre-brace and the 4th month, and between the 4th month and the 12th month. For the CAD/CAM method, significant reduction ($p < 0.05$) was found between the 4th month and the 12th month. The lowest AVR was found at the 4th month for both methods.

Table 4. The mean, standard deviation and range of AVR in the first 4 visits.

Visit	Apical Vertebral Rotation (degree) mean ± 1SD (range)	
	Conventional Method (n = 43)	CAD/CAM Method (n = 104)
Pre-brace	12.0 ± 6.8 (0 - 26)	10.0 ± 6.2 (0 - 30)
4th month	9.6 ± 6.4 (0 - 30)	9.9 ± 6.1 (0 - 29)
8th month	10.8 ± 6.2 (0 - 25)	10.4 ± 6.2 (1 - 27)
12th month	11.9 ± 7.6 (0 - 30)	11.1 ± 6.6 (0 - 27)

2.3. Trunk Listing

The mean, standard deviation and range of trunk listing of the two subject groups are shown in Table 5. No significant differences were found in both methods in the comparison between the pre-brace and the following three visits.

Table 5. The mean, standard deviation and range of trunk listing in the first 4 visits.

Visit	Trunk Listing (millimeter) mean ± 1SD (range)	
	Conventional Method (n = 43)	CAD/CAM Method (n = 104)
Pre-brace	16.9 ± 11.1 (0 - 59)	12.8 ± 9.5 (0 - 40)
4th month	13.6 ± 11.6 (0 - 43)	12.7 ± 8.8 (0 - 40)
8th month	15.9 ± 11.2 (0 - 56)	10.3 ± 8.2 (0 - 40)
12th month	14.8 ± 11.2 (1 - 47)	12.0 ± 8.1 (0 - 33)

2.4. Learning Curve of Orthotists

The mean, standard deviation and range of the working time of the 10 Orthotists used in different processes of the CAD/CAM method are shown in Table 6. In all the studied processes, significant reductions ($p < 0.05$) in working time were found in the comparisons between 1999 and the following three years, especially in the first two years. The number of times required for scanning also decreased but not to a significant level.

In the Prince of Wales Hospital, the average number of spinal orthosis fabricated each year using the conventional method (Year 1995 – 1998) and the CAD/CAM method (Year 1999 – 2002) were 113 and 424 respectively. The mean productivity of spinal orthosis was found to be 275% higher in the CAD/CAM method as compared with the conventional method.

Table 6. The mean, standard deviation and range of working time of Orthotists used in different processes of the CAD/CAM method.

Year	Working Time of Orthotists (minute) mean ± 1 SD (range)				Number of time for scanning mean ± 1 SD (range)
	Preparation	Patient Positioning	Measurement	Design & Modification	
1999	19.0 ± 9.5 (5 - 40)	13.6 ± 5.8 (8 -25)	18 ± 8.5 (5 - 25)	38.1 ± 13.0 (20 - 60)	3.1 ± 0.13 (2-4)
2000	12.3 ± 5.4 (1 - 20)	9.6 ± 5.5 (4 - 20)	14.2 ± 1.1 (5 - 22)	29.9 ± 16.0 (15 - 60)	2.2 ± 0.43 (2-3)
2001	10.1 ± 4.3 (4 <-15)	7.3 ± 2.8 (4 - 12)	13.1 ± 6.9 (5 - 21)	25.5 ± 11.1 (15 - 46)	1.9 ± 0.56 (1-3)
2002	9.4 ± 4.3 (1 - 15)	6.6 ± 2.0 (1 - 10)	11.5 ± 5.8 (5 - 20)	23.6 ± 10.6 (12 - 40)	1.9 ± 0.56 (1-3)

3. Discussion

The spinal orthoses fabricated either by the conventional method or the CAD/CAM method were found to be effective for controlling curve progression in the first twelve months of orthotic treatment. This result is comparable to the previous studies [13, 14, 15, 16, 17, 18]. The Cobb angles in both methods was reduced to its lowest value at the fourth month and then increased again. This is similar to the study done by Lonstein and Winter [19] that the best curve improvement was found at the first 6 months of orthotic treatment, then the treatment effect decreased gradually. Smith [20] considered that the loss of initial improvement might be due to the biomechanical effectiveness of the orthosis in relation to factors such as growth and flexibility of spine. The spinal orthosis might not match with body growth; therefore, the controlling force of the spinal orthosis would no longer be effective.

Significant decrease ($p < 0.05$) in AVR was showed between the pre-brace and the 4^{th} month in the conventional method, and the 4^{th} month and the 12^{th} month in the CAD/CAM method. There was a tendency for both methods to reduce AVR to the lowest values at the 4^{th} month. This finding is similar to Wong et al.'s study [13]. Olafsson et al. [15] pointed out that the effect disappeared gradually with time and the spinal orthosis could not cause any significant long-term improvement of AVR.

In the application of the CAD/CAM system, significant decrease ($p < 0.05$) in the working time of all the studied processes between 1999 and the following three years was revealed. Apparently, the Orthotists' experiences increase with year of practice. The mean productivity of spinal orthosis is 275% higher in the CAD/CAM method as compared with the conventional method in the period of 1995 to 2003.

For the CAD/CAM method, one Orthotist is able to capture the body image by laser scanning better than using the conventional method since two Orthotists are required in the plaster casting process. As a consequence, the waiting time from prescription to measurement of patient could be shortened. Furthermore, the data of the body shape can be stored in the computer rather than keeping plaster casts in the store room. Cold, wet and embarrassment of the patients which occurs in conventional methods can be avoided after using the non-contact laser scanning CAD machine. Conversely, a neat, clean and tidy environment can be provided to the patients. However, there are drawbacks of CAD/CAM method. Apart from the costly investment in setting up and running and maintaining the machines and foam blank replenishment, the demand for expertise (there is a long learning curve) and the material of the foam blank (usually non-degradable and causing health and environmental problems) are issues to be solved.

4. Conclusion

The CAD/CAM method can offer similar clinical results in comparison with that of the conventional method. In addition, the productivity of spinal orthosis was found to be 275% higher in the CAD/CAM method than the conventional method in the studied period. Reducing the service delivery time of the spinal orthoses to patients with AIS is very important in clinical practice as an earlier management of progressive scoliosis can facilitate better treatment outcome. In light of this, using the CAD/CAM method can be an effective and efficient way to deliver the spinal orthosis. Therefore, it can be considered to substitute for conventional methods.

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The Accumulation of Bone Mineral Content and Density in Idiopathic Scoliotic Adolescents Treated with Bracing

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Abstract. We aimed to investigate the accumulation of bone mineral content (BMC) and bone mineral density (BMD) during bracing treatment in patients with adolescent idiopathic scoliosis (AIS). Using a dual energy x-ray absorptiometer, initial and follow-up BMC and BMD measurements were taken in the lumbar spine (L2-L4) and the dominant (left) femoral neck of a total of 40 AIS patients who were treated with braces. Using a paired 't' test, both BMC and BMD of both sites, at the follow-up of about 6 months and 12 months, were significantly higher than those right before bracing treatment ($p<0.05$). BMD measured at all sites increased at a rate similar to reported normal values in patients who had normal BMD as well as those who had lower initial BMD. No significant correlation was found between increase in BMC and BMD and daily brace wear ($p>0.05$). In conclusion, both BMC and BMD levels grew during brace treatment in AIS at a speed similar to reported normal values, suggesting that bracing dose not appear to adversely affect the accumulation of bone mass in AIS.

Keywords. Idiopathic scoliosis, BMD, Bracing, Adolescent

Introduction

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional spinal deformity occurring mostly in girls between 10 and 17 years old, affecting growth and development of adolescents [1-2]. Previous studies have shown that there is a significant association between osteopenia and AIS [3-6]. Recently, bracing has been accepted as a standard non-operative treatment for immature AIS patients with a mild curve [7]. However, it has postulated that bracing would inhibit the accumulation of bone mass in adolescents. In current study, we attempted to investigate the accumulation of bone mineral content (BMC) and bone mineral density (BMD) in AIS patients during bracing and to determine whether it is adversely affected by bracing.

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1. Subjects and Methods

1.1. Patients and Methods

A perspective study was performed on outpatients with AIS receiving bracing treatment. Inclusion criteria were as follows: initial skeletal immature (Risser 0 to 3); out of brace Cobb angle 15 to 45 degrees, or annual curve progression greater than 5 degrees; available chronological age and menstrual status (in girls only), and aged from 10 to 17 years; treatment with Milwaukee or Boston braces; followed at a 3-4 months interval with a duration of over 1 years; and no known conditions and medications which would impact on bone remodeling and calcium metabolism. The diagnosis of AIS was based on physical examination and standing postero-anterior (PA) roentgenography of the whole spine with a Cobb angle above 10°, after excluding congenital, neuromuscular, and other known etiologies of scoliosis.

The choices of brace, including Milwaukee and Boston braces, was based on the patients' curve patterns. In patients with a major thoracic, a double thoracic curve or a double thoracic and lumbar curve, the Milwaukee brace was considered, and with a thoraco-lumbar or lumbar curve, a Boston brace was used. If the curve pattern changed, the brace would be replaced appropriately.

At each follow-up (FU), further PA X-rays of the whole spine were compared to the earlier X-rays. If the difference of Cobb angle of the major curve was within 5 degrees, the curve was considered stable; if the Cobb angle increased or decreased more than 5 degrees, the curve was considered worsened or improved, respectively. Initially bracing time of 22 hr/d was recommended, as well as the date of 1st FU about 3 months later. During follow-up, if the curve was stable, bracing time was not altered in the first six months and shortened to 18-20 hr/d in next six months; if it worsened, bracing time remained at 22 hr/d; and if improved, or with a Risser sign greater than 3 and/or over 1 year since menarche, bracing time was then shortened by 2-4 hr/d at each FU.

At the time bracing was performed, a detailed personalized instruction list was given to AIS patients as well as their patients. The instructions mainly emphasized daily bracing time, but also included information about daily food intake and physical activity. Since recent studies showed that AIS had the same poor habit of food intake as healthy Chinese adolescents and revealed that less calcium intake and fewer physical activities might contribute to osteopenia in AIS [6, 8], in the current series, food intake of all patients was not assessed, whereas, high-calcium food such as milk and meats as well as daily physical activity over 0.5 hr when out of braces was recommended. During follow-up, information about food intake and physical activity relating to each patient was provided by their parents; this was found to be more consistent than the personalized instruction.

Body weight and height of each patient were recorded initially, at the second FU and fourth FU after bracing. Weight was measured to the nearest 0.1 kg in normal indoor clothing without shoes and height was measured without shoes on a wall-mounted stadiometer to the nearest 0.1 cm with the mandible plane parallel to the floor. Body mass index (BMI) was computed by dividing weight (kg) with height squared (m^2).

Right before bracing, at second FU and fourth FU after bracing, the BMC and BMD were measured on using dual-energy X-ray absorptiometry (DEXA, Lunar, USA) with at various skeletal sites: the postero-anterior lumbar spine (vertebrae L2–L4, LS) and left femoral neck (FN). The in vivo precision deviations in all subjects for BMD measurements at the different skeletal regions gave a mean coefficient of variation (CV) for all regions of 0.92 ± 0.42% (mean ± S.D.; range, 0.44–1.92%). The control spine phantom scan was performed every day with a long-term (>7 years) CV of 0.33–0.40%.

1.2. Statistical Analysis

To quantify bracing time, averaged daily bracing time (ADBT) was computed as follows: ADBT=**Σ**monthsbraced×dailybracingtime / **Σ**monthsbraced.

A paired t test was used to analyze the accumulation of BMC and BMD of all patients during bracing treatment. Correlation coefficients were determined for bivariate relationships of the accumulation of BMC and BMD of all sites with chronological age, menstrual status, body weight, height, BMI, Cobb angle, and change in BMI. The association of accumulation of BMC and BMD versus ADBT was analyzed with a regression model.

2. Results

In the present study, out of 72 AIS patients initially recruited, 54 patients were assessed until their second FU and 40 of which assessed until their fourth FU. Thus, the statistical analyses in current series were based on the 40 patients. There were 37 girls and 3 boys, with an average age of 13.0 yr (range 10.2yr~16.3 yr). The mean initial Cobb angle was 29.5° (range 15°~45°). Of the 40 patients, double thoracic curves were identified in 2 patients, a thoracic curve in 14, a right thoracic and left lumbar curve in 11, a thoraco-lumbar curve in 4, and a lumbar curve in 9. Table 1 shows the characteristics of AIS patients at entry, second FU and fourth FU. There was a mean of 6.9 and 6.3 months' interval for the second FU and fourth FU, respectively, relative to the initiation date.

At the second FU and fourth FU, 33 (89.2%) and 35 (94.6%) of 37 girls were menstruating. The body height, weight and BMI in all patients increased both at second FU and fourth FU in contrast to values at entry. With increases in age, the Risser sign indicated increased maturity, whereas the Cobb angle decreased during the FU.

In this series, only 45.0% (18/40) and 65.0% (25/40) of patients had a relatively normal BMD of lumbar spine and femoral neck, respectively, in comparison to normal references established in our previous report. At the second FU, there were 90.0% (37/40) and 87.5% (35/40) of AIS patients who had a positive annual increase in value for BMC and BMD of the femoral neck, and 82.5% (33/40) and 72.5% (29/40) for those in lumbar spine, respectively. At the fourth FU, 95.0% (38/40) and 92.5% (37/40) of AIS patients presented with increases in femoral neck BMC and BMD, and 87.5% (35/40) and 87.5% (35/40) in lumbar spine BMC and BMD, respectively.

Table 1 Characteristics of AIS patients at entry, second FU and fourth FU

Characteristics	n	At entry	second FU	fourth FU
Age (yr)	40	13.0±1.4	13.6±1.3	14.1±1.4
Years since menarche (yr)	37	0.43±0.51	0.91±0.66	1.35±0.59
% Menstruating girls	37	75.7%(28/37)	89.2%(33/37)	94.6%(35/37)
Height (cm)	40	155.3±6.3	158.6±6.1***	159.8±6.0***
Weight (kg)	40	40.8±5.6	43.5±6.2***	45.3±6.4***
BMI (kg/m^2)	40	16.87±1.61	17.25±1.91***	17.74±2.05***
Risser sign	40	1.8±1.3	3.0±1.3***	3.4±1.2***
Cobb angle (°)	40	29.5±7.8	27.9±6.4*	26.2±6.1**

FU=Follow-up. All data are shown in mean ± S.D. *p<0.05, **p<0.01 and ***p<0.001 show significant difference in contrast to values at entry.

Table 2 Annual accumulation rates of BMC and BMD in the femoral neck and lumbar spine

Site of BMC and BMD	Rate in the first 6.9±0.5 months	Rate in the whole 13.2±0.4 months
FN BMC(g)/yr	0.61±0.55	0.59±0.58
FN BMD(g/cm2)/yr	0.060±0.043	0.058±0.046
LS BMC(g)/yr	4.82±3.27	4.88±3.08
LS BMD(g/cm2)/yr	0.059±0.046	0.059±0.042

All data are shown in mean ± S.D., and *p<0.05 shows significant difference.

Table 3 Annual accumulation rates of BMC and BMD in patients with or without lower initial BMD

Site of BMD	Patients with lower initial BMD		Patients with normal initial BMD	
	Percentage (n)	Annual rate	Percentage (n)	Annual rate
FN BMD(g/cm2)/yr	37.5% (15)	0.060±0.051	62.5% (25)	0.058±0.048
LS BMD(g/cm2)/yr	55.0% (22)	0.060±0.049	45.0% (18)	0.059±0.050

All data are shown in mean ± S.D., and *p<0.05 shows significant difference.

The annual increase rates were computed (Table 2). The rates in the first 6.9 months and the whole 13.2 months were not equal to each other. During bracing, in the femoral neck, BMC grew at a rate of 0.61 g/yr, and BMD 0.058 g/cm^2/yr. In the lumbar spine, the accumulations of BMC and BMD were 4.88 g/yr and 0.059 g/cm^2/yr, respectively. As shown in Table 3, the accumulations of BMD in patients with or without lower initial BMD demonstrated no significant difference.

The mean ADBT was 20.6 hr during the whole period, and 21.4 hr and 19.2 hr prior to the second FU and fourth FU, respectively. The annual rates of change of BMC and BMD at both sites were not correlated with ADBT. There were positive relationships of BMC and BMD at entry and follow-up against age, menstruating status, Risser sign as well as BMI. Similar findings were recorded for BMC and BMD at the fourth FU. No significant relationships were found for BMC and BMD increase against BMI changes.

3. Discussion

In current study, it was found that most AIS patients had a positive accumulation of BMC and BMD in the femoral neck and lumbar spine over a one-year period of bracing treatment. The annual changes of BMC for the femoral neck and lumbar spine were 0.59 g and 4.88 g per year, and BMD 0.058 g/cm^2 and 0.059 g/cm^2 per year, respectively. BMD of both sites increased at a similar rate in patients who had normal BMD or lower BMD before bracing. Moreover, the annual changes of BMC and BMD were not correlated with daily bracing time.

Lower bone mass has been reported widely in AIS by other authors and our group [3-6]. Cook *et al* [3] first reported AIS patients suffered from lower bone mass, and Cheng *et al* [4] found generalized low bone mass and osteopenia in both axial and peripheral skeletons in AIS. It bas been suggested that osteopenic status in AIS persists throughout adolescence into adulthood. Recent work by our group implied that AIS patients on the China Mainland also had lower bone mass [5]. In this series, over 37.5% of patients had a relatively lower BMD than the normal reference.

Recent studies showed that fewer physical activities might partly contribute to osteopenia in AIS [6,8], indicating that any intervention which leads to fewer physical activities would adversely affect bone mass accumulation. Presently bracing treatment is a preferred choice for AIS patients with a mild curve [7]. However, it has been postulated that brace wear would adversely affect the accumulation of bone mass in adolescents [8]. The work of Synder *et al* showed that, after adjustment, spine and hip BMD values were the same for AIS patients treated with braces or observation [9]. Very recently, Synder *et al* [10] reported the accumulation of BMD during bracing treatment, which suggested bracing treatment did not appear to inhibit bone density accumulation in girls with AIS. In the current study, BMC and BMD of 40 AIS patients treated with brace were followed over 13.2 months. BMD accumulation in most patients turned out to be positive, and the annual changes were 0.059 and 0.058 $g/cm^2/yr$ in lumbar spine and femoral neck, similar to reported normal values [11,12] in which rate healthy adolescents' BMD increased. Additionally, BMD at both sites increased at a similar speed in patients who had normal or lower initial BMD. Furthermore, the BMC at both sites showed significant increases, and the annual changes of BMC and BMD were not correlated with daily bracing time. These results were in accordance with Synder *et al*'s work [10], indicating that bracing treatment dose not appear to adversely affect the accumulation of bone mass in AIS.

There is a limitation in current study in that there was not a positive control, consisting of age-matched and curve-severity-matched AIS patients, who received observation. With such a control group, the conclusion would be more conclusive in that bracing treatment does not adversely impact on the accumulation of bone mass in AIS.

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Prediction of Brace Treatment Outcomes by Monitoring Brace Usage

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Abstract. Brace treatment is the most commonly used non-surgical treatment method for adolescent idiopathic scoliosis (AIS). This study determined whether curve progression can be predicted by how often and how well children with AIS wear their braces. Twenty subjects (3M, 17F) who were diagnosed with AIS and had worn their braces from six months up to 1 year participated into this study. All subjects were prescribed Boston style braces and have now completed their brace treatment. On average, the brace was used 57% of the prescribed time. Peterson's risk of progression (Risser sign, age, apex of curve and imbalance of curve) predicted only 3-8% of the curve progression of brace subjects. Knowing how brace subjects used their braces in terms of brace tightness increases the prediction rate to 12-21%; and wear time further increase it to 25-36%. Adding the multiple of brace tightness and wear time improves curve progression prediction to 41-54%. To be most effective, the brace should be worn as prescribed in both tightness and time manners.

Keywords. Brace management, scoliosis, instrumentation, quality and quantity of brace usage

1. Introduction

Adolescent idiopathic scoliosis (AIS) is a three-dimensional lateral curvature of the spine with vertebral rotation. This lateral curvature affects the rib cage and presents as deformities of the trunk. Treatment modalities for scoliosis are based on patient's physiologic (not chronologic) maturity, curve severity, curve location, surface deformities, and the estimated potential for progression [1]. Patients who have moderate sized curves, documented progression and remaining growth may be recommended brace treatment. The goal of bracing is to halt curve progression during the high risk period of the adolescent growth spurt. To be effective, surgeons and orthotists suggest the brace must be worn for up to 23 hours per day [2]. An effective brace should, while the patient has the brace on, reduce the Cobb angle of the braced curve. Two types of brace actions have been discussed in the literature; one is the brace provides mechanical support to the body (passive component) and the other is the patient pulls her body away from pressure sites (active component). Although no conclusive statement has been made, most researchers believe that the passive components may be more important. If the passive component plays a significant role in the treatment of scoliosis, the effectiveness of brace treatment then depends on both the quantity (compliance) and quality (tightness) of brace usage.

Although braces have been used to treat scoliosis for more than 30 years, their effectiveness is still controversial. Some studies have reported that brace treatment is non-effective [3,4], whereas others have concluded that brace treatment is able to alter the natural history of AIS [5-8]. Since brace treatment is a long term commitment, early prediction of treatment outcome may help surgeons to change treatment protocol more appropriately. To measure the quality and quantity of brace usage, a low-powered portable load monitoring system has been developed [9, 10]. The wear pattern during daily activities and the study period can be recorded. Besides the brace usage, pre-determined risk factors may also play a certain role to determining which curves will progress. Peterson et al. [11] developed a formula to calculate the risk of progression based on Risser sign, apex of the curve, age and imbalance.

2. Objective

This study was to determine whether the brace treatment outcomes can be predicted by the brace usage in terms of wear time (quantity) and wear tightness (quality).

3. Methods

3.1. Brace Monitoring Device

The brace monitoring device (Figure 1) (dimensions: 55mm x 80mm x20mm; weight 60g) consisted of a programmable digital data acquisition system and a force transducer (FS01, Honeywell Inc.). The transducer was sensitive to the forces normal to the brace surface, but not to shear forces. It was usually embedded underneath the pressure pad area. The data acquisition system consisted of a microcontroller, a real time clock (RTC), a memory and a battery pack. It also has strap tension indicator lights consisting of one green and two red light emitted diodes (LED) which provide information to subjects regarding how tightly they wear their braces. The prescribed tightness level is set by the subject's orthotist in a standing position. When a subject first dons her brace, she can check the LEDs. The high red LED (H) indicates the tightness level is above 120% of the prescribed level; while the low red LED (L) indicates the tightness level is below 80% of the prescribed level. If the tightness level is within 80 to 120% of the prescribed level, a green LED will be on (set as the target range). The range 80-120 % of the prescribed level was deemed to be on target so that fluctuations due to breathing would not trigger an inappropriate feedback from the LEDs. Usually the device was attached to the brace with Velcro, but it could also be carried by the subject in a fanny pack or clipped onto their pants. The cable between the force transducer and the device was 2 feet long so that the subject could view the LED by holding the device in her hand. The memory inside this system could log data for up to 4 months.

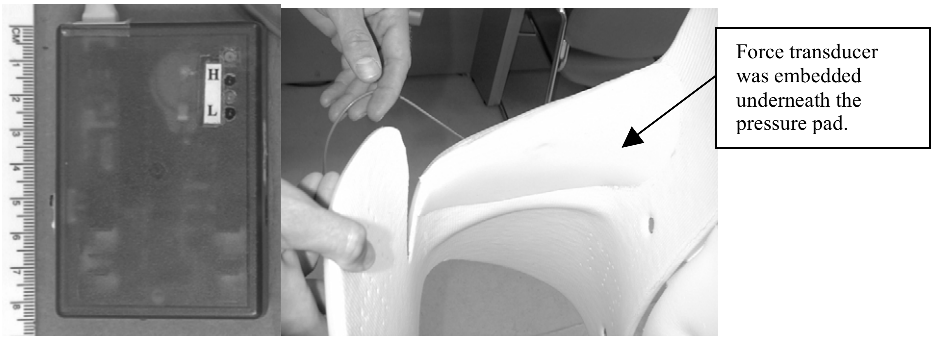

Figure 1. The brace monitoring system.

3.2. Clinical Trials

Twenty brace subjects, 3 males and 17 females, age 13.4 ± 1.7 years, who have worn their braces from 6 months up to 1 year were recruited. All subjects signed the consent form before they participated into this study. The selection criteria included subjects who were 1) diagnosed with juvenile or adolescent idiopathic scoliosis, 2) between 9 - 15 years old and 3) prescribed brace treatment. The Cobb angle of the treated curve at pre-brace and in-brace at time of monitoring were 32.2 ± 7.6° and 22.7 ± 8.5°, respectively. The prescribed wear time was 20.7 ± 3.2 hours per day, which was defined by the orthopaedic surgeons. Although full time brace treatment may dictate to wear the brace up to 23 hours per day, surgeons found it difficult to persuade patients to be fully compliant. Based on conservation with patients and families, surgeons decided on the prescribed hours. The target force was set by the orthotist after the transducer was installed while the subjects were standing. Since there was no scientific data reported on the actual optimum tightness, the orthotists attending our scoliosis clinic defined the wear tightness based on their experiences. Laboratory measurements and training session were provided so that the subject felt comfortable to use the system outside the laboratory. The sample rate was set to be one sample per minute with actual force level recorded at each sample. The study period was from 4 to 16 days. The quality of brace wear was assessed as a continuous variable using the actual load levels rather than the categorical range level. The quantity of brace wear was determined by how many hours per day or the proportion of the prescribed wear time that the subjects wore their braces.

3.3. Data Analysis

Correlation analysis was performed to determine which factors were independently related to curve progression. Both R^2 and adjusted R^2 (which controls for small sample size and number of independent variables) were calculated. The risk of progression, the quantity and quality of brace usage were the variables which were considered. The risk score was calculated based on Peterson's risk of progression formula when the brace was prescribed. The age threshold was adjusted from 13 years (females) to 15 years for males in Peterson's risk score as males physically mature later than females. An unpaired 2-tailed Student's t-test and Mann-Whitney U test were used to determine the differences between effective and non-effective brace wear for the terms quantity, quality and the quality*quantity interaction. This was done for threshold of effectiveness of at least 5 degrees progression.

4. Results

Twenty subjects who were recruited in this study have completed their brace treatment. The demographics of the subjects and their curve response to bracing are shown in Table 1. The curve size prior to bracing was 32 $\pm$ 8°. While in the brace, the Cobb angle improved by 9 $\pm$ 6°. At skeletal maturity, after bracing, the Cobb angle was 4 $\pm$ 9° higher than prior to bracing. The prescribed force for each subject varied since the transducer had variable pre-load when embedded in the major pressure pad. The average prescribed force was 1.4 $\pm$ 0.5 N (range 0.6N to 2.1N or 5 to 18 kPa based on a transducer surface area of 1.17 cm^2). Although the prescribed brace time was 20.8 $\pm$ 3.2 hours, the average brace wear was 12 hours (57% of the prescribed time).

The risk of progression, quality and quantity of the brace usage with the brace outcomes (Cobb angle changes) are summarized on Table 2. The results of the unpaired 2 tailed Student's t-test and Mann-Whitney U test of the effective and non-effective brace wear interact with quantity, quality and quality and quantity are shown in Table 3. Individual measures were unable to predict whether the brace would be effective.

Table 1. The demographic information and curve response of the 20 subjects.

Subject #	Gender	Age at Monitor	Study Period (days)	Prescribed (hrs.)	Target (N)	Cobb in-brace	Cobb out of brace	Cobb after weaning
1	F	12.2	11	23	1.22	16	24	36
2	M	12.5	14	23	0.92	30	37	65
3	M	15.8	11	23	0.92	36	40	40
4	F	13.5	10	23	0.78	13	36	27
5	F	13.5	5	23	1.17	29	33	46
6	F	15.7	5	20	0.84	30	32	35
7	F	13.8	16	23	2.11	18	31	26
8	F	15.9	12	23	0.57	20	40	38
9	F	13.6	4	23	1.51	36	50	50
10	F	13.3	14	23	2.11	16	20	25
11	F	14.9	14	23	1.48	22	30	30
12	F	11.0	4	18	1.94	18	28	32
13	F	12.0	10	14	1.74	30	35	41
14	F	14.5	12	23	1.42	15	29	25
15	F	12.0	10	20	1.20	34	40	44
16	F	14.2	14	20	1.20	26	33	27
17	F	13.5	14	12	2.00	5	25	25
18	F	14.2	14	18	1.90	16	18	25
19	M	9.0	14	20	2.10	26	35	35
20	F	12.0	14	20	1.30	18	27	27
	Average	13.4	11.1	20.8	1.42	23	32	35
	S.D.	1.7	3.8	3.2	0.49	9	8	11

Table 2. Summary of the treatment outcomes with risk of progression, quality and quantity measurement

Subject #	Cobb change	Peterson Risk (%)	Quality (%)	Quantity (%)	Quality*Quantity	Effective (>5)
1	12	73	62.5	37.2	23.3	Progression > 5 degrees
2	28	73	10.7	39.2	4.2	Progression > 5 degrees
3	0	22	86.7	11.7	10.1	Stable
4	-9	11	73.8	72.2	53.3	Stable
5	13	55	67.7	61.4	41.6	Progression > 5 degrees
6	3	11	36.2	41.8	15.1	Stable
7	-5	3	49.5	58.2	28.8	Stable
8	-2	3	62.5	86.2	53.9	Stable
9	0	87	32.7	91.1	29.8	Stable
10	5	3	13.0	38.5	5.0	Stable
11	0	55	67.5	22.8	15.4	Stable
12	4	73	45.5	81.5	37.1	Stable
13	6	39	50.1	37.6	18.8	Progression > 5 degrees
14	-4	55	19.0	84.0	16.0	Stable
15	4	22	48.8	43.0	21.0	Stable
16	-6	73	79.1	54.1	42.8	Stable
17	0	21	73.6	42.0	30.9	Stable
18	7	21	72.4	76.9	55.7	Progression > 5 degrees
19	0	73	51.2	72.1	36.9	Stable
20	0	73	72.7	82.9	60.3	Stable

Table 3. The results of the unpaired 2 tailed Student's t-test and Mann-Whitney U test of the brace effectiveness with the quantity, quality and quality*quantity.

$>5^{o}$ threshold	#	Quantity	Quality	Quality*Quantity
Effective	15	58.8 ± 24.9	54.1 ± 22.2	30.4 ± 16.9
Non-effective	5	50.5 ± 17.9	52.7 ± 17.9	28.7+20.1
Mann-Whitney U		0.28	0.86	0.90
p-value		0.50	0.90	0.85

The four independent variables, risk of progression, quality, quantity and quantity*quality were forced into the regression models for predicting curve progression. When the stepwise regression was performed (Table 4), the factors correlated with curve progression were risk of progression (R^2 = 0.08; adjusted R^2 = 0.03), risk of progression + quality (R^2 = 0.21; adjusted R^2 = 0.12), risk of progression + quantity + quality (R^2 = 0.36; adjusted R^2 = 0.25) and the risk of progression + quality + quantity + quantity * quality (R^2 = 0.54; adjusted R^2 = 0.41).

Table 4: Results of four independent variables forced into the Stepwise regression model

	R^2	*Adjusted R^2
Cobb angle vs. risk of Progression	0.08	0.03
Cobb angle vs risk of progression + quality	0.21	0.12
Cobb angle vs risk of progression + quality + quantity	0.36	0.25
Cobb angle vs risk of progression + quality + quantity + quantity * quality	0.54	0.41

*Adjusted R^2 controls for small sample size and number of independent variables

5. Discussion

Individual measures of Peterson's Risk score, quality, quantity, and quality*quantity of brace wear were poor predictors of brace effectiveness. Taken together, however, these measures predict a moderate amount (41-54%) of the brace effectiveness. Although brace treatment is currently favoured as a means to treat children with moderate scoliosis, it remains controversial. Prediction of brace treatment outcomes has not been well documented. Many studies have documented that the apparent effectiveness of the brace treatment is related to the compliance of patient. However, this study suggests that the quality of brace usage is at least as important as the compliance. When all 4 factors, Peterson's risk score, quality, quantity and quality * quantity were used, 41-54% of the curve progression can be predicted.

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Research into Spinal Deformities 5
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The Sforzesco Brace and SPoRT Concept (Symmetric, Patient-oriented, Rigid, Three-dimensional) versus the Lyon Brace and 3-Point Systems for Bracing Idiopathic Scoliosis

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Abstract. We have developed a new rigid brace, the Sforzesco brace, according to a new concept SPoRT (Symmetric, Patient-oriented, Rigid, Three-dimensional, active). The aim of this study is to verify the first results of the SPoRT concept compared to a classical 3 point system. Design: a pair-controlled retrospective study. Population: 15 patients (22 females), 14.0±1.7 years, 39.8±9.8° Cobb (°C). We examined for differences between the two groups, at the start with SPoRT worst than LY. All °C and °B parameters (maximal, average and single localizations) decreased significantly in both groups, apart from thoracic °C in LY. SPoRT had better results than LY ($P<0.05$) for maximal °C and average °C. Moreover, °C clinical results were better ($P<0.05$) in SPoRT than LY. SPoRT had better results than LY in aesthetic ($P<0.05$) of the shoulders and waists . Brace is effective in the short term also in high degree curves, and SPoRT obtained statistically significant 80% better °C results than LY in the worst scoliosis curve, and 40% in the average of all curves, as well as better aesthetic.

Keywords. Idiopathic scoliosis, Brace, Correction, Controlled study

1. Introduction

Bracing is considered to be effective in the treatment of adolescent idiopathic scoliosis [1-6].

There are few studies comparing the efficacy of different braces or different concepts of bracing. The concept prevailing today includes an asymmetrical construction to reverse scoliosis, mainly using a mechanical 3-point system, in the best cases, in a three-dimensional way (Chêneau 2000, Lyon, Rigo-Chêneau System). With the aim of avoiding casts for the most important curves of patients who wished avoid surgical treatment [7] [8], we developed a new rigid brace (the Sforzesco brace): its use, together with our experiences and thoughts developed during the years [7] [8], permitted the development of a new model of correction. We term this concept SPoRT (Symmetric, Patient-oriented, Rigid, Three-dimensional), because all these components are fully included in the construction of the braces. The aim of this study is to verify the first results of the SPoRT concept using the Sforzesco brace, comparing it to 3-point classical systems.

2. Materials and Methods

For the study, we examined the first 18 consecutive patients treated with the Sforzesco brace following their first evaluation at our Institute. We searched in our database for patients previously treated with Lyon brace that could be compared with the studied population. There were 4 criteria of agreement for each patient (gender, Ponseti classification, previous treatment, Risser stage) and 3 for curves (Cobb degrees, Bunnel degrees, number of vertebrae involved). We were not able to match 3 patients; these were excluded from further analysis. Group SPoRT (Sforzesco Brace) : 15 patients (10 females), 14.2±1.7 years, 40.1±10.8° Cobb (°C), 10.9±3.7° Bunnell (°B). Group LY (Lyon Brace) : 15 patients (12 females), 13.6±1.6 years, 39.6±8.6°C, 12.0±4.7°B. All patients were required to wear the brace 23 hours per day and were evaluated both clinically and radiographically at the start of treatment and after 6 months of brace wearing: As we considered actual results, radiographs were made immediately after wearing the brace. We suggest that the Lyon brace is a totally classical design which follows a 3-point system for lateral and horizontal correction.

Figure 1

The Sforzesco brace (Figure 1) is a custom-made TLSO developed made with the same material as the Lyon brace, but with only two large lateral components that completely cover the back from the pelvis to the armpits and the abdomen; these components are linked to a posterior aluminium central bar, and the brace closes anteriorly with straps on the abdomen and with another transverse aluminium bar at the level of the manubrium sternalis; to construct the components of the brace, the material eliminated on one side of the cast in order to create a force is added symmetrically on the other to give room for correction; correction is completed through insert placed in the brace; the brace completely follows body shape, being almost totally invisible under the clothes.

Statistical analysis: paired t-test, Mann-Whitney, Fisher's Exact and chi-square with α = 0.05.

3. Results

At the baseline we found differences between the two groups (SPoRT vs. LY – P<0.05): time from menarche (1.9±1.2 vs. 1.4±0.7), average °C (40.1±10.8° vs. 39.6±8.6°), maximal °C (46.5±7.0° vs. 43.3±7.1°), lumbar °C (40.5±12.1° vs. 33.7±7.0°), thoracic °B (9.9±4.2° vs. 12.4±4.1°).
All °C and °B parameters (maximal, average and single localizations) decreased significantly in both groups, apart from thoracic °C in LY.

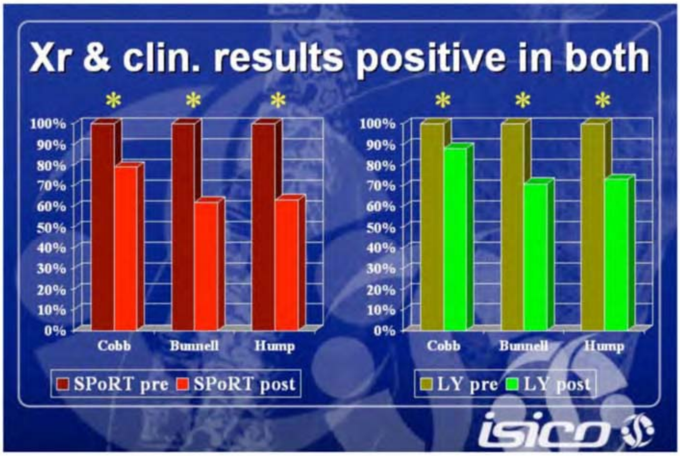

Figure 2

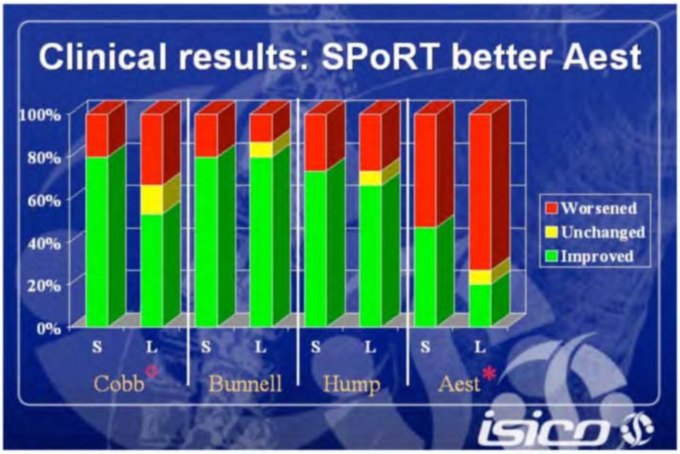

Figure 3

SPoRT had better results than LY ($P<0.05$) for maximal °C (worst curve: -9.8±5.4° vs. -5.5±7.4°) and average °C (-8.4±6.7° vs. -5.9±6.7°). Moreover, °C clinical results were better ($P<0.05$) in SPoRT than LY (12 improved >5°C, 3 unchanged, 0 progressed vs. 8/5/2). We found different results on the sagittal profile (distance from plumbline in mm. T12: -5.7±9.3 vs. +2.3±8.0 – L3: -6.7±11.7 vs. -0.33±10.3). SPoRT had better results than LY for shoulder profiles ($P<0.05$) (9 improved, 6 unchanged, 0 worsened vs. 5/8/2) and waists (10/5/0 vs. 5/8/2).

4. Discussion

While such a short term study cannot be used to draw definitive conclusions, it is already possible to identify some features related to future efficacy of the treatment. Moreover, when a new treatment is introduced, it is often not possible to wait for some years before verifying its utility, both for patients in therapy and children whose possible future need of the new options cannot be ignored. In this study, all patients treated with the brace at its introduction were included in the study, but the small number of cases was not sensitive enough to reach a firm conclusion. In spite of this shortcoming, in SPoRT we already obtained 80% better statistically significant °C results than LY in the worst scoliosis curve, and 40% in the average of all curves, as well as a better aesthetic result. On the other hand, while the reduction of the thoraco-lumbar distance from plumb-line can be considered as a good result, the same is not so for the lumbar curve, and this needs to be carefully considered in any future developments. Since the first cases were prescribed the brace, we have changed some details of it, and have obtained a new insight into its use, requiring verifying in future studies. However, the SPoRT concept already appears to offer promising results. Finally, this study confirms short-term effectiveness of brace treatment, whatever the brace concept used, with only 2 (out of 30) curves progressing with large angles such as the ones considered here.

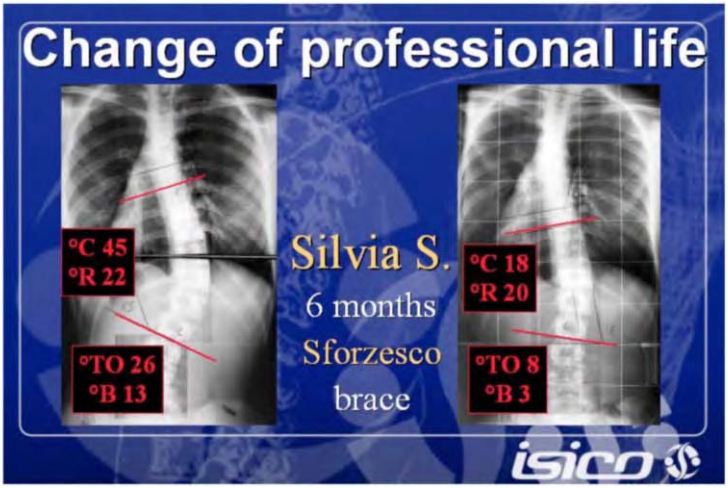

Figure 4

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Research into Spinal Deformities 5
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The ScoliOlogiC® „Chêneau light" Brace - Does the Reduction of Material Affect the Desired Correction?

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Abstract. The „Chêneau light" brace, developed according to the Chêneau principles, promises a lesser impairment of quality of life in the brace. However material reduction should not result in reduced effectiveness. Therefore the primary correction effect in the „Chêneau light" brace has been evaluated and compared with that of other traditional braces.
Material and method: The correction effects of the first 99 patients (main diagnosis AIS or EOS; 7 boys, 92 girls), treated according to the principles of the „Chêneau light" brace were evaluated after an average treatment time of 6 weeks by a full-body X-ray made in the standing position while wearing the brace and compared with the last X-ray before bracing. The average curvature angle of the whole group was 41°, the average age was 13 years.
Results: The Cobb angle in the whole sample has been reduced by an average of 14,7°, which corresponds to a correction effect of 42%. In patients from this sample who had their first brace (n=53; Cobb angle 36,6°) the in-brace correction was at 49,8%. The correction effect correlated slightly negative with age (r = -0,18; p = 0,034) and correlated negatively with the Cobb angle measured before treatment (r = -0,49; p = 0,0001).
Conclusions: The use of the „Chêneau light" brace leads to correction effects above average when compared to correction effects of other braces described in literature. The reduction of material seems to affect the desired correction in a positive way.

Keywords. Scoliosis, brace treatment, Correction effect, Rigo classification, Chêneau brace, "Chêneau light"® brace

Introduction

The latest developments in the field of bracing, aim at improving specificity [1] and at a proper sagittal realignment [2].

Although the effect of brace treatment has been questioned [3] there is evidence that brace treatment can stop curvature progression [4-9], reduce the prevalence of surgery [10-12] and improve cosmesis [13-15]. Poor cosmesis for the patient may be the most important problem, which can be solved or at least reduced by the use of advanced bracing techniques including the best possible correction principles to date [13]. Pattern specific bracing is desirable and it was Rigo [1] who implemented a new classification with 15 different curve patterns. All those curve patterns demand individual principles of correction in 3D, however 5 key patterns have been identified which we can start working with in everyday practice. These key patterns have been included into a guideline for brace construction that can be used for the custom plaster cast technique, for CAD designed braces as well as for the braces constructed via construction kits like the "Chêneau light"® brace [16].

The „Chêneau light"® brace (Patent pending), developed according to the Chêneau principles, promises a lesser impairment of quality of life of the patients while in the brace. This is realized by using less material in comparison to traditional bracing systems, which are intended for scoliosis treatment (Fig. 1 and 2). However material reduction should not result in reduced effectiveness. Since scoliosis corrective bracing treatment depends on the primary correction effect achieved in the brace [17-19], the primary correction effect in the „Chêneau light"® brace has been evaluated and compared with that of other braces used traditionally.

Material and Method

The correction effects of the first 99 patients (7 boys, 92 girls), treated according to the principles of the „Chêneau light"® brace were evaluated after an average treatment time of 6 weeks by full-body X-ray made in the standing position while wearing the brace and compared with the last X-ray before bracing. The average curvature angle of the whole group was 41° (23°-71° according to Cobb), the average age was 13 years (SD 1,74). AIS or EOS were the main diagnoses, however other aetiologies have been included like scoliosis in a patient with Marfan-Syndrome (n=1), Masa-Syndrome (n=1) and a patient with congenital scoliosis (n=1).

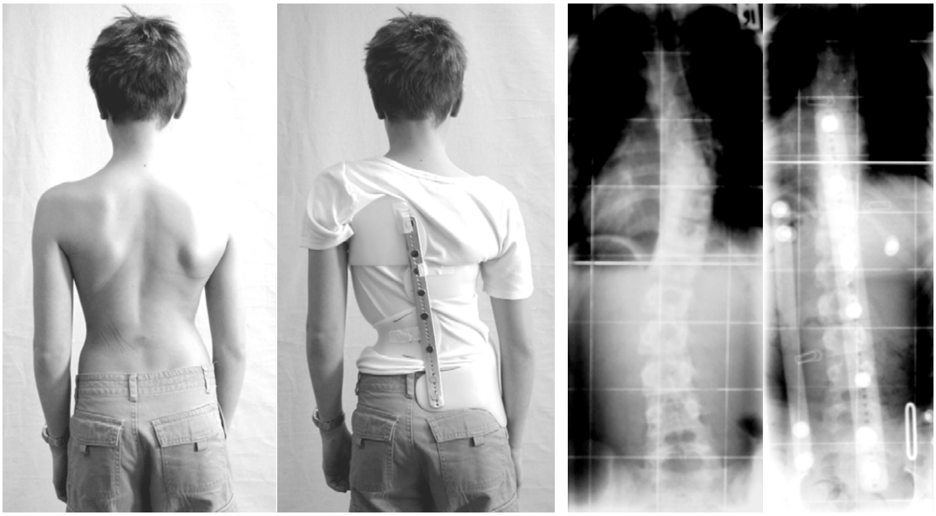

Figure 1. Overcorrection of a thoracic curve from 33° Cobb to –12° in a 12 year old boy with the help of a "Chêneau light"® brace; functional 4-curve model Rigo T6. On the picture on the left a little decompensation to the right can be seen, whereas on the picture (middle left) in the brace, the patient is decompensated slightly to the opposite side.

Figure 2. 14 year old girl, Risser 2 with 62° before treatment, in her first brace 40°, and now in her second brace (Chêneau light) 34°. Note that the brace is also open ventrally allowing a more comfortable treatment during Summer. In the dorsal aspect (2nd. Picture from left) the brace mirrors the deformity (left picture). This can be regarded as the clinical sign for a proper adjustment.

Results

The average Cobb angle in the whole sample was reduced by an average of 14,7°, which corresponds an average correction effect of 42%. In the patients from this sample who had their first brace (n=53; Cobb angle 36,6°) the in-brace correction was at 49,8%. In the patients the „Chêneau light"® was the second or third brace (n= 46; Cobb angle 45,5°) the in-brace correction was at 33,2%. The correction effect correlated slightly negative with age (r = -0,18; p = 0,034) and correlated negatively with the Cobb angle measured before treatment (r = -0,49; p = 0,0001).

Discussion

The correction effects achieved by use of the Chêneau light brace are comparable to those of others reported in literature [4-7]. After having improved the correction of the braces also in sagittal plane, we were able to improve the correction effect in frontal plane as well. Compared to the correction effects we achieved 2003 [8], the results now seem significantly better.

In the normal range of brace indications a correction effect of at least 20% is necessary to prevent progression [17], while a correction effect of at average 30% promises some final corrections [18]. A correction effect of 40% and more in a growing adolescent leads to a final correction of at average 7° Cobb [19].

Wong et al. [20] report correction effects of 40 % in patients with an average Cobb degree of 30,6° (21° - 43°). However in his collective no patients with double curve pattern have been included, which generally corrected worse than single curves in our preliminary study [21].

Bullmann et al. [22] reported average correction effects of 43% in the Chêneau brace in patients with a Cobb angle of 31° (25° - 40°). The final rate of success in this study however, was only 58%, which has to be regarded as rather disappointing, when compared to the success rate of 80% we reported on in another study [9] with a correction effect of less than 40%.

Unfortunately still today studies with insufficient bracing technologies are published with correction effects of at average less than 25% [23], while the standard in advanced centres is reported to be different already for more than 20 years. In the latter study [23] less than 80% of the population had at least some correction effect in the brace at all. To irresponsibly apply such poor treatment nowadays easily can be avoided and it needs to be, for our patients deserve a positive effect when they sacrifice their quality of life over years to the brace in good faith.

Conclusions

The use of the „Chêneau light“® brace leads to correction effects above average when compared to those of other braces described in literature. The reduction of material seems to affect the desired correction in a positive manner while the brace-covered areas of the trunk could be largely reduced in the patients treated.

Acknowledgement

The authors appreciate the patients permission to publish the photos taken with them showing the brace.

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Biomechanical Modeling of Brace Design

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Abstract Objective: To study the biomechanical effectiveness of brace design parameters in right thoracic idiopathic scoliosis. Methods: A finite element model (FEM) of the spine, rib cage, pelvis and abdomen was adapted to the geometry of 8 patients with right-thoracic idiopathic scoliosis using a multi-view radiographic reconstruction technique. A detailed parametric FEM of a thoraco-lumbo-sacral orthosis and a Box, Hunter & Hunter experimental design method were used to analyze the contribution of brace design parameters (brace size, number of straps, strap tension, position of the thoracic pad, lordosis reduction design) and of patient's spine stiffness. Results: The mean Cobb angle correction of the thoracic curve was 5.1º (0º to 16º). The most influential parameters were, in descending order, the strap tension, lordosis reduction design and spine stiffness. Their effects are independent and remain weak (-3º when strap tension increases from 20 N to 60 N). Changing the position of the thoracic pad (slightly above or below the apex) doesn't have a significant effect. No significant correction of the axial rotation and rib hump was obtained. Discussion & Conclusion: Frontal curve correction varied significantly, which justifies the need for an adequate adjustment of the brace. A more efficient design for the correction of transverse deformities remains to be found. The "active" correction component by the muscles was not included, but one can anticipate that its action would be concurrent to the passive brace mechanisms, enabling supplementary correction. A new tool simulating brace treatment has been developed, which allows rational design of braces.

Keywords Scoliosis, Brace, Finite element model, Design, Optimization

1 Introduction

Scoliosis is a three-dimensional deformity of the spine and of the rib cage. For moderate deformities, bracing is the most common treatment. Its efficiency in preventing the progression of frontal curves is generally admitted [9]. However the three-dimensional (3D) aspects of the correction were analyzed by Labelle et al. [6] who concluded that the Boston brace does not significantly correct the transverse plane deformities (rib hump and axial rotation), or decompensation and that it reduces the thoracic kyphosis (back flattening). To better understand their biomechanical working principles, forces generated by braces have been measured and the role of strap tension has been investigated [8]. For practical and ethical reasons, due to the problem of exposing a patient to multiple x-rays, it is infeasible to fully investigate brace biomechanics solely with experimental clinical studies. Consequently, numerical models have been used. The most common method consists of simulating brace treatment by directly applying forces on a finite element model of the human torso [1,12]. But the methods that apply directly external forces on a model of the trunk do not allow for the thorough study of brace biomechanics. The correlation between strap tension and generated forces or geometrical corrections can not be studied with such models. The design of the brace, its geometry, the position of the openings and of the pads, and other related components, can not be directly optimized.

To go beyond these limits, a detailed parametric explicit brace model and a realistic simulation process were developed [2,11]. The objective of this study was to study with this model the effect of specific design parameters on the forces and the three-dimensional corrections generated by braces for patients with a right-thoracic scoliosis.

2 Methods

The model is based on the three-dimensional (3D) geometry of the spine, rib cage and pelvis of a specific patient (Fig.1, a). On 3 calibrated radiographs (lateral, postero-anterior and postero-anterior with a 20° incidence) anatomical landmarks are digitized and reconstructed in 3D using the Direct Linear Transformation algorithm (DLT). An atlas of fully reconstructed vertebrae and ribs along with a free-form interpolation technique are then used to obtain the final geometry. The accuracy of this multi-view radiographic reconstruction technique is 3.3 mm on average (SD 3.8 mm) [3].

Based on this geometry, a personalized finite element model of the patient's torso is built (Fig. 1, b). The Ansys 10.0 FE Package is used (Ansys Inc., Canonsburg, PA, USA). The main components of the model have been described elsewhere [4,11,12]. The following boundary conditions were applied. The displacement of the first thoracic vertebrae T1 is coupled to the displacement of the first sacral vertebrae S1 in the sagittal plane. T1 is free in the frontal plane. The two nodes of the pelvis corresponding to the coxo-femoral joints are fixed in space, which allows the pelvis to tilt.

Based on this finite element model of the patient's trunk, a personalized geometrical model of a brace is created. It is based on 7 generative curves. Their intrinsic shape is defined by 9 parameters while their global position is defined by 3 parameters. These parameters are initially calculated on the finite element model of the patient. The geometry of the brace is therefore custom-fit. It can then be modified a posteriori to test different brace designs. A surface interpolating the 7 generative curves is then created. This surface is divided into sub-surfaces; some of these can be deleted to create openings in the brace or selected to introduce a pad. The latter are created by extruding the chosen sub-surfaces towards the inside by an appropriately defined thickness (Fig. 2).

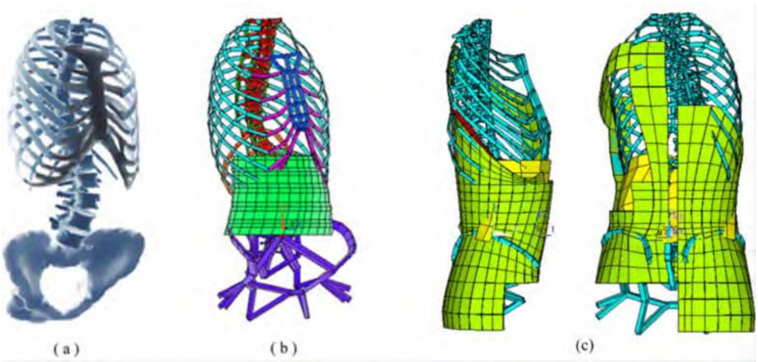

Figure 1 (a) Patient-specific geometrical model and (b) Biomechanical finite element model. The intercostal ligaments are not shown for clarity (c) Superposition of the trunk and brace models.

An automatic procedure was used to mesh the brace exterior layer into quadrilateral shell 4-node elements. Pads were modeled by 8-node hexahedrons. The element edge length were fixed to 20 mm, which makes a total of 1588 nodes and 1412 elements for the brace model (Fig. 1, c). The material of the exterior rigid shell was polyethylene (E = 1500 MPa, ν = 0.3), the material of the pads was polyethylene foam (E = 10 MPa, ν = 0.3) [13].They are assumed to be linear elastic. A point-to-surface contact interface was then created between the brace model and the trunk model. Contact points were located on the ribs nodes, on the exterior nodes of the abdomen and on the exterior nodes of the pelvis. The contact surfaces were located on the interior surfaces of the rigid shell and of the pads elements. Friction was taken into account (mu = 0.6).

The simulation of the brace installation and adjustment was divided into 3 steps. First the brace was opened so that the patient can fit into it. Secondly, the opened brace was placed over the patient, the displacements imposed during the first step were deleted and a balanced contact between the brace and the torso was established. Thirdly, two or three sets of co-linear forces, which represent strap tensions, were applied at the strap fixations on the posterior part of the brace.

For 8 patients with right thoracic curves of different magnitudes and apices (Table 1), braces similar to the Boston Brace system were modeled [5]. Their shape is symmetric relatively to the sagittal plane. Pads have been placed on the right thoracolumbar and on the right trochanter regions. Openings have been cut in the left thoracolumbar, in the left trochanter and in the right high thoracic regions (Fig. 2). A Box, Hunter and Hunter full experimental design was used to evaluate the effect of different design factors on the forces and the geometrical corrections generated by the brace. The factors had 2 modalities each and were: the number of straps (2 or 3) (Fig. 2, a), the strap tension (20 N or 60 N), the lordosis reduction design (flattening of the lordosis or conservation of the curves of the patient) (Fig. 2, b), the vertical position of the thoracic pad (on the rib corresponding to the apex vertebrae or two ribs above) (Fig. 2, c), the lateral position of the thoracic pad (posterior or lateral) (Fig. 2, d), and the global size of the brace (either fitted to the patient or 5% too large). Moreover, for each patient, the initial rigidity of the intervertebral discs was divided by 2 in order to test the influence of the spine global stiffness. That makes a total of 7 factors and 128 (2^7) simulations, including 64 different braces, for each patient.

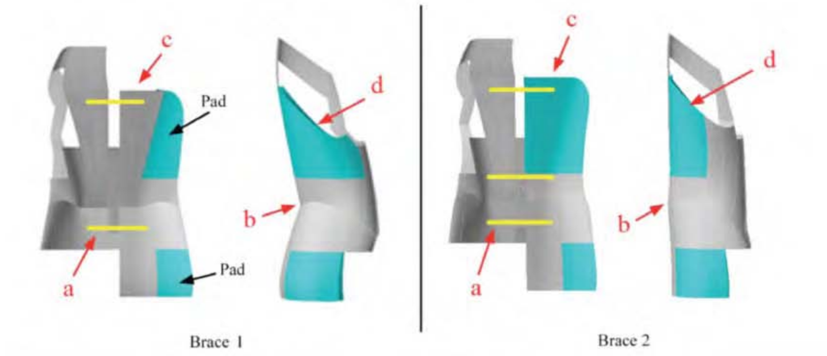

Figure 2: Brace design factors used in the design of experiments

Table 1: Description of the patients and simulated correction of the main thoracic curve

Patient	Initial Thoracic Cobb Angle	Apex of the thoracic curve	LenkeType	Maximum Correction	Mean Correction
1	22°	T9	1A	-15°	-7.7°
2	42°	T9	1A	-11°	-6.4°
3	42°	T9	1C	-11°	-5°
4	32°	T9	1B	-9.6°	-5.1°
5	34°	T10	1A	-14°	-5.9°
6	40°	T11	1B	-16.8°	-5.8°
7	31°	T7	1C	-5°	-2°
8	40°	T8	1B	-8.9°	-3°

Table 2: Evolution of the clinical indices

Clinical Indice	Mean	Standard Deviation	Minimum	Maximum	Most influential factor and its effect
Main thoracic Cobb (°)	-5.1	2.8	+ 0.1	- 16.8	Strap tension (- 2.6)
Kyphosis (°)	-1.2	2.6	+ 5	- 9.5	Lordosis design (-1.3)
Lordosis (°)	-3.7	2.5	+ 1.4	- 14.3	Lordosis design (-2.4)
Axial Rotation (°)	+ 0.05	2.4	+ 6.6	-5.3	Strap Tension (+0.8)
Rib Hump (°)	+ 1.3	3	+ 42	- 5.2	Strap Tension (+1.4)
Sacral Slope (°)	-2.3	2.4	+3	-11.1	Lordosis design (-2.2)

3 Results

Table 1 gives for each patient the description of the scoliotic curves before treatment and the mean and maximal simulated correction of the main thoracic curve generated by the 64 tested braces. The description of the curves is done according to the Lenke classification [7]. Table 2 gives the evolution of the principal clinical indices when all the simulations are taken into account and the effect of the most influential factor for each indice.

Table 1 shows that the mean and maximal correction of the thoracic curve are relatively small and depend on its characteristics. The curves with an apex above T8 (Patients 7 and 8) are less corrected than those with an apex below T9. Patient 1, who has the smallest initial scoliotic curve, is more corrected on average. Table 2 shows that globally the tested braces tend to reduce the lordosis and to tilt the pelvis backward (reduction of the sacral slope). The evolution of the kyphosis presents great variability. On average, no significant correction of the transverse deformities (rib hump and sacral slope) was obtained. The most influential factor for the correction of the main thoracic curve is the strap tension (-2.6° when the strap tension increases from 20 to 60N), followed by the lordosis design (-2° when the lordosis profile is flattened), the global spine stiffness (-1.2° when the global stiffness is divided by 2) and the number of straps (-0.75° when the number of straps increases from 2 to 3). These effects are independent. As expected it is the lordosis reduction design that influenced most of the evolution of the sagittal profile of the spine (lordosis, sacral slope and kyphosis).

4 Discussion and Conclusion

The brace simulation process used in this study is proposed as an improvement over previous studies [1,12]. The forces generated by the brace are in equilibrium with the reaction forces of the trunk, their directions are realistic and account for friction. This method has a positive impact on the selection of realistic boundary conditions which are very unrestrictive.

Only the “passive” action of the brace was considered as no muscles were modeled. The active action (a patient would tend to self-correct its scoliotic deformities by seeking to reduce pressure exerted by brace pads) is thought to be an important factor for curve correction and is, for example, another basic principle of the Boston brace [5]. However, the existence of this active action is still controversial [10,14]. It is also reasonable to assume that the active action of the brace, if any, would be concomitant to its passive action. Optimizing the passive action of the brace would result in optimizing its global action.

Because the active action is not modeled, it is difficult to validate the model quantitatively. However it is interesting to remark that some of the findings of this study (the role of the lordosis reduction in the correction of frontal curves, the difficulty to correct curves with high apices, the lack of correction of transverse deformities) are in agreement with clinical studies [5,6]. These results are promising but should be confirmed by a study on a larger number of patients.

In conclusion, we showed the feasibility of studying the effectiveness of brace design with a detailed finite element model. The results show that the correction of the main thoracic curve depends of its characteristics and that, for a given patient, the correction varies according to the brace design, which justifies the need for an adequate adjustment. This study should now be extended to a greater number of patients, on other types of curves (lumbar and double curves) and a greater number of design parameters should be included. This model could then be a tool enabling a more thoroughly understanding of brace biomechanics.

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Spinal Hemiepiphysiodesis Correlates with Physeal Histomorphometric Gradients

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Abstract. Compression of a growth plate is known to correlate with changes to growth plate structure. The purpose of this study was to determine if the height of the physeal hypertrophic zones and chondrocyte size were directly related to the distance from a spine implant. The implant was designed with the goal of slowing spine growth asymmetrically. For stapled vertebrae, hypertrophic zone height, cell height and cell width were decreased across the coronal plane of the growth plate, with the lowest values under the staple, 8 weeks postoperatively.

Keywords. Growth plate, histomorphometry, mechanobiology, spine deformity treatment, physical effects on cells

Introduction

Current treatments for spine deformity in children and adolescents are invasive and expensive. Potential new treatments under development are based on selective control of spine growth. Different designs of implants include staples, tethers, and plates. The main mechanism of action is presumed to be an increasing compressive stress differential. However, details of implant structure strongly affect their interaction with the physiological system.

The biomechanical environment of a growth plate has been shown to affect the final volume and shape achieved by chondrocytes during hypertrophy [1,2,3]; chondrocytic volume regulation and shape modulation during hypertrophy have been reported to explain some differences in growth rates. Cell shape and volume, in turn, are related to many biological factors, including regulation of cell maturation, production of structural proteins, nutrient movement, biochemistry and genetic expression [4,5,6,7,8]. Excessive physeal compression has been shown to correlate with changes in growth plate structure and function [3,9,10]. The efficacy of growth modulation methods, therefore, may be assessed at least in part by the spatial distribution of structural changes within the growth plate.

The purpose of this study was to determine whether the structure of the vertebral growth plate varied with distance from a particular staple-like implant in an inverse analog model of spine deformity treatment [11] at one post-operative time. Changes in disc width were also determined.

Figure 1: Implant blades spanned intervertebral disc (D) and two longitudinal growth plates (G) of adjacent vertebral bodies (V). Porcine vertebrae have bony endplates (E). Post-op and 8-week radiographs showed increasing curvature with time.

Methods

Custom spine staples were implanted into the left side of the mid-thoracic vertebrae of five live, skeletally immature pigs, following procedures approved by an IACUC. Six staples were implanted per pig from T6-7 to T11-12. Each staple spanned an intervertebral disc and two growth plates. Bone screws fixed each staple to the vertebral bodies (Fig. 1). After surgery, the animals were maintained in individual cages for 8 weeks, after which the spines were harvested for routine histology.

Coronal sections were cut, photographed, fixed in formalin, and decalcified. Half vertebra sections were embedded in paraffin, cut (4 μm sections), and stained with hematoxylin and eosin. Variables were measured for stapled level T8 and for unstapled level T4, which served as the paired control. Digital images of the growth plates and calibration slide were acquired under controlled conditions over more than half the total area of the growth plate at specified intervals (Fig. 2). The separate sections were assembled into a composite microscopic image of the growth plates across the entire frontal plane. The height of the hypertrophic zone of the growth plate and the height and width of the cells within the zone were measured using image analysis software. Statistics included paired t-tests to determine differences between the section of the growth plate directly within the staple blades and the corresponding control section.

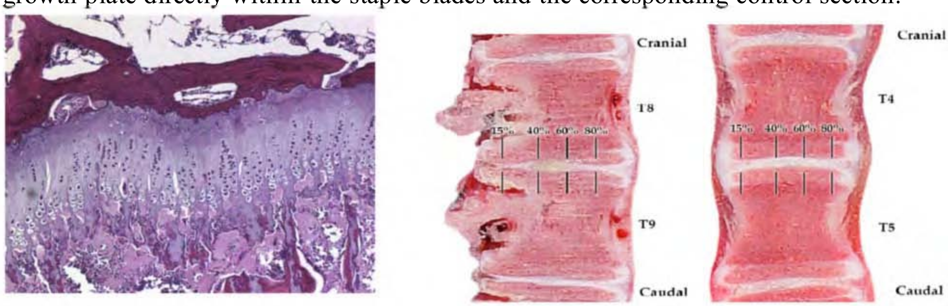


Figure 2. Vertebral growth plate section, porcine (100X), and locations of 4 regions of interest for vertebral growth plates for treated and untreated levels.

Variables were measured at well over 50% of the physeal area in 4 regions: directly within the staple blades (~15%), and at 40%, 60%, and 80% of the distance from the stapled edge to the opposite cortex. The variables were measured for a total length along the growth plate of at least two millimeters within each of these areas. Each region contained the same total area. Images were acquired using light transmission microscopy (100x) with digital camera systems (Olympus MAX80 and MagnaFire S99800 digital camera and/or a Zeiss Axioscop with RT Color Diagnostic Instruments Software). Images were layered to overlap such that the microscope view was reproduced (Adobe Photoshop 7.0) (Fig. 3).

The hypertrophic zone was defined by the presence of hypertrophic chondrocytes which were clearly larger and paler than proliferative zone cells. The height of the hypertrophic zone was defined as the distance from the top edge of the upper most hypertrophic cell to the bottom edge of the lowest hypertrophic cell. These measurements were taken along the vertical axis of the local growth plate boundaries. The height of each hypertrophic cell was defined as the distance from the highest to the lowest point of the cell along the direction used to measure the local zone height. The width of each cell was defined as the distance from the left to right edges of each cell, perpendicular to cell height.

For zone heights, on average, 48 discrete height measurements were recorded for each 2 mm area, for an average of 193 measurements per vertebra at approximately equally spaced intervals. Every qualifying cell in over half of the total area of the growth plate hypertrophic zone was measured. On average, 195 cells were measured in each region of the 2 mm length, for an average of 779 cells per vertebra.

Disc widths were measured from T4 to T13 at 25%, 50%, and 75% of the distance across the frontal plane.

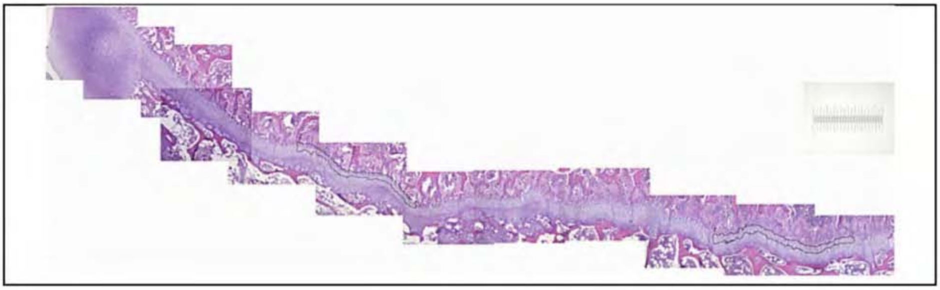
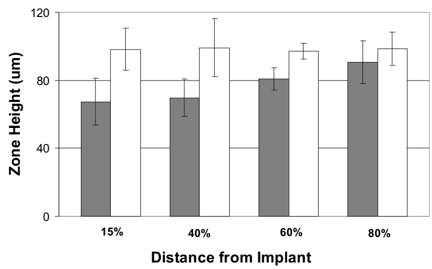
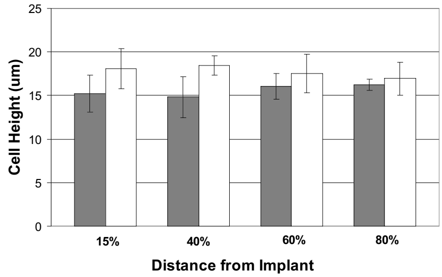


Figure 3. Montage of images from half of one vertebral growth plate, with calibration slide.





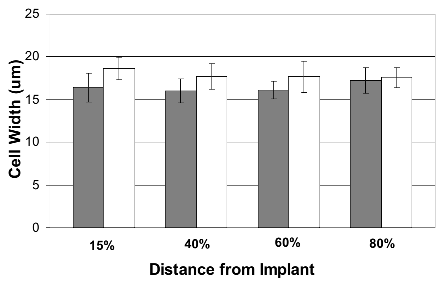


Figure 4. Growth plate height, cell height, and cell width were functions of distance from the implant for treated (gray) but not control (white) vertebral levels.

Results

For stapled levels, mean hypertrophic cell height and width and zone height decreased across the coronal plane of the growth plate, with the lowest values under the staple on the concave side of the curve (Fig. 4). Mean zone height under the staple was 80% of its contralateral side and 70% of control. The mean height of the control hypertrophic zones ranged from 97.0 to 99.5 μm, while that of the stapled levels ranged from 67.4 to 90.7 μm. Mean cell height under the staple was 85% of its contralateral side and 78% of control. Mean cell height of stapled vertebrae was less than controls in every section. Cell heights ranged from 14.8 to 16.2 μm in stapled vertebra, and from 16.9 to 18.4 μm in control sections. Mean cell width of stapled vertebrae was slightly less than controls in every section. The mean width of cells from stapled vertebrae ranged from 16.0 to 17.3 μm, while the mean width of controls ranged from 17.5 to 18.6 μm.

Disc width of stapled vertebrae was significantly less than controls across the entire section. Disc width under the staple was 83% of contralateral and 48% of control; the unstapled side remained 44% less than control.

Discussion

Spinal hemiepiphysiodesis decreased growth plate hypertrophic zone and cell cross-sectional areas within the implant in a quadruped model of deformity treatment. Physeal parameters showed a graduated response that did not dissipate completely on the contralateral side. These results, while not measures of cell function or absolute cell size, may be adequate to assess and improve the potential efficacy of this or similar implants.

They may also be correlated with mechanical stress magnitudes required to suppress growth. Zone and cell height reductions due to treatment compare at least qualitatively with related models using rodents [3,9]. Limitations include control of the section plane, small sample size, and both global and local anatomical and mechanical differences between species. Control physis measures are not yet available by level; it is not known if absolute differences between control level T4 and treated level T8 may be due, in part, to a gradient by thoracic level. However, the main effects were the differences from side to side across the plane of each level.

Effects on the disc due to changes in factors such as nutrition [12], static stresses [13], and dynamic stresses [14] are well known. Whether the magnitudes of stress, which are likely self-limiting in this system, are deleterious to the disc is not yet known. Disc height reductions were clear, indicating that further disc assessments are warranted.

Conclusions

Spinal hemiepiphysiodesis using staple type implants decreased the height of the hypertrophic zone of the vertebral growth plates. Cell height was also decreased, without an increase in cell width. Vertebral structure at the cell and tissue levels correlated with implant location. The decreased cell size, plate height, and disc thickness in the treated vertebrae are consistent with compression of the vertebral growth plate and disc. Decreased cell width and height suggest that cell growth, as well as vertebral growth, was slowed on the concave side of the curve in this model. The lack of increase in cell width disproves that the chondrocytes were undergoing lateral expansion under compression, either to maintain a constant volume or to grow orthogonal to the direction of the applied compressive stress

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Radiological Results of Dobosiewicz Method of Three-Dimensional Treatment of Progressive Idiopathic Scoliosis

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Abstract. The aim of the study was the radiological evaluation of the three-dimensional asymmetric treatment of scoliosis in strict symmetric initial positions. Material and Method. 152 patients (137 F and 15 M) with idiopathic progressive scoliosis (85 single scoliosis cases and 67 double-major) with proven curve progression were retrospectively analysed on the basis of radiological evaluation in the period of years 1999-2004. Mean age of assessed group was 14.22 years (range 7÷21, SD=2.57), mean time of observation 31.80 months (range 18÷63, SD=10.75). All children were treated with Dobosiewicz method of three-dimensional asymmetric correction in strict symmetric initial positions and with rigid Cheneau brace when indicated. Results. Mean initial value of Cobb angle was 25.92 degrees (range 9÷62, SD=10.59), mean initial rotation of apical vertebra was 9.55 degrees (range 0÷30, SD=7.66). The outcome values were 31.04 degrees (range 5÷76, SD=13.96) and 12.97 degrees (range 0÷35, SD=8.41), respectively. Mean progression of Cobb angle during entire period of observation was 5.12 degrees (range –21 ÷ +38, SD=9.62), mean progression of apical vertebra rotation was 3.42 degrees (range -21 ÷ +25, SD=6.03). Further multi-factor analysis is discussed in full text. Results are also presented in the form of radiograms. Conclusion. The radiological results demonstrated prevalent stabilisation of scoliotic curves in children treated with Dobosiewicz method between October 1999 and December 2004.

Key words: idiopathic scoliosis, conservative treatment

1. Introduction

In the Department of Rehabilitation in Katowice (Poland) the Dobosiewicz method is employed as routine procedure in conjunction with the Cheneau brace when indicated. The biodynamic method of three-dimensional correction in symmetric initial position of idiopathic scoliosis is based on the pathomechanics of scoliosis development. The method presumes active, segmental, three-dimensional correction in the region of the apex of a curvature. Correction is phase-locked with respiratory movement. Proprioceptive facilitation is applied on the concave side during inspiration and exteroceptive facilitation on the convex side during expiration. Main assumption of this method is creation of thoracic kyphosis with simultaneous dilation of intercostal and paravertebral spaces on the concave side of scoliosis. Most exercise positions should be maximally kyphotic and symmetric to allow asymmetric movement of trunk and exclude action of erector spinae and psoas major muscles and axial gravity load on spine. Stabilisation is provided by superficial muscles of chest and back, anterior abdominal wall muscles control movement and correct pelvic rotation and inclination. Rectus abdominis by decrease of pelvic inclination causes additional elongation of posterior column of a thoracic and lumbar segment of the spine. [1,2] The study was carried out to assess results (radiological evaluation) of the conservative treatment of progressive idiopathic scoliosis according to Dobosiewicz method.

2. Material and methods

152 patients (137 F and 15 M) with progressive idiopathic scoliosis (with proved radiological progression of Cobb angle), hospitalized at least two times in the Department of Rehabilitation between October 1999 and December 2004, were evaluated in view of the outcome of the Dobosiewicz method or the Dobosiewicz method and ridig braces, regarding Cobb angle and apical vertebra axial rotation angle (with Perdriolle technique). Mean age of assessed group was 14.2 years (range 7÷21, SD=2.57), mean time of observation - 31.8 months (range 18÷63, SD=10.75). Two groups were isolated regarding scoliosis morphology (single–65 patients and double-major –67 patients) and three groups regarding time of treatment (18-35 months, 18-63 months, 36-63 months). 82 patients (53.9%) applied simultaneously with Dobosiewicz method ridig brace (Cheneau) in various temporary spacing. Data are presented as mean ± 1 SD or as percentage.
We did not take into account patients compliance in this analysis.

3. Results

In group 152 patients mean initial (in point of treatment start) value of Cobb angle (all curvatures) was 25.9 degrees (range 9÷62, SD=10.59), mean initial axial rotation angle of apical vertebra was 9.5 degrees (0÷30, SD=7.66). The outcome values were 31.0 degrees (5÷76, SD=13.96) and 12.9 degrees (0÷35, SD=8.41), respectively.
Mean progression of Cobb angle during entire period of observation was 5.1 degrees (range–21÷ +38, SD=9.62), mean progression of apical vertebra axial rotation angle was 3.4 degrees (range -21÷ +25, SD=6.03). More results–see Table 1-5 and Figure1-5.

Table 1. Results of the conservative treatment. Cobb angle values in degrees. Single IS.

Period of treatment	18-35 [months]		18-63 [months]		**36-63** [months]	
N–numer of patients	N=59		N=85		N=26	
Cobb values [º]	Initial	Outcome	Initial	Outcome	Initial	Outcome
mean	**25,4**	**28,3**	**24,7**	**28,9**	**23,0**	**30,5**
SD	10,27	15,88	9,82	14,91	8,69	12,61

Table 2. Results of the conservative treatment. Cobb angle values in degrees. Double-major progressive IS.

Period of treatment	18-35 [months]				18-63 [months]				**36-63** [months]			
	TH		L		TH		L		TH		L	
Cobb values [°]	N=43				N=67				N=24			
	I	**O**	**I**	**O**	**I**	**O**	**I**	**O**	**I**	**O**	**I**	**O**
mean	**28,1**	**32,3**	**26,5**	**28,9**	**26,8**	**33,2**	**25,5**	**29,9**	**24,3**	**34,9**	**23,7**	**31,7**
SD	12,30	14,83	12,13	13,26	11,27	14,04	11,29	13,36	8,68	12,50	9,41	13,67

I-initial values; O- Outcome values; TH-thoracic curve; L-lumbar curve; N–numer of patients

Table 3. Results of the conservative treatment. Apex vertebra axial rotation angle values in degrees (mean ± SD). Single progressive IS.

18-35 [months]		18-63 [months]		**36-63** [months]	
numer of patients - 59		numer of patients - 85		numer of patients - 26	
Initial	Outcome	Initial	Outcome	Initial	Outcome
12,1 ±8,36	14,6 ±9,12	11,6 ±8,0	14,6 ±8,96	10,5 ±7,15	14,8 ±8,76

Table 4. Results of the conservative treatment. Apex vertebra axial rotation angle values in degrees (mean ± SD). Double-major progressive IS.

18-35 [months]				18-63 [months]				**36-63** [months]			
TH		L		TH		L		TH		L	
N=43				N=67				N=24			
I	O	I	O	I	O	I	O	I	O	I	O
8,2 ±6,53	9,8 ±6,52	9,7 ±8,31	12,8 ±9,11	7,2 ±5,85	10,1 ±6,4	9,2 ±8,12	13,2 ±9,1	5,33 ±3,68	10,6 ±6,25	8,1 ±7,82	13,9 ±9,22

I-initial values; O- Outcome values; TH-thoracic curve; L-lumbar curve; N–numer of patients

Table 5. Results of the conservative treatment in percentages. Patients at which value of radiological measurements were numbered to the group of the improvement or worsening differed more than 5 degrees.

	Single progressive IS						**Double-major progressive IS**											
Period of treatment	18-35 [months]		18-63 [months]		**36-63** [months]		18-35 [months]				18-63 [months]				**36-63** [months]			
							TH		L		TH		L		TH		L	
	N=59		N=85		N=26		N=43				N=67				N=24			
	C	r	**C**	r	**C**	r	**C**	r	**C**	r	**C**	r	**C**	r	**C**	r	**C**	r
Worsening %	**33**	23	**40**	27	**56**	40	**46**	13	**24**	24	**51**	24	**32**	28	**63**	46	**50**	42
No change %	**44**	72	**40**	69	**40**	60	**43**	85	**63**	72	**39**	74	**59**	69	**29**	54	**50**	58
Improvement%	**23**	5	**20**	4	**4**	0	**11**	2	**13**	4	**10**	2	**9**	3	**8**	0	**0**	0

N–numer of patients; C-Cobb angle; r-apex vertebra axial rotation angle; TH-thoracic curve; L-lumbar curve

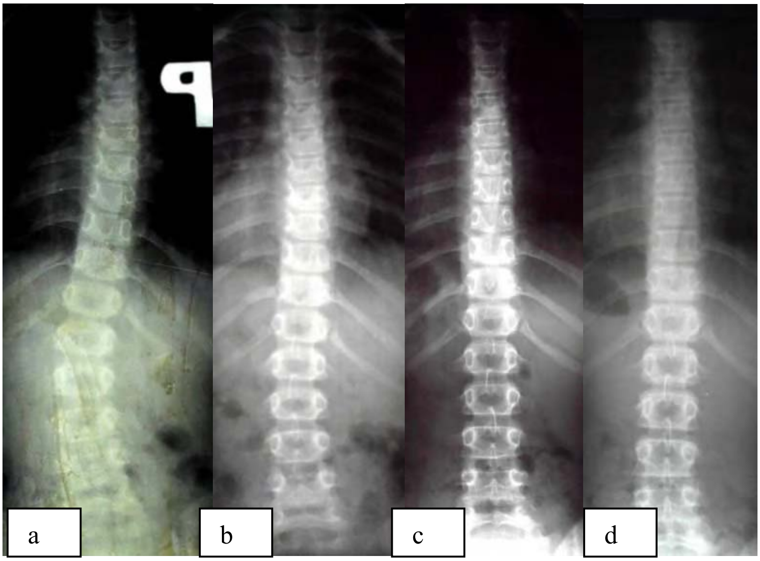

Figure 1. Girl treated exclusively by physiotherapy (without brace). She was five years old in start of the therapy **(a)** - in L C=21, AVR=10 and in TH C=15, AVR=12; **(b)** after 18 months - in L C=13, AVR=5 and in TH C=10, AVR=10; **(c)** after 47 months - in L C=0, AVR=2 and in TH C=6, AVR=5; **(d)** after 58 months of therapy - only in TH C=7, AVR=0. C-Cobb angle; AVR-apex vertebra axial rotation angle; TH-thoracic curve; L-lumbar curve.

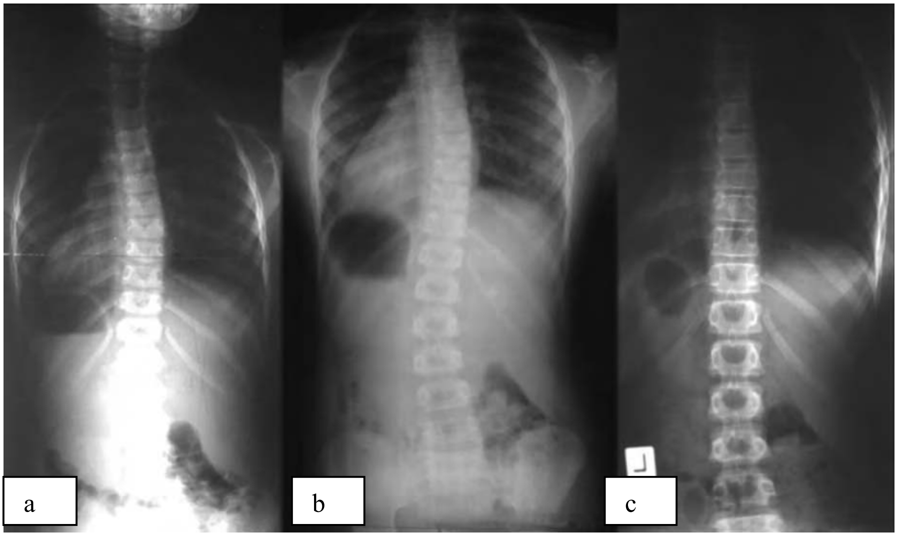

Figure 2. Girl treated exclusively by physiotherapy (without brace). She was seven years old in start of the therapy **(a)** - C=17, AVR=15; **(b)** after 34 months - C=17, AVR=5; **(c)** after 57 months of therapy - C=6, AVR=0. C-Cobb angle; AVR-apex vertebra axial rotation angle.

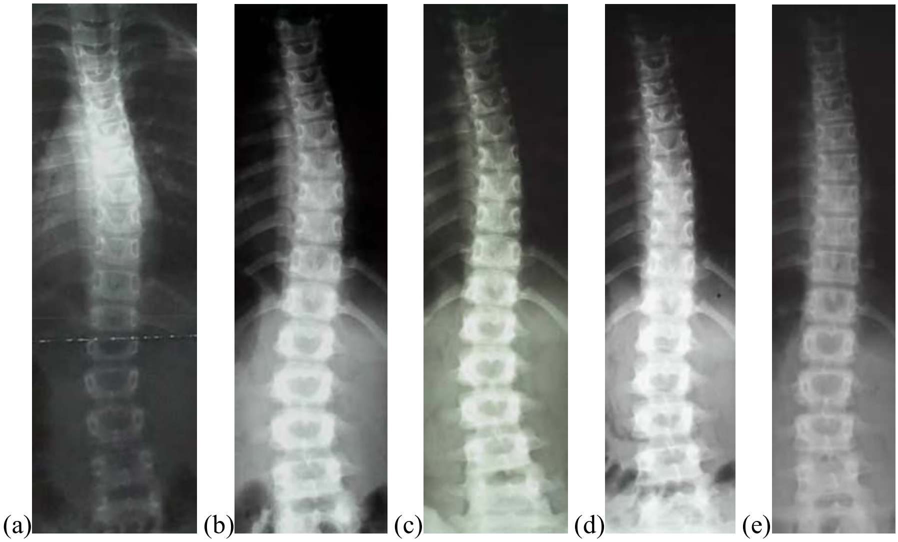

Figure 3. Girl treated exclusively by physiotherapy (without brace). She was eight years old in start of the therapy **(a)** - in L C=15, AVR=3 and in TH C=15, AVR=5; **(b)** after 13 months - in L C=17, AVR=3 and in TH C=26, AVR=2; **(c)** after 19 months - in L C=19, AVR=5 and in TH C=23, AVR=2; **(d)** after 30 months - in L C=12, AVR=5 and in TH C=16, AVR=3; **(e)** after 46 months of therapy - in L C=11, AVR=4 and in TH C=14, AVR=3;. C-Cobb angle; AVR-apex vertebra axial rotation angle; TH-thoracic curve; L-lumbar curve.

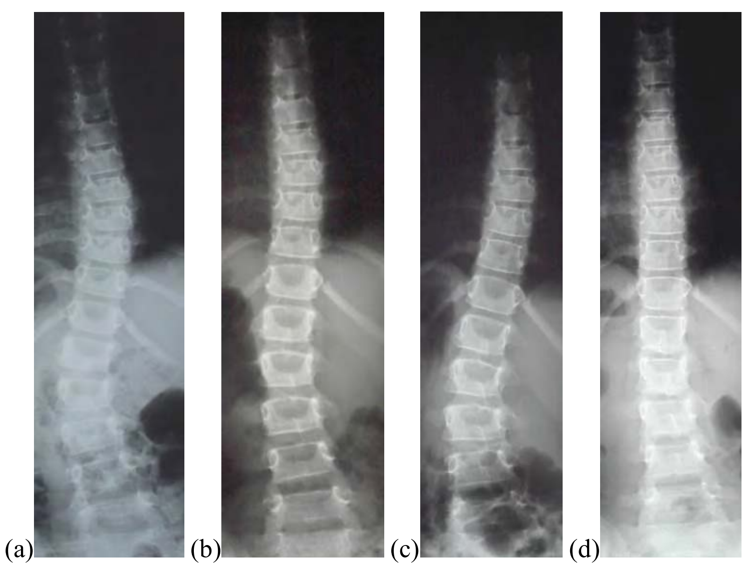

Figure 4. Girl treated by physiotherapy and brace (brace using - 21 months). She was six years old in start of the therapy **(a)** - in L C=30, AVR=5 and in TH C=28, AVR=8; **(b)** after 14 months - in L C=17, AVR=2 and in TH C=15, AVR=7; **(c)** after 25 months - in L C=27, AVR=5 and in TH C=18, AVR=5; **(d)** after 36 months - in L C=8, AVR=0 and in TH C=7, AVR=7.C-Cobb angle; AVR-apex vertebra axial rotation angle; TH-thoracic curve; L-lumbar curve.

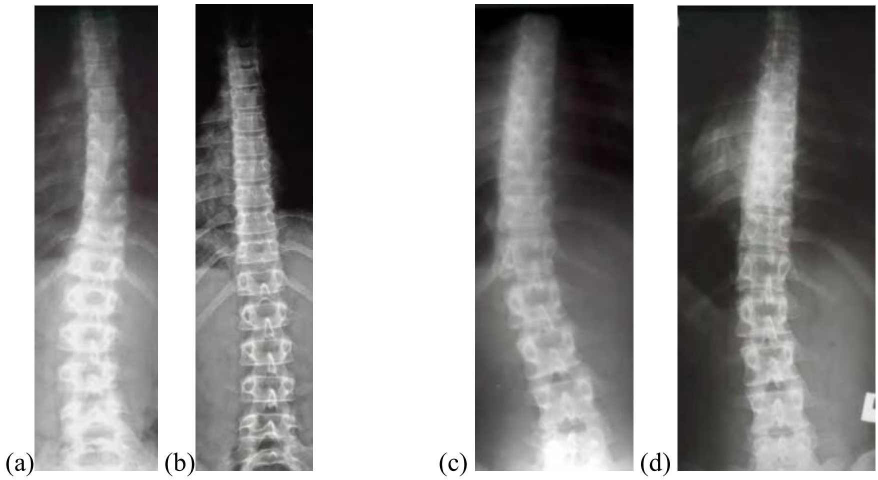

Figure 5. Girls treated exclusively by physiotherapy (without brace). **1st girl** was 11 years old in start of the therapy **(a)** - in L C=18, AVR=10 and in TH C=18, AVR=0; **(b)** after 18 months - in L C=0, AVR=5 and in TH C=0, AVR=0. **2nd girl** was 14 years old in start of the therapy **(c)** - C=25, AVR=10; **(d)** after 36 months - C=16, AVR=10.C-Cobb angle; AVR-apex vertebra axial rotation angle; TH-thoracic curve; L-lumbar curve.

4. Discusion

The Dobosiewicz method is difficult and requires frequent corrections during therapy. Largest effectiveness is achieved near daily, systematic exercises (the best together with trained parents). The basic aim of this method is to stop a progression, or correction of scoliosis. The Dobosiewicz method also improves the functions of respiratory and cardiac systems. [2,3,4,5] Presented results do not take into account the factor of patient's co-operation during therapy.

5. Conclusion

The radiological results demonstrated prevalent stabilisation of scoliotic curves in children with progressive idiopathic scoliosis, hospitalized and treated at least two times in the Department of Rehabilitation between October 1999 and December 2004.

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Trunk Rotational Strength Training for the Management of Adolescent Idiopathic Scoliosis (AIS)

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Abstract Quantified trunk rotational strength training has shown promise as a non-operative management option for individuals with AIS. The purposes of our study are to test whether a quantified trunk rotational strength training protocol can increase trunk strength and stabilize or decrease curve size. Seven adolescents with AIS (5 female 2 male; mean 14yrs ± 2.6yrs; mean Cobb 28°± 6° range 20°-37°) underwent four months of supervised trunk rotational strength training, and repeat strength test. Trunk strength in both directions increased significantly after training ($p<0.05$). Average Cobb angle decreased to 23°± 11° (range 6°–35°). Four individuals showed reduction (>5°) in their original curve, and 3 remained the same (±5°). The strength training protocol significantly increased isometric rotational strength and scoliosis was stabilized short term.

Keywords Strength training; scoliosis, conservative management; trunk rotation

Introduction

Exercise is widely viewed as an ineffective treatment for adolescent idiopathic scoliosis (AIS) [1-3]. Recently this dogma has been challenged [4-12]. In the earlier, unfavorable reports, a series of trunk stabilization exercises, intended to improve posture or pelvic stability, were used and may not have been intensive enough to affect the spinal curve. The recent favorable reports have generally been a variation of earlier themes utilizing an intensive exercise program, often with a home training component, combined with custom bracing for larger curves [4-6]. However, a new form of therapy, trunk rotational strength training, has recently been introduced and favorable preliminary results reported [7, 10]. Additionally, it has been shown that these types of conservative management options have not been thoroughly tested so as to include or rule out this training when treating AIS [13].

Spinal muscle abnormalities, such as differences in muscle fiber type, size, and activation levels have been reported in patients with AIS by a number of investigators [14-23]. Several paraspinal elctromyographic studies have revealed increased activity on the convex side particularly in patients with progressive curves [24, 25]. Circulating calmodulin [26] and muscle intracellular calcium [27] has also been found to be increased in progressive AIS. Calmodulin is calcium binding receptor protein and effects the contractile function of muscle. Altered, i.e. decreased, permeability of the muscle cell membrane is thought to prevent this binding action. Increased muscle activity, as seen with resistance training, has been shown to increase intracellular calcium and plays an important role in the pattern of genes that are expressed in the muscle [28]. These genes lead to determining the fiber type and how the muscle functions overall including muscle atrophy or hypertrophy [28].

Trunk muscle strength is a logical suspect for involvement in AIS pathogenesis as suggested through decreased muscle mass, relative weakness, and/or asymmetry. Decreased muscle mass is suggested as AIS females have decreased mesomorphism generally [29] and those with progressive curves less trunk mesomorphism and greater trunk ectomorphism [30]. Relative weakness is suggested by the significant decrease in normal females' trunk muscle strength from age 8 to 13 years, even though their extremity strength is increasing. Males' trunk as well as extremity strength increases over the same time span [31]. Trunk muscle strength asymmetry in AIS is recently reported using a measurement of trunk rotational strength and showed the reduction after a strength training program [7, 10]. It is important to further confirm those findings since the AIS related trunk rotational strength asymmetry may serve as a useful index in evaluating clinical outcomes of the management of AIS.

The purposes of this study are to compare the baseline trunk rotational strength side difference, develop a standard trunk rotational strength training protocol and determine its effect on strength after four months of training, and determine the short term effect of the training protocol on curve size.

Methods

A total of nine adolescents (8 females, 1 male), average age of 14 ± 1.7 years, with diagnosed AIS participated in the study (table 1). Subjects had an average Cobb angle of 29°±6° (range 20°-37°). Inclusion criteria: a) diagnosis of idiopathic scoliosis; b) Cobb angle between 20° - 40°; c) Risser sign < III d) age from 10 to 17 years old. Exclusion criteria include patients with any diagnosable neuromuscular disease or other cause of scoliosis. One patient (ST6) was originally tested as part of a baseline strength measurement and was not considered a candidate for the strength protocol due to her skeletal maturity (Risser III+). She later requested to join the strength training protocol when a family practitioner thought he noticed the curve had changed. She was allowed into the study because she was pre-menarchal.

Cobb Δ° – Change of Cobb angle after strength training with negative value indicating the decrease of the Cobb angle Each subject was tested in the baseline evaluation for trunk rotational strength using a standard testing protocol developed for this study. Briefly, a Biodex Multi-joint System 3 Pro (Biodex Medical Systems; Shirley, NY) was used to test trunk rotational isometric strength at five pre-rotated trunk positions: 36°, 18°, 0°, -18°, and -36° (negative values indicating a right trunk position) in both the contraction towards and away from the midline. Recorded torque data was processed using a “stable one” moving window to determine the mean value within a specified one-second window and then normalized to lean body weight to obtain the trunk rotational strength.

The training program lasted for four months with two training sessions per week, or a total of 32 training sessions. The training was conducted on a MedX Rotary Torso

Machine (MedX 96 Inc., Ocala, FL, USA), the same training machine used by Mooney et al. [7, 10]. Trunk rotation was resisted by a weight stack providing a constant resistance through the full range of trunk rotation. Based on the results of a reliability study subjects had significantly higher strength in the high force arcs than in the low force arcs. Therefore, the weights used in strength training were different in high and low force arcs in order to improve subject's strength in all arcs.

The preparation phase introduced the subject to the training environment and trunk rotational movement during the first 2-3 visits. In the first visit, after the warm-up, exercise began using 30% of the subject's lean body weight (LBW) for the high force arc and 20% LBW for the low force arc. The subject was instructed to perform 3 sets of 10 repetitions.

The strength training was broken into preparation and strengthening phases with a different number of training sessions (days) within each phase. Each training session would always begin with a warm-up, followed by strengthening, and end with a "burn-out" period. The warm-up consisted of a seven-minute walk on the treadmill at a speed of 3.0 mph and then one set of 20 repetitions on the trunk rotational machine at 20 lbs (the lightest weight) through the full range of motion. Strengthening was performed in the two different force arcs, high and low, on both the right and left side. The "burn-out" session consisted of 20 to 40 repetitions of 20 or 30 pounds (therapists' discretion) of weight. The participant would rotate from the pre-rotated position through the entire range of motion.

The goal of the strengthening phase was first to reach equal strength on the right and left sides and then increase the strength on both sides at the same pace. Training began with a weight of 25-45% of subject's LBW for low force arc, and 35-55% of subject's LBW for high force arc. The subject was instructed to complete 3 sets of 7 repetitions for each side for both low and high force arcs. The weight would be increased for the next training session by 5% of subject's LBW *only if* the subject could perform the task successfully on both sides. If the subject showed difficulty in lifting the increased weight, the therapist would assist the subjects' early attempts during the concentric direction and then allow the subject to lower the weight eccentrically. The increase of weight stack during training was decided separately on either the high or low force arc. Therefore, increases of weight proceeded at different paces for two force arcs depending on subject's performance on the specific force arc. The strengthening phase continued to the end of the training program.

Although not described in detail here, upon completion of the four month supervised strength training portion, all subjects were educated on a home exercise protocol. This consisted three sets of 15 repetitions of heavy Theraband® trunk rotational exercises three to five times per week. The goal of this phase was to maintain trunk muscle strength and activity.

A follow-up strength test and radiographic examination was performed at the end of the four-month training. Instead of reporting strength values as left direction or right direction, trunk strength is presented here in relation to the curve direction i.e. contractions towards the convexity of the curve and contractions towards the concavity of the curve. The pre- and post-training strength asymmetry at each of the five trunk positions was determined by comparing the convex and concave strength values. Paired t-tests were used for all comparisons and alpha was set at $p<0.05$.

Results

Baseline and four month follow-up trunk rotational strength values normalized to lean body weight for all five testing positions are presented in Figure 1.

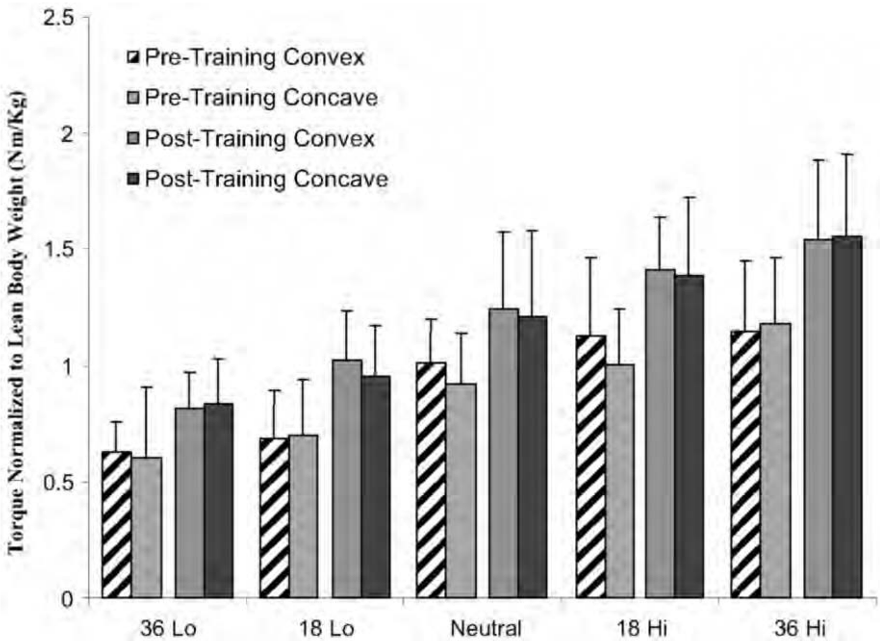

Figure 1 Pre-training and post-training torque values normalized to lean body weight. There were two marginally significant differences between convex and concave values at neutral and 18 Hi ($p<0.08$ and 0.09 respectively). All pre-training values were significantly lower than all post-training values, with the exception of one marginal difference at convex neutral ($p< 0.06$).

Strength increased significantly in all positions. On average the increase in strength was 22 percent (range 10-32%). There were two marginally significant differences between strength towards the convexity of the curve and towards the concavity of the curve. This was at neutral ($p<0.08$) and 18 Hi ($p<0.09$) positions (figure 1).

Baseline and follow-up curve measurements are presented in table 1. The average baseline curve size was 29° ± 6° and follow-up average curve size was 24° ± 10°. This difference reached significance ($p<0.02$). There were four patients that were able to be followed for an additional four months, (eight months from the start of training). This data is displayed graphically in figure 2.

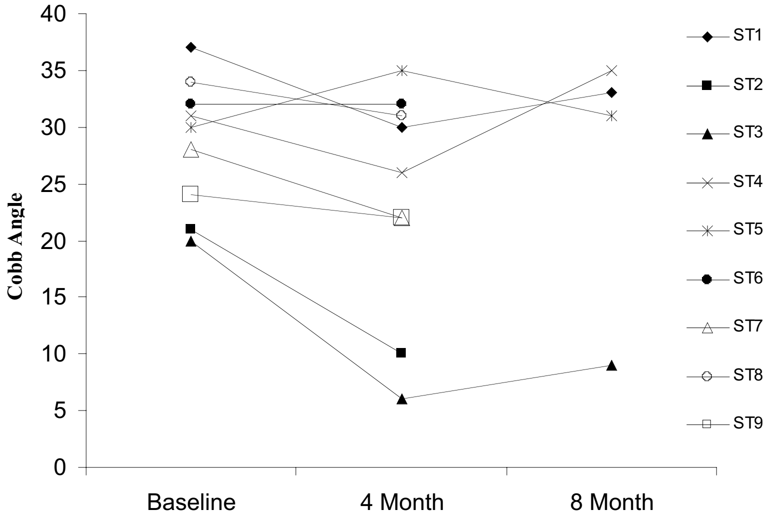

Figure 2 Cobb angle measurements overtime for all patients. ST 1, 3, 4, and 5 were able to be collected for a full eight months.

Subjects' compliance for the supervised training program was quite high. The subjects received 30 to 35 training sessions. The training period for subjects was on average 4.7 months (ranged 4-6 months). No injuries occurred during the training sessions.

Conclusions

Exercise is not generally considered an effective conservative management for AIS, especially in the United States [1-3]. There are numerous studies that challenge this dogma [4-12].

We found no trunk strength asymmetry in the patients at baseline, with two marginal differences at neutral and 18 Hi (figure 1). We report elsewhere that there appears to be a strength asymmetry in AIS patients. The patients enrolled in this arm of the study were also from the same group in which an asymmetry was measured. The lack of a significant asymmetry in the smaller cohort may be an artifact of the decrease in numbers.

We have suggested that this strengthening protocol is an effective option for the conservative management of AIS that is at least as effective as bracing. This is an ongoing study that will continue to recruit more patient numbers and extend follow-up so as to further confirm or refute this result. In any case strength training is showing promise as in the non-operative management of AIS.

The four patients who were able to be followed for an additional four months had mixed results. ST5, who originally showed a possible progression (measured at 5° change) showed a decrease in that amount after an additional four months. It should be noted that her strength continued to increase during follow-up home training. ST4, who originally showed a slight curve decrease, showed an increase in curve size after another four months. His strength decreased, he did not home strengthen,, and he has been re-enrolled in supervised strength training.

Table 1. Subject information including baseline and follow-up Cobb angles measured from radiographic films for each subject. For an easy comparison, the information on six patients after strength training is also included in this table.

Subject	ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	ST9
Sex	F	F	F	M	F	F	F	M	F
Menses (yr+mo)	No	13+3	No	NA	No	No	No	NA	No
Weight (kg)	50.4	48.2	31.1	44.1	39.6	51.7	39	49.8	49.8
LBW (kg)	42.7	39.9	29.4	42.6	37.8	49.7	37.2	47.5	46.9
Pre Strength Training									
Age(yr+ mo)	15+8	13+5	10+10	15+0	11+10	15+8	14+5	15+3	13+1
Height (cm)	156.8	170.2	149.9	162.6	151.1	160.5	152.4	170.2	167.6
Risser	0	II	0	0	0	III+	0	II	0
TRC	Closed	Closed	Open	Open	Open	Closed	Closed	Closed	Closed
Cobb °	37	21	20	31	30	32	23	34	24
Pattern (side)	Thoracic (L)	ThoracoL (L)	ThoracoL (L)	TL/L (L)	D Thor (R)	Thoracic (R)	D Thor (R)	TL/L (L)	Thoracic (R)
Post Strength Training									
Age (yr+mo)	16+5	13+9	11+3	15+6	12+3	16+3	14+9	15+9	13+5
Height (cm)	156.2	174.6	152.4	167	154.3	161	154	173.2	168.1
Height Vel (cm/yr)	0	13.2	6	9	7.7	<1	4.8	6	1
Risser	I	III	0	0	0	IV	0	IV-	II
TRC	Closed	Closed	Closed	Open	Open	Closed	Closed	Closed	Closed
Cobb °	30	10	6	26	35	32	22	31	22
Cobb Δ°	**-7**	**-11**	**-14**	**-5**	**5**	**0**	**-1**	**-3**	**-2**

LBW – lean body weight
Risser – Risser sign
TRC – Tri radiate cartilage
AVR ° - Apical vertebral rotation

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Chapter 5

Surgical Treatment

Research into Spinal Deformities 5
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Multiple Vertebral Wedge Osteotomy for Adolescent Idiopathic Scoliosis

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Abstract. 19 idiopathic and 1 syringomyelia scoliosis patients (17 females and 3 males) underwent fusionless, multiple vertebral wedge osteotomy and with follow-up for an average of 8.9 years. The average age at surgery was 16.4 years. The average curve magnitude measured by Cobb was 64.0° before surgery, 38.8° after surgery, 43.7° one year after surgery, 46.9° two years after surgery and 48.2° at the latest follow-up. The difference between the Cobb angle two years after surgery and latest follow-up was not significant. There were no major complications such as neurological problems.

Keywords. adolescent idiopathic scoliosis, fusionless surgery, vertebral osteotomy

Introduction

Spinal fusion has been the standard of care for surgical treatment of scoliosis. With fusion surgery, flexibility and mobility of the fused region are inevitably lost. Even the range of motion of the unfused region has decreased after surgery [1,2]. Although most of the long term studies reported that fused patients were comparable to age matched controls with regard to the quality of life and daily activities [3-8], adjacent segment problems such as early degenerative change at the lumbar segments [3,5,9-12] or proximal junctional kyphosis [13,14] have been reported. Low back pain was more frequent among the fused patients [3,8-10,15-18]. Incidence of implant related complications was relatively high [19,20]. Also, questions about late infections have been raised [20-23].

To eliminate these drawbacks of fusion surgery, we have performed fusionless, multiple vertebral wedge osteotomy for the treatment of adolescent idiopathic scoliosis (AIS) since 1987. Our attempt was to obtain correction with multiple vertebral wedge osteotomy and maintain it over the long term, and establish the procedure as a definitive surgical treatment for AIS. The purpose of this study was to determine whether the multiple vertebral wedge osteotomy could safely obtain correction of the deformity with AIS and maintain it over time.

1. Materials and Methods

The study sample consisted of 20 patients (17 females and 3 males) with 19 idiopathic and one syringomyelia scoliosis. Inclusion criteria were idiopathic scoliosis with right thoracic curve, the magnitude of which was a Cobb angle of greater 50 degrees. Preoperative radiographic studies revealed syringomyelia in one patient: the patient had a right thoracic curve and was otherwise normal, including negative neurological findings. This patient was not excluded from the sample under treatment because it was considered that spinal shortening by the osteotomy would not result in neurological deterioration.

1.1. Description of the surgical procedure

All surgery was undertaken with an anterior approach via thoracotomy, with the patient in the lateral decubitus position. Rib heads on the convex side were resected to identify neural foramina and pedicles. The inferior cut was made with an osteotome parallel to and 2 to 3 mm above the inferior endplate. The second cut was made with an osteotome 8 to 10 mm above the inferior cut at the bottom of the wedge. The apex of the wedge was made on the concave side of the curve with an osteotome and an air drill. In the upper half of the curve, it was attempted to make the bottom of the wedge to run obliquely, so that derotational movement could occur by closing the wedge (Figure 1). The posterior wall of the vertebral body and the inferior one-third of the pedicle on the convex side were removed with an air drill and a Kerrison rongeur. When the osteotomy was completed, the fragments became mobile independently of each other by turning of the osteotome between them. Five to six non-absorbable sutures were placed at each osteotomy site. Supra- and inter-spinous ligaments were cut percutaneously with a blade before the closure of the osteotomies. Zielke screws were inserted into cranial and caudal adjacent vertebrae to the osteotomized segments and wedges were closed as much as possible by the Zielke system. Sutures were secured and Zielke system instruments were removed. Postoperatively, patients were allowed to walk after the chest tube was removed. The cast or an orthosis was continued until pain diminished, generally, two to three months after surgery.

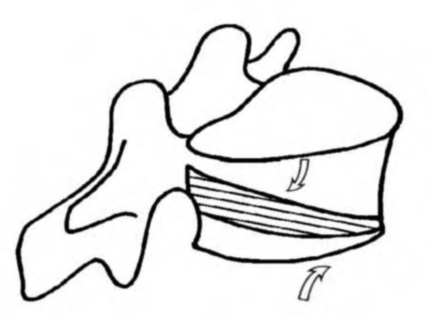

Figure 1. By closing the obliquely oriented wedge, rotational motion occurred in the vertebra.

1.2. Data Collection and Analysis

The coronal Cobb angle before surgery, on the first standing radiograph after surgery, one year after surgery, two years after surgery and at latest follow-up were compared. Sagittal alignment was measured with the Cobb method at the osteotomized region and between the third and twelfth thoracic vertebrae. The rib hump was measured with a scoliometer. Complications of the treatment were investigated. For statistical analysis, paired t tests were used for continuous variables measured at two time points. A p value of < 0.05 was considered significant.

2. Results

The average age of the patients at surgery was 16.4 years (range 13 to 28 years). Risser sign was 0 in two patients, I in two, IV in five, and V in 11. Curve type according to the King classification was type II in two patients, III in nine, IV in five, and V in four. The average preoperative curve magnitude was 64.0° (range 52 to 78°) as measured by the Cobb method. The patients underwent wedge osteotomies on 3.6 vertebrae on average (range, 2 to 5 vertebrae) in the region from T6 to T12. The average operation time was 662 minutes (range, 430 to 830 minutes) and the average estimated blood loss was 1155 ml (range, 200 to 2500 ml). There were no neurological complications. One superficial wound infection necessitated debridement. Except for one patient who needed 3 units of allogenic blood transfusion, blood loss could be covered by the patient's pre deposited autologous blood. The average follow-up period was 8.9 years (range 2.0 to 17.2 years).

2.1. Deformity Correction

Changes of Cobb angle are shown in Figure 2. The average coronal curve before surgery was 64.0° (range, 52 to 78), which was corrected to 38.8° (range, 19 to 57) on the first standing radiograph after surgery: initial correction rate was 39%. At one year after surgery, the average Cobb angle was 43.7° (range, 14 to 72). Because of the deterioration of their deformity after surgery, two patients were converted to posterior instrumentation and fusion surgery at 29 and 16 months after the initial procedure, respectively. With regard to these two patients, the Cobb angle just prior to the second procedure was used in the later analysis. The average Cobb angle was 46.9° (range, 17 to 78) at two years after surgery and was 48.2° (range, 14 to 78) at the latest follow-up (mean, 8.9 years). Final correction rate was 24.7% for all the patients, but for 16 patients with Risser IV or V, that was 29.4% (61.3° before surgery and 43.3° at the latest follow-up). The difference between Cobb angle before surgery and at latest follow-up was statistically significant ($p < 0.0001$). The difference between Cobb angle on the first standing radiographs and two years after surgery was statistically significant ($p = 0.0212$), whereas between two years after surgery and at latest follow-up it was not significant ($p = 0.1451$).
In the sagittal plane, kyphosis at the vertebrae which underwent osteotomies increased by 13.3° on an average, and thoracic kyphosis between the third and twelfth thoracic vertebrae also increased by 12.0°. The average rib hump measured with a scoliometer was 16.4° before surgery and 11.7° at the latest follow-up ($p = 0.0171$). Case illustrations are shown in figure 3.

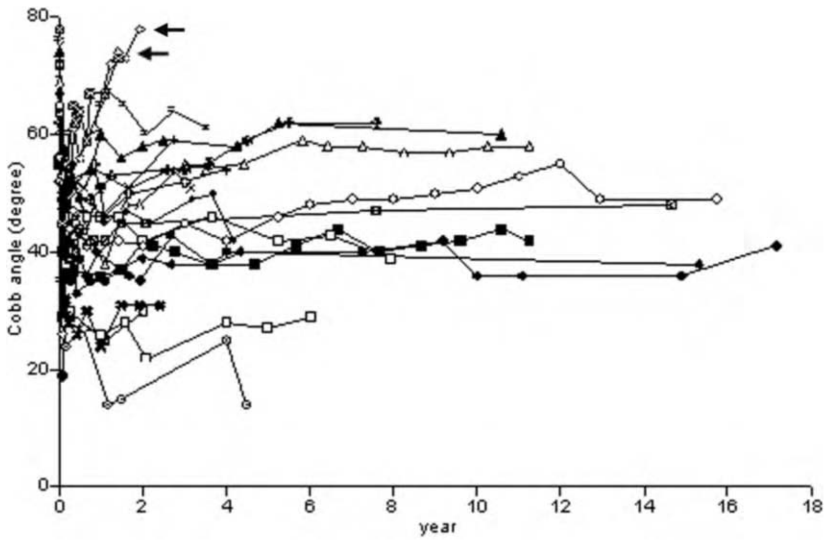

Figure 2. Changes of Cobb angle. Two patients whose curve deteriorated after wedge osteotomy (arrows) were converted to posterior instrumentation surgery.

3. Discussion

The current study was undertaken in order to determine whether multiple vertebral wedge osteotomy can safely obtain correction of the deformity with AIS and maintain it for a long term. Although the operative time was long, perioperative complications were very few. Two patients who needed reoperation due to deterioration of the deformity after multiple vertebral wedge osteotomy had either a preoperative curve of 76˚ and Risser I or with a preoperative curve of 78 and Risser 0. These results indicated that our methods were not suitable for patients with larger curve (> 70˚), or skeletally immature patients with Risser sign of 0 and I. Because thoracic kyphosis increased after surgery, patients with kyphoscoliosis were also contraindication of our procedure. As the results of this study, 25% correction of the coronal plane deformity was obtained at an average follow-up of 8.9 years. Although statistically significant loss of correction had occurred during the first two years after surgery, correction was maintained thereafter. Further long-term observation is necessary to make certain whether any additional increases of the Cobb angle occurs.

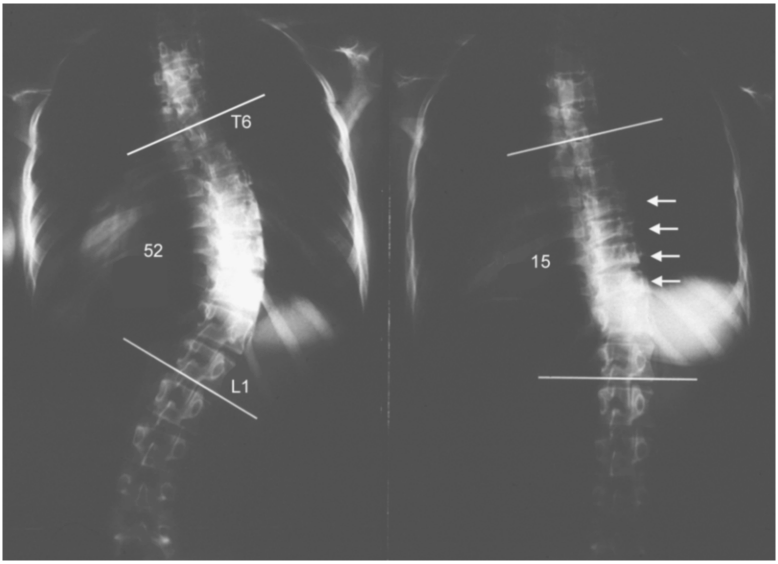

Figure 3. Standing posterior-anterior radiographs of a 17-year-old female before surgery and two years after wedge osteotomies on T8, 9, 10 and 11 (arrows). Curve from T6 to L1 was reduced from 52˚ to 15˚.

Conclusion

Fusionless, multiple vertebral wedge osteotomy could safely correct the scoliotic deformity in adolescent idiopathic scoliosis and the correction is maintained for a long term.

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Research into Spinal Deformities 5
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Experimental Usage of Hydroxyapatite Preadsorption with Fibronectin to Increase Permanent Stability and Longevity of Spinal Implants

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Abstract. Hydroxyapatite has been used in orthopaedic and particularly in spinal surgery by precoating implants to indirectly increase osteoblasts' adhesion and subsequently their stability and longevity. Fibronectin preadsorption synergistically with appropriately constructed hydroxyapatite's surface texture to enhance osteoblasts' adhesion has not been, to the authors' knowledge, previously investigated. In osteoporotic spines, methods to increase implant stability (pedicle screws and cages) are of major value.

Objective: This experimental study investigated the contribution of fibronectin preadsorption to enhance osteoblasts' adhesion and strength on hydroxyapatite.

Methods: Hydroxyapatite substrata with two different surface roughnesses (rough HA180 and the smooth HA1200) were produced and human osteoblasts were seeded on them after culture. Prior to osteoblasts seeding, the hydroxyapatite substrata were immersed in fibronectin solution. Osteoblast attachment on each of the two hydroxyapatite substrata was evaluated by recording the number of cells, while the osteoblast's adhesion strength was determined by measuring the shear stress required to detach the cells from the hydroxyapatite substrates.

Results: Fibronectin preadsorption increased the number of attached osteoblasts on smooth and rough hydroxyapatite substratum at 40% and 62% respectively, while it increased osteoblast attachment strength on the smooth and rough substratum at 165% and 73% respectively.

Conclusions: Fibronectin preadsorption and smooth hydroxyapatite surface texture synergistically increased the adhesion's strength of human osteoblasts"in vitro", while preadsorption and rough hydroxyapatite surface increased the number of attached osteoblasts. Further studies in primates and human beings should be carried out to disclose the clinical relevance of the above mentioned observations in spine surgery.

Keywords: Fibronectin, preadsorption, Hydroxyapatite, osteoblast adhesion strength

Introduction

Osteoblast adhesion onto biomaterial's surfaces (titanium, tantalium, hydroxyapatite etc) currently used in spine surgery is particularly important to bone-biomaterial interactions and tissue engineering applications. The strength and the type of osteoblast adhesion on biomaterials are determined by proteins adsorbed onto implant surfaces from physiological fluids, along with those produced by the osteoblasts, depending on the substratum's properties [1]. Cell adhesion to proteins provides mechanical coupling to the underlying substrate and triggers signals that direct subsequent cellular responses, including proliferation and differentiation [2]. Adsorption of adhesion proteins from serum-containing solutions mediates osteoblast adhesion "in vitro".

Among serum proteins, fibronectin (FN), vitronectin and collagen type I have been found to promote mostly osteoblast adhesion on biomaterials [1,3,4,5,6]. FN-preadsorption increases cell attachment on various substrates [4,7,8,9,10]. Precoating of bioactive and non-reactive glasses with FN resulted in higher osteoblast detachment strength [9,11].

Surface roughness and topography of biomaterials also play a crucial part in cell-biomaterial interaction. Variations in surface texture or microtopography affects the cellular response to an implant [4,12,13,14,15]. Cell adhesion, proliferation and detachment strength have been shown to be surface roughness-sensitive and increased as the roughness of Hydroxyapatite (HA) increased [14].

Traditional calcium-phosphate ceramics CaP (HA, BCP, β-TCP) have commonly been used as granules or blocks to accelerate or improve spinal fusion. Hydroxyapatite coating is a surface modification that has been suggested as a method to improve the bone-implant interface. Osteogenic proteins and transforming growth factors have been used for osteoinduction in interbody fusion cages [16,17,18,19].

The purpose of the present investigation was to determine the role of FN in facilitating the initial attachment of osteoblasts on HA and the synergistic effect of HA surface roughness on osteoblast adhesion on it.

Materials and Methods

The HA powder was prepared by slow mixing precipitation through calcium nitrate and ammonium phosphate solutions at pH 10.0 and 70^0 C under stirring. The HA powder was compacted in disc shape pellets of 10 mm diameter by pressing at 150 MPa and sintered at 1200^0 C for 10 hours and they were further processed to produce surface with different values of surface roughness. Surface roughness was produced by polishing with Silicon carbide (SiC) metallographic paper 180, and 1200-grit (HA180 and HA1200 respectively), to a single direction in order to obtain regular and similar morphology for all samples. Before the seeding of the cells, all discs were autoclaved. In all experiments, cells were cultured on discs placed in 12-well plates (Costar). Cells cultured directly on the surface of the tissue culture plate were used as a control.

Surface roughness of the HA disks was measured by profilometry using a Mitu-loyo SURFTEST 301 (Tokyo, Japan) profilometer. Five disks were measured from each of the two different surfaces to obtain an average surface roughness value R_a. Five individual measurements were made on each specimen. Statistically significant differences in the R_a values were determined by ANOVA statistical analysis. Differences were considered significant if $P<0.05$. The morphology and texture of surfaces was determined by SEM

The adsorption on HA of two proteins, bovine serum albumin (BSA) (electrophoresis, pure >96%, Sigma, Germany) and FN (bovine plasma FN, lyophilized, >96% pure, Life Technologies, Karlsruhe, Germany) was studied by radiolabeling. FN and BSA were 125I-labeled as previously described [15]. Prior to protein adsorption, the HA-disks were washed with PBS 0.1 M, pH 7.4. The labeled protein was introduced with an arbitrary concentration of 4 μCi/ml (7x104 CPM/mg). The adsorption was carried out by incubating the samples with protein solutions for 0, 15, 30, 60, 120 or 180 min. The radioactivity of each sample was counted in triplicate with a gamma counter and the surface concentration (mg/cm2) of the protein was calculated.

Prior to the cell seeding, the HA disks were coated with FN, diluted in PBS (0.1 M, pH 7.4), by immersion in the solution for 30 min at 220 C. Subsequently, they were immersed in 1% BSA for 30 min, in order to block the non-specific adhesion sites (adhesion mediated by proteins, different from FN, contained in the culture medium) [20]. The coating concentration was 10 μg/ml [21]. The disks allowed to air dry and were washed with PBS. Immediately before cell seeding the disks were equilibrated in serum-free medium.

For the purpose of the present study, human bone marrow stromal cells were obtained by aspiration from the femoral canal of patients aged 50-70 years, who underwent elective total hip replacement. All donors have been preoperatively controlled for systematic and local infection and malignancy, while specimens taken intraoperatively were sent for histology and cultures for bacteria. From each donor, a “single-cell” suspension was prepared by repeatedly aspirating the cells successively through 19 and 21 gauge needles. The cell suspension was cultured until confluence in α-MEM (Gibco, Life Technologies GmbH, Karlsruhe, Germany) with 10% fetal calf serum (FCS) supplemented with 2,5 μg/ml Fungizone (Gibco), 50 μg/ml, gentamicin (Gibco), 10-8 M dexamethasone (Sigma, Aldrich Chemie GmbH, Germany), 1.5 mM β-glycerol phosphate (Sigma) and 50 μg/ml ascorbic acid (Sigma) and incubated at 37o C in a humidified atmosphere of 95 % air and 5% CO2. These specific culture conditions “direct” the bone marrow cell culture to form osteoblasts [20]. Positive identification of the cultured cells as osteoblasts was by staining for alkaline phosphatase activity (Sigma diagnostic kit, 85L-2, St. Louis, MO).

Cell attachment on each substratum was evaluated by recording the number of cells attached after 2 hours of incubation as follows: The cells were seeded onto the materials with a density of 15,000 cells/cm^2 and incubated. Afterwards, the specimens were washed with PBS to eliminate unattached cells. The adherent cells were removed from the substratum by incubation with trypsin 0,25 % in EDTA (Gibco). The resulting cell suspension was counted with a particle counter (Coulter® Z2, ETL Listed, NY). The results were expressed as the number of adherent cells per surface unit of the material or the plastic culture plate (positive control).

Cell attachment was also quantified with the determination of the activity of N-acetyl-β-D-hexosaminidase which is a lysosomal enzyme [15].

The adhesion strength of the osteoblasts was determined by measuring the shear stress required to detach the cells from their substrate. The shear stress was applied to the osteoblasts on the HA discs using a rotating device, described elsewhere [14].

Results

The surface roughness Ra of HA when polished with 1200 grit Sic paper was significantly (P<0.001) more than that obtained with 180 grit paper. In particularly, the R_a -value of the HA surfaces were 0.8± 0.2 and 4.5±0.5 μm when polished with SiC paper of 1200- and 180-grit, respectively. The obtained pattern of the HA-surface was alternatively parallel grooves and ridges spaced apart about 25 and 75 μm for HA1200 and HA180 respectively.

Fig. 1 shows the surface concentrations of the two proteins (FN and BSA) which were absorbed on the smooth HA1200 and rough HA180 substrata as a function of time. Radiolabeling indicated that FN proteins were absorbed in a very short time.

Surface roughness influenced the adsorption of both FN and BSA proteins. The smooth substrate HA1200 adsorbed larger quantities than the rough HA180 and more specifically HA1200 adsorbed approximately 2.6-fold larger quantities of both FN and BSA than rough HA180. The surface concentrations of FN reached a plateau in about one hour. On the contrary, BSA concentrations did not reach a plateau after 3 hours.
The number of osteoblasts attached on each substratum per HA surface unit is shown in Fig. 2.
The osteoblasts' attachment, enzymatically assessed, is depicted in Fig. 3. The number of attached osteoblasts, determined by both methods (counting and enzymatically), increased as the HA surface roughness increased. FN preadsorption also increased the number of adherent osteoblasts on all substrates. FN preadsorption on HA1200 increased at 40.3% the number of attached osteoblasts. Synergistically, the roughness produced with SiC 180-grit and FN preadsorption increased the number of attached osteoblasts at 61.5%, using the smooth surface HA1200 as reference. The values 40.3% and 61.5% were the average values derived from the two different methods of osteoblasts calculation: direct osteoblasts counting and enzymatic determination.

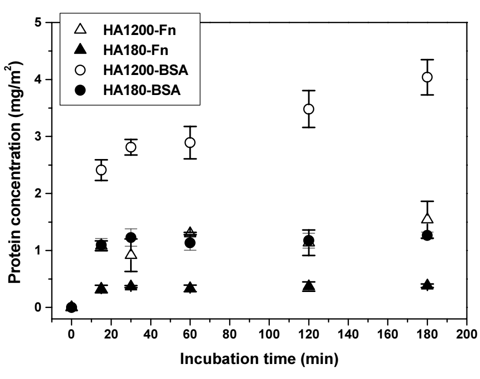

Figure 1: Surface concentrations of FN and BSA absorbed on smooth (HA1200) and rough (HA180) HA surface as a function of time, determined by radiolabeling.

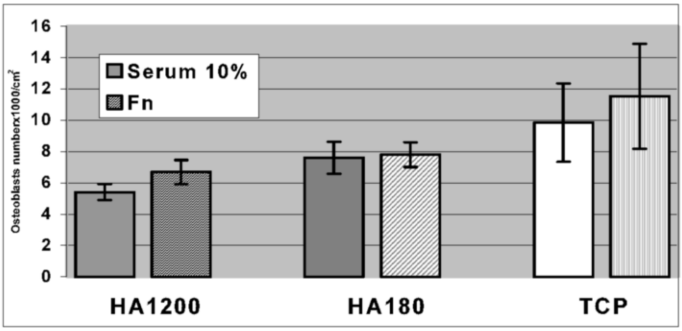

Figure 2: Human osteoblasts' attachment on HA disks with two surface roughness values and the control (tissue culture plastic, TCP), after two hours of incubation, determined by the particle counter. The substrates are precoated with FN or immersed in culture medium + 10% serum before cell seeding. Values are the mean ± SD.

Statistically significant ($P < 0.01$) differences were found in the number of adherent osteoblasts between smooth and rough substrates, both with and without FN preadsorption.

Osteoblasts' attachment experiments on protein preadsorbed substrates confirmed the inhibitory effect of adsorbed BSA and the promoting effect of FN (Fig. 4).

Although the smooth HA1200 substrate absorbed 3-fold larger quantity of FN than the rough HA180, HA1200 substrate displayed almost equal increase of osteoblasts' attachment, when it was coated with FN.

Figure 5 displays the percentage of the remaining attached cells, after exposure to shear stresses for 10 min, as a function of the applied stress, on the two HA substrates (HA1200 and HA180), either precoated with FN or not. This percentage was calculated as the number of the attached cells on a 1 mm^2 surface divided by the number of cells on a 1 mm^2 surface in the centre of the HA disk, where the magnitude of the applied shear stress was zero.

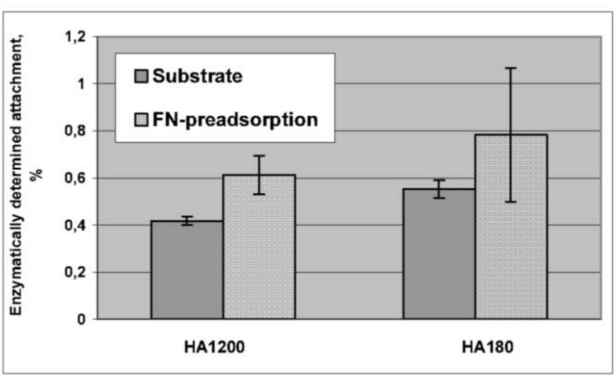

Figure 3. Human osteoblasts' attachment on HA disks with two surface roughness values after two hours of incubation, determined enzymatically. The substrates are precoated with FN or immersed in culture medium + 10% serum before cell seeding. Values are shown as mean ± SD.

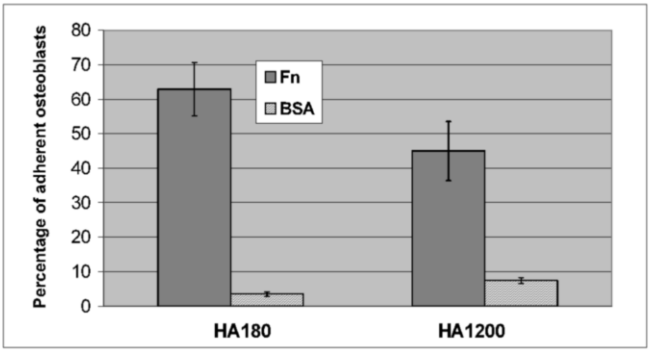

Figure 4. Human osteoblasts' attachment on HA disks with two surface roughness values. Adhesion is displayed as the percentage of cells attached after two hours of incubation. The substrates were precoated either with FN or with BSA. Values are the mean ± SD.

τ_{50} is defined as the shear stress required to detach 50% of the osteoblasts (or 50% of the osteoblasts remaining attached) and can be regarded as the attachment strength of the cells on the substrate. The attachment strength was 85 MPa and 130 MPa for the HA1200 and HA180 substrata, respectively. This means that the osteoblasts' attachment strength of the cells on the rough HA180 surface was 53% larger than that on the smooth HA1200 surface.

FN preadsorption increased the value of τ_{50} at 165% and 73% for HA1200 and HA180 respectively.

No differences in the values of the attachment strength were observed between the smooth and rough substrata, when they had preadsorbed FN. The latter should be due to the increased amounts of FN preadsorption on HA1200.

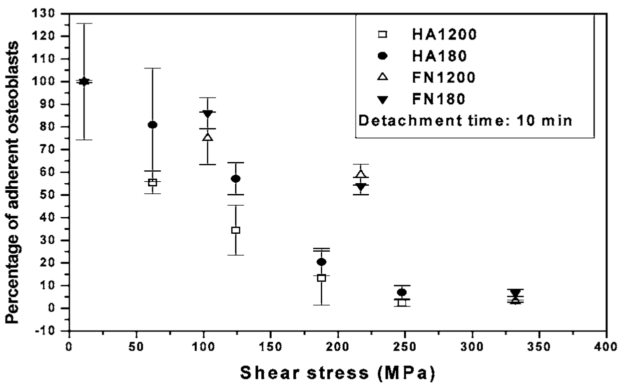

Figure 5. Percentage of the osteoblasts remaining adherent on HA disks as a function of the applied shear stress. Substrates precoated either with FN or immersed in culture medium + 10% serum before cell seeding. Values are the mean ± SD. HA1200=polished with 1200-grit paper, immersed in culture medium + 10% serum, HA180=polished with 180-grit paper, immersed in culture medium + 10% serum, FN1200=polished with 1200-grit paper, precoated with FN, FN180=polished with 180-grit paper, precoated with FN.

Discussion

The almost immediate event that occurs upon implantation of biomaterials is the adsorption of proteins on their surface [18,19]. Once on the biomaterial's surface, these proteins can desorb or remain "in-situ" to mediate tissue-implant interactions producing a "conditioning film" on biomaterials [22,23]. In fact, the nature of this film that is deposited on biomaterials is believed to be responsible for the implant behaviour [24]. Currently, different approaches are being used to achieve the desired bone-implant interface and specifically to increase the bone adhesion strength on it that subsequently will safeguard a permanent implant's stability. Thus, an "ideal" spine implant's surface such as HA that is used as osteoconductive bone substitute (sea coral, calcium phosphate etc) should have a surface with osteoconductive property to enhance spine fusion. Furthermore, the combined use of preadsorbed HA graft substitute and pedicle screws pre-coated with preadsorbed HA in patients with osteopenic bone, who undergo long spine fusion for spinal deformities (polio, neuromuscular diseases etc), should theoretically increase the implants initial and permanent stability and fusion rate.

Nowadays, much effort is being devoted to methods of modifying surfaces of biomaterials to achieve the desired biological responses. These modifications can be classified as physicochemical, morphological or biochemical [25]. The morphological methods are alterations in surface morphology and roughness or porous coatings, etc. The goal of the biochemical surface modification is to immobilize proteins, enzymes or peptides on biomaterials for the purpose of inducing specific cell and tissue response, with molecules delivered directly to the interface.

Proteins typically adsorb as quickly as they arrive at the relatively empty biomaterial's surface, taking into account the selectivity of adsorption of different surfaces. Preadsorption of a protein on a biomaterial is the covering of the biomaterial with this particular protein before implantation. This preadsorption is very important, since in a later phase after implantation of a biomaterial, it is difficult for other arriving to the biomaterial proteins to find and fit into an empty spot on the biomaterial's surface. Albumin, the main protein of the plasma and interstitium, is one of the proteins that arrives first to the biomaterial' surface after its implantation, because of its high concentration in serum and its low molecular weight, depending on albumin's affinity for adsorption onto this surface. Preadsorption of bovine serum albumin (BSA) onto biomaterials' surface partially inhibits osteoblasts attachment [15,26].

Osteoblasts' adhesion onto biomaterial's surface is particularly important for the interactions between bone and biomaterial and tissue engineering applications. The strength and the type of osteoblasts' adhesion on biomaterials are determined by proteins (FN, vitronectin, collagen, etc) depending on the biomaterial's surface properties [1].

Hydroxyapatite, and generally calcium phosphate-containing bone graft substitutes are currently successfully used in spine surgery as osteoconductive bone grafts substitutes alone or mixed with bone graft and/or bone marrow both in anterior, posterior and posterolateral spinal fusion. In addition, precoating of pedicle screws with HA has been used to increase in some instances their pullout strength and stability, to decrease failure rate (pullout, vertebral breakage, screw migration etc) and thus to enhance posterior fusion rate in patients with weak and osteopenic bone. Precoating of mesh cages used in anterior spinal surgery with HA preadsorbed with FN should theoretically increase their stability and longevity avoiding migration of the cages placed in osteoporotic vertebral bodies.

A complete understanding of the osteoblast behavior at a biomaterial's interface is essential for the clinical application and usefulness of biomaterials. In the present investigation, the authors examined the role of FN in facilitating the desired initial attachment of osteoblasts on HA and the synergistic effect of HA surface roughness on osteoblasts's adhesion. Additionally, the present study has determined the number of adherent osteoblasts on HA surface and estimated the osteoblasts's adhesion strength. The significance of adhesion strength on biomaterials is obvious because it contributes much to permanent implant fixation.

The HA roughness, produced for the experiments of the present study, consisted of almost parallel grooves and ridges, since it has been accepted that surface regular patterning is an important factor for cell proliferation and differentiation [12]. The authors of the present study believe that constructing the outer surface of pedicle screws and cages used for vertebral body replacement with HA with parallel grooves should at least theoretically increase the adhesion strength of the osteoblasts, creating permanent stability.

In this study, FN and BSA adsorption from single protein solutions of 10 μg/ml in PBS on HA surfaces was studied in order to see the affinity of HA for these proteins and the time of their adsorption. It was revealed that the "plateau" amounts of proteins absorbed were 1.2 mg/m^2 on HA1200 and 0.45 mg/m^2 on HA180.

Lhoest et al [27] reported that following FN preadsorption about 50% of the smooth HA surface (HA1200) and 25% of the rough HA surface (HA180) was covered by FN. Thus, the HA adsorbed a rather low amount of FN, leaving at least half of the HA surface uncovered. The osteoblasts' response is therefore highly affected by the physicochemical properties (roughness) of HA. The low (25%-50%) coverage of HA surface with FN is disadvantage of this method of preadsorption and at least theoretically another method that could better immobilize FN molecules on the HA surface could offer superior HA-surface coverage and subsequently increase implant stability.

In the present study, the area of the total HA surface that was bound with FN did not directly correlate with FN activity to promote osteoblast attachment. In the present study, osteoblasts' adhesion strength, was greater on rougher HA substrates, while FN adsorption was lower on them. It has been previously shown that osteoblasts' adhesion and spreading are greater for FN absorbed on hydrophilic surfaces than on hydrophobic ones [21]. FN is known to undergo conformational changes upon adsorption [28,29]. This is probably the explanation for the greater adhesion on rough HA that was shown in this study. The substratum physicochemical features influence the adhesive behavior of osteoblasts through FN and cell surface receptor reorganization and conformation [30[31,32].

According to Lhoest et al [27], the surface concentration value of 1.3 mg/m^2 found in this study, corresponds to a 50% coverage of the surface of HA180 with BSA, and the 3-fold greater value for HA1200 reveals perhaps that second layer of BSA has been adsorbed. This is the reason for the inhibitory effect of absorbed BSA on cell adhesion on both HA surfaces.

In conclusion, the major findings of this study are: 1) HA surface roughness has a significant effect on cell adhesion as confirmed by both cell counting and enzymatic analysis, 2) rough HA surfaces were associated with higher numbers of cell adhesion, 3) coating HA with FN increased cell adhesion compared to coating with serum albumin, and 4) osteoblasts's adhesion strength was similarly increased by surface roughness and by pre-treatment with FN.

Further clinical studies in primates and human beings should be carried out to show "in vivo" the clinical relevance of the above mentioned observations. If the results are reasonable then fibronectin preadsorption and surface roughening could be used in special indications in spine surgery to improve implants' stability and longevity.

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Relation Between the Sagittal Pelvic and Lumbar Spine Geometries Following Surgical Correction of Adolescent Idiopathic Scoliosis: A Preliminary Study

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Abstract. The influence of surgery on the relationship between the lumbar spine and the pelvis in adolescent idiopathic scoliosis (AIS) remains mostly unknown. The sagittal spinopelvic balance of 40 patients with AIS undergoing posterior spinal instrumentation and fusion was studied. After surgery, the total lumbar lordosis (LL) and the LL below fusion remained correlated to the sagittal pelvic geometry. LL within fusion, which is set by the instrumentation, was also related to the LL below fusion. This preliminary study shows that pelvic morphology probably has an important impact on the postoperative sagittal lumbar alignment. Evaluation of the sagittal pelvic geometry could therefore be useful in the preoperative planning of surgery for AIS. Further studies with more patients are still needed in order to confirm this hypothesis and to evaluate if the distal fusion level influences the spino-pelvic balance.

Keywords. Adolescent idiopathic scoliosis, lumbar lordosis, pelvic morphology, sagittal alignment, spinal instrumentation

Introduction

Correlations between sagittal spinal and pelvic geometry have been reported in many studies. Significant relationships were found in healthy subjects [1-11], as well as in subjects with adolescent idiopathic scoliosis (AIS) and spondylolisthesis [3-5,7-9]. When surgery for subjects with AIS is required, restoration or preservation of the physiological spinal sagittal curves is as important as the correction of the spinal coronal curves. In addition to posterior spinal instrumentation and fusion (PSIF), postoperative spinal sagittal alignment can be influenced by many other factors. Our hypothesis is that the pelvic morphology influences the postoperative lumbar spine geometry. However, the relationship between pelvic parameters and lumbar lordosis after PSIF has not been studied in detail, and remains poorly understood.

This preliminary study was undertaken in order to investigate the influence of PSIF on the relationship between sagittal spinal and pelvic geometries in patients with AIS treated by surgery.

Materials and Methods

Forty patients diagnosed with AIS treated with PSIF were included in this study. The preoperative and postoperative (at last follow-up visit) digital standing lateral radiographs of the spine and pelvis including the two femoral heads were reviewed. A minimum follow-up of 6 months was available for all patients. All radiographs were taken in the same standardized position.

All radiographs were evaluated using the SpineView software (SurgiView, Paris, France). This software allows to calculate each parameter after identifying the upper and lower endplate of each vertebra from L1 to S1 and the two femoral heads. The following parameters were measured (Figure 1): 1) lumbar lordosis (LL) between L1 and S1, 2) lumbar lordosis within fusion (LL within fusion) between L1 and the lower endplate of the lowest instrumented vertebra, 3) lumbar lordosis below fusion (LL below fusion) between the lower endplate of the lowest instrumented vertebra and S1, 4) pelvic incidence (PI), 5) sacral slope (SS), and 6) pelvic tilt (PT).

Pearson correlation coefficients were calculated between each pelvic and spinal parameter using the InStat software (GraphPad Software, San Diego, USA). The level of significance was set at 0.01 due to the multiple statistical tests performed in this study.

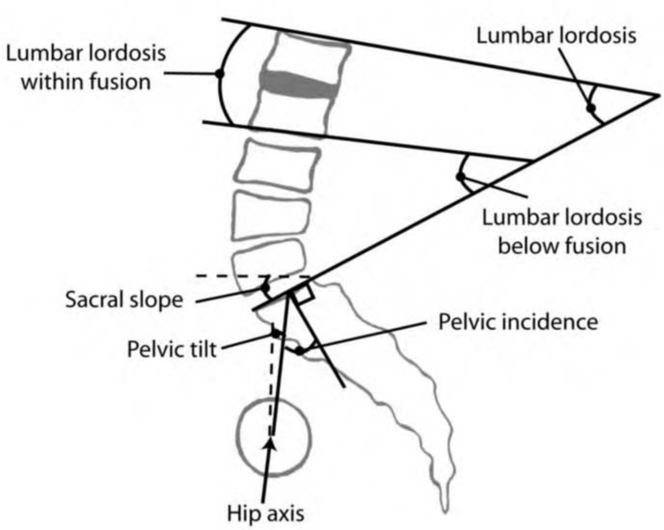

Figure 1. Sagittal lumbar and pelvic parameters from the standing lateral radiograph. The hip axis is located midway between the center of the two femoral heads.

Results

Many significant correlations could be found between pelvic and spinal parameters, before and after surgery. Table 1 presents the results from the correlation analysis. PI and SS were strongly correlated with LL both preoperatively and postoperatively. On the opposite, none of the lumbar parameters was significantly influenced by PT. Strong correlation is found for postoperative LL below fusion with SS. The correlation coefficient between PI and LL below fusion is not significant. None of the pelvic parameters seem to influence the LL within fusion. A strong negative correlation is found between LL below fusion and within fusion postoperatively.

Table 1. Correlations between pelvic and sagittal spine parameters

	Preop		Postop	
Parameters	r	P-value	r	P-value
LL-PI	**0.54**	*$<10^{-3}$*	**0.69**	*$<10^{-4}$*
LL-SS	**0.76**	*$<10^{-4}$*	**0.88**	*$<10^{-4}$*
LL-PT	0.002	*0.99*	0.22	*0.18*
LL within fusion-PI			0.35	*0.06*
LL within fusion-SS			0.47	*0.01*
LL within fusion-PT			0.07	*0.72*
LL below fusion-PI			0.31	*0.05*
LL below fusion-SS			**0.45**	*$<10^{-2}$*
LL below fusion-PT			0,046	0,78
LL within fusion-LL below fusion			**-0,52**	*$<10^{-2}$*

Discussion

The spine, pelvis and lower limbs all interact with each other in order to maintain a stable and economical sagittal alignement [2,8]. This is the first study that specifically investigates the influence of pelvic geometry on the sagittal spinal geometry in patients with AIS after PSIF.

The results support our hypothesis that the pelvic morphology influences the postoperative lumbar spine geometry. Indeed, PI and SS are significantly correlated with LL. Similarly, SS is correlated with LL below fusion. On the other hand, the correlation between PI and LL below fusion is not significant ($r = 0.31$ with $p = 0.05$). This surprising result may be explained by the limited number of patient included in this preliminary study. In fact, in normal adolescents [12], the pelvic morphology (PI) is strongly correlated to the sacro-pelvic orientation (SS), which in turn determines the LL. The impact of the pelvic parameters on the segmental lumbar lordosis is limited to the LL below fusion because any of these parameters present a significant correlation with LL within fusion.

This study also demonstrates that there is a strong negative relation between LL within and below fusion. This finding suggests the possible deleterious effect of inadequate amount of LL within fusion that may produce overcompensation in LL below fusion. The occurrence of the flatback syndrome with Harrington instrumentation is a good example of the inability to restore or maintain a physiological LL [13,14].

With the close interdependence that is found pre and postoperatively between the sagittal lumbar alignment and the sagittal pelvic parameters, it seems interesting to include these parameters in the preoperative planning of patients with AIS in order to determine the proper lumbar lordosis to restore or maintain. Further studies with more patients are still needed in order to confirm this hypothesis. Increasing the number of patients would also allow to evaluate if the lowest level of instrumentation has an impact on the postoperative spinopelvic relations.

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Timing of Osteotomy for Thoracolumabar or Lumbar Kyphosis Secondary to Ankylosing Spondylitis

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[Abstract] Objective: Ankylosing spondylitis may lead to a rigid thoracolumbar kyphotic deformity. Several authors have reported the results of patients treated by a lumbar osteotomy, but there is no consensus on the level of the osteotomy and on timing of osteotomy. The purpose of this study is to explore timing of osteotomy for thoracolumabar or lumbar kyphosis secondary to ankylosing spondylitis by analyzing the natural history of 78 AS patients. **Method:** To analyze the factors related to influence the timing of osteotomy for thoracolumabar or lumbar kyphosis secondary to ankylosing spondylitis. Patient Sample There were 78 patients including 69 male and 9 female; the mean age at the time of surgery was 38 years (range, 22–56 years). The characteristic of natural history of these 78 patients is lumbar pain stage, slowly progressive kyphosis stage, accerlated progressive kyphosis stage, stabilized kyphosis stage.The average preoperative deformity was 61° (range, 40°to 87°). Twenty-eight patients underwent V shape osteotomy, and 50 patients underwent transpedicular osteotomy. **Result:** The average age of occurrence of lumbar pain symptom is 21 years,the average duration of slowly progressive kyphosis stage is 3 years (range, 1 to 8 year), and the average duration of accerlated progressive kyphosis stage is 4 (range, 2 to 10 year).The patients were followed up for a period of 4-60 months (mean 49 months). The total correction postoperatively was 40°±11°, the average loss of correction was 5° at the final follow-up. Excellent results were obtained in 74 patients (95%), and good results were obtained in 4 patients (5%), there were no fair or poor results. **Conclusion:** Lumbar pain arrests for more than 6 months (exclusive of mechanical pain of lumbar), normal blood sedimentation rate continues for two times, and reactive protein is negative. These factors must be considered in timing of osteotomy for thoracolumabar or lumbar kyphosis secondary to ankylosing spondylitis.

[Key words] Ankylosing spondylitis; Kyphosis; Osteotomy

Introduction

Ankylosing spondylitis (AS) causes characteristic rigid and fixed spinal deformities. The chief complaint is an inability to look straight ahead. The kyphotic deformity may restrict a patient activities of daily living such as walking down the street, lie down flat in bed. In severe cases, visceral compression may cause intra-abdominal complications. It also causes psychological effects because of appearance factor. The kyphosis is best corrected with lumbar lordosating osteotomy to restore the patient's balance and ability to see straight ahead and to improve their daily activities [1]. The intervention should also improve diaphrag-matic respiration and relieve visceral compression caused by the inferior margin of rib cage [2]. Several authors have reported the results of patients treated by a lumbar osteotomy, but there is no consensus on the timing of osteotomy.The purpose of this study is to explore timing of osteotomy for thoracolumabar or lumbar kyphosis secondary to ankylosing spondylitis by analyzing the natural history of 78 AS patients.

Materials and Methods

The patients consisted of 69 men and 9 women; the mean age was 38 years (range 22–56 years). The average age of occurrence of lumbar pain symptom is 21 years. Kyphosis progression of these 78 patients was classified into four stages (lumbar pain stage, slowly progressive kyphosis stage, accerlated progressive kyphosis stage, stabilized kyphosis stage) according to disease course and analyzing history retrospectively.

Standing anteroposterior and lateral radiographs were obtained before and immediately after surgery and at last follow up (minimum 2 years). The average preoperative deformity was 61° The average preoperative deformity was 58° (range, 40° to 87°). The most common apex of kyphosis was thoracolumbar in 51 patients, lumbar in 27 patients. Four cases had cervical kyphosis, two had atlantoaxial subluxation. Preoperative pulmonary function test show that twelve patients had severe restrictive ventilatory disorder, 9 patients had mild restrictive ventilatory disorder.

Lumbar pain arrests for more than 6 months (exclusive of mechanical pain of lumbar), normal blood sedimentation rate continues for two times, and reactive protein is negative. These factors must be considered in timing of osteotomy for thoracolumabar or lumbar kyphosis secondary to ankylosing spondylitis. After receiving general anesthesia, all procedures were performed with posterior osteotomy fixation and pedicle screws were inserted into several segments above and below the osteotomy level by monitoring somatosensory-evoked potentials. Twenty-eight patients underwent V shape osteotomy, and 50 patients underwent transpedicular osteotomy. The postoperative protection was plaster body cast in all patients for 3 months.

Results

The average duration of lumbar pain stage is 5 years(range, 1 to 10 year), the average duration of slowly progressive kyphosis stage, accerlated progressive kyphosis stage and stabilized kyphosis stage is 3 years (range, 1 to 8 year), 4 (range, 2 to 10 year),and 4（range,1 to 8 year）respectively. The patients were followed up for a period of 4-60 months (mean 49 months). The total correction postoperatively was 40°±11°, the average loss of correction was 5° at the final follow-up. Excellent results were obtained in 74 patients (95%), and good results were obtained in 4 patients (5%), there were no fair or poor results.No fatal complications were observed. Three dural tears occurred during surgery while the os-sified ligamentum flavum was dissected away from the midline, and the dura was adherent to the ligamentum and could not be separated. The dura was sutured intraoperatively.

Discussion

Ankylosing spondylitis is a chronic inflammatory disease that predominantly affects the axial skeletal. It causes progressive ossification of the annulus fibrosus and other spinal ligaments that ultimately leads to a rigid, kyphotic spine. Ankylosing spondylitis (AS) causes characteristic spinal deformities such as flattening of the normal lumbar lordosis and an increasing smooth thoracic kyphosis with the head and neck thrust forward [3]. The loss of lumbar lordosis or increased thoracic kyphosis seen in patients with ankylosing spondylitis can result in severe sagittal alignment deformities. The chief complaint of the majority of patients is their inability to look straight ahead. In order to reduce the chin-brow to vertical an-gle(CBVA) and to maintain sagittal balance during stand-ing, the patient rotates their pelvis backward, extends their hips, and flexes their knees and ankles. This results in a fatiguing standing position. The kyphotic deformity may restrict activities of daily living such as interpersonal communication, driving a car, walking down the street, or personal hygiene [1] In severe kyphotic deformities the resulting compression of the abdominal viscera may cause intraabdominal complications. In this study, 24 patients with severe deformity caused compression of the abdominal viscera, with indigestion, and four patients had significant psychosocial impairment.

Literature on natural history and prognosis of AS is paucity[4].The natural course of AS was examined over a 23 year period in 51 patients; their mean disease duration was 38 years. Seventy four percent of the patients who had mild spinal restriction after 10 years did not progress to severe spinal involvement. In contrast, 81% of the patients who had severe spinal restriction were severely restricted within the first 10 years [5]. In current study, kyphosis progression of these 78 patients was classified into four stages (lumbar pain stage, slowly progressive kyphosis stage, accerlated progressive kyphosis stage, stabilized kyphosis stage) according to disease course and analyzing history retrospectively. The characteristic of lumbar pain stage is low back pain, morning stiffness. The kyphosis has a relative slow progress stage after lumbar pain stage, we refer this stage as slowly progressive kyphosis stage, this stage lasts for 3 years averaged. The third stage is accerlated progressive kyphosis stage. The fourth stage is stabilized kyphosis stage, the characteristic of this stage is the formation of rigid thoracolumbar kyphosis with lumbar pain arrest.

The indication for surgical intervention was deformity more than 50° , impairment of function and the social and psychological impact of a severe progressive thoracic kyphosis with loss of horizontal gaze [6,7,8]. Low back pain, morning stiffness sleeping disturbance are the characteristics of AS patients with active disease [4.] AS patients with active disease will have an increased level of C reactive protein (CRP) and a raised erythrocyte sedimentation rate (ESR).Inflammatory back pain, according to Calin et al, is present if four of the following five features are present: (a) age at onset <40 years; (b) back pain >3 months; (c) insidious onset; (d) morning stiffness; and (e) improvement with exercise [9].

As for the timing of osteotomy, these factors should also be considered in timing of osteotomy for thoracolumabar or lumbar kyphosis secondary to ankylosing spondylitis.such as, lumbar pain arrests for more than 6 months (exclusive of mechanical pain of lumbar), normal blood sedimentation rate continues for two times, and reactive protein is negative. If the osteotomy was performed in active disease stage, bone destruction may occur, recurrence of kyphosis and loss of correction may be progressive.

Before operative intervention, it is essential to assess general and specific problems that may result in perioperative complications. Respiratory function may be compromised by the kyphotic deformity; Ankylosis of the ribs to the vertebral bodies often limits chest expansion. In such cases, preoperative pulmonary function testing may be indicated to evaluate respiratory reserve. In current study, preoperative pulmonary function test show that twelve patients had severe restrictive ventilatory disorder, 9 patients had mild restrictive ventilatory disorder. We adopt some measures aim directly at blood gas analysis and pulmonary function test result, no respiratory problem occurred.

Specific problems need to be evaluated are cervical and hip joints function. For evaluation of the cervical spine, attention should be paid to assess if there exist atlantoaxial subluxation.or cervical kyphosis, In this study, four cases had cervical kyphosis, two had atlantoaxial subluxation.

Careful attention should be given to function of hip joints, because hip involvement (arthritis) was a risk factor for radiographic spinal progression. Furthermore, hip involvement was more prevalent among patients with juvenile onset of symptomatic disease, and subsequently, total hip replacement was significantly more prevalent among patients with juvenile onset disease [10], if there is ankylosis associated with a hip flexion deformity, total hip replacement should be performed before any surgical correction of the spinal deformity. In this study, decreased motion or ankylosis of the hips associated with a flexion deformity was treated in four patients with a bilateral or unilateral total hip replacement. Six months later, spinal osteotomy was performed, at the final follow-up, the clinical outcome is excellent.

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Biomechanical Assessment of Variable Instrumentation Strategies in Adolescent Idiopathic Scoliosis: Preliminary Analysis of 3 Patients and 6 Scenarios

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Abstract. Since the introduction of modern multi-segmental instrumentation systems, disagreement exists about the appropriate instrumentation strategies for the "optimal" correction of scoliotic deformities, and the difference between alternative scenarios is difficult to predict a priori. The purpose of this study is to evaluate the effect of different instrumentation strategies using a computer assisted surgery simulator (S3). We obtained from 32 experienced Fellows of the *Scoliosis Research Society* and members of the *Spinal Deformities Study Group* the detailed preoperative planning for three AIS patients with Lenke curve types 1A, 3A and 5C. Their scenarios were individually simulated using a computer model implemented in a *spine surgery simulator* (S3). The resulting Cobb angles varied for the 3 cases (e.g.: main thoracic: 6-17°; 16-29°; 16-30°). The variability of correction remained important when sub-classifying the results according to the instrumentation strategies: A- "Pedicle Screws Constructs"; B- "Hooks Constructs"; C- "Hybrid Constructs". But overall, the average correction was better in group A (71%) than in groups B (55%) and C (54%). For the first time the effect of various instrumentation strategies can be assessed preoperatively thanks to S3. A large variability of instrumentation strategies exist within experienced surgeons and these produce rather different results. This study also questions the criteria for optimal configuration and standards to objectively design the best surgical construct.

Keywords. Biomechanical modeling, Scoliosis, Preoperative planning

1. Introduction

Scoliosis is a three-dimensional deformation of the spine which severe cases usually are treated by spinal instrumentation and fusion. Since the introduction of recent advanced instrumentation systems, the surgeon has a wide range of possibilities to perform the surgery: various implants (mono- and multiaxial pedicle screws, different hooks, etc.), diverse rod shape possibilities as well as intraoperative reduction maneuvers (simple rod rotation, direct apical vertebra derotation, cantilever, etc.). As a result, their surgical decision-making process has considerably increased in complexity and difficulty. Although several clinical publications have attempted to assess the effects of surgical strategies [1-3], no clear consensus exists on an appropriate treatment for optimal clinical outcome. As surgical operation approaches remain on the expertise of the surgeon, on empirical and trials-and-errors methods, there exists an enormous possibility to rationalizing surgeon's preoperative planning and thus, to obtain better surgery results. The purpose of this study is to evaluate the effect of various strategies of surgical instrumentation of the scoliotic spine using a computer assisted surgery simulator (S3).

2. Materials and Methods

Three females (18, 16 and 13 years) candidate for surgical treatment of AIS with Lenke curve types 1A, 3A and 5C were selected (Table 1, Figure 1). Thirty-two experienced surgeons fellows of the *Scoliosis Research Society* and members of the *Spinal Deformities Study Group* provided their detailed preoperative planning for the three cases, e.g.: the implant types (transverse process, pedicular and laminar hook, mono-axial and multi-axial screw), the screw trajectory (straight-forward or anatomic) and their vertebrae locations as well as the rods shapes and the parameters of the rod maneuvers (attachment order, rod rotation and direction, reduction maneuvers).

Table 1 - Preoperative Curve Characteristics of the Three Patients

Patient	Lenke type	Cobb (°) Proximal thoracic (PT)	Main thoracic (MT)	Thoracolumbar / Lumbar (TL/L)
1	1A	26	34	9
2	3A	45	62	43
3	5C	28	64	46

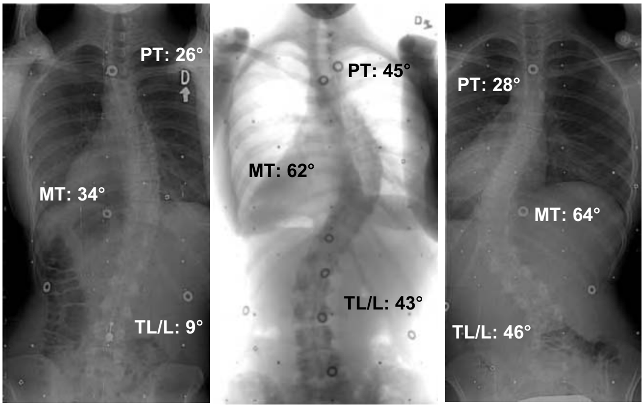

Figure 1. Preoperative posteroanterior radiographs of the three patients

From these results, six significant classes based on different instrumentation types (e.g.: screws construct only, hooks construct only and hybrid construct (combined hooks/screws)) were identified per patient (figure 2). The scenarios of instrumentation were individually simulated using a validated kinetic model using flexible mechanisms [4] implemented in a *spine surgery simulator* (S3). The model was personalized to the patient using 3D reconstruction of the spine shape [5,6] as well as side bending radiographs and an optimization approach [7]. The boundary conditions were imposed to represent the behavior of the anesthetized patient on the operating table. All degrees of freedom were fixed at L5, except the frontal plane rotation. At T1, the vertebra translates and rotates freely in the frontal plane. The intervertebral and implant-vertebra links were modeled as flexible joints and mechanical properties are based on experimental data [8,9].

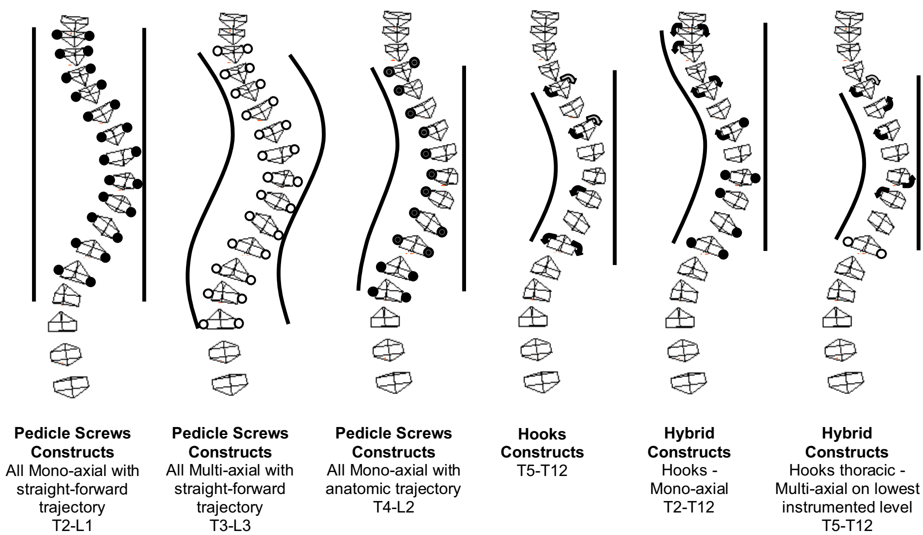

Figure 2. Instrumentation classes for the case #2

3. Results

The resulting Cobb angles, known as the gold standard measure of the deformity in the frontal plane, as well as kyphosis and lordosis angles of the sagittal plane varied differently for the 3 cases (Table 3). For example, in the case #2, the simulated post-operative proximal thoracic Cobb angle varied from 7° to 20°, from 16° to 29° for the main thoracic and from 41° to 46° for the thoracolumbar/lumbar (Table 2, Figure 3).

When sub-classifying the results according to the instrumentation strategies: “Pedicle Screws Constructs” [n=9]; “Hooks Constructs” [n=2]; “Hybrid Constructs” [n=7], the variability of correction remained important with up to 11° of standard deviation. But overall, the average correction was better in the group of pedicle screws (71%) than in the group of hooks (55%) and hybrid (54%).

Table 2 - Simulated Post-instrumentation Geometric Indices for Case #2

Instrumented segments	1	2	3	4	5	6
PT	20°	NI	NI	NI	7°	NI
MT	17°	23°	16°	27°	25°	29°
TL/L	NI	41°	46°	NI	NI	NI

Note: NI=Not instrumented.

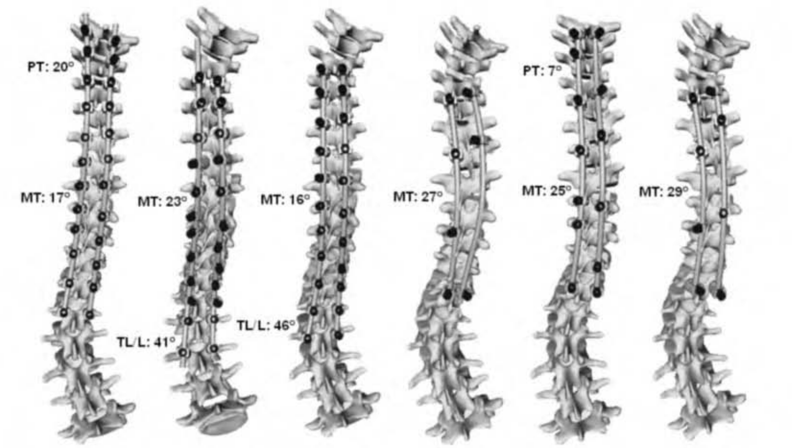

Figure 3. Simulation results for the case #2

Table 3 - Simulation Results of Six Instrumentation Classes for the Three Patients

Geometric Indices	Preoperative	Simulation Results Avg ± STD; [Min; Max]
Proximal thoracic Cobb angle (°)		
Patient 1	26	21 ± 5; [15;28]
Patient 2	45	30 ± 14; [7;42]
Patient 3	28	21 ± 5; [15;29]
Main thoracic Cobb angle (°)		
Patient 1	34	11 ± 5; [6;17]
Patient 2	62	23 ± 5; [16;29]
Patient 3	64	21 ± 5; [16;30]
Thoracolumbar / Lumbar Cobb angle (°)		
Patient 1	9	8 ± 5; [4;17]
Patient 2	43	45 ± 4; [40;51]
Patient 3	46	28 ± 4; [22;31]
Kyphosis angle (°)		
Patient 1	40	27 ± 4; [22;35]
Patient 2	46	40 ± 12; [22;53]
Patient 3	37	39 ± 5; [30;46]
Lordosis angle (°)		
Patient 1	25	26 ± 17; [3;52]
Patient 2	37	32 ± 4; [24;34]
Patient 3	51	43 ± 3; [37;47]

4. Discussion

Our study compared for the first time the effect of various instrumentation strategies on the same patients, which is possible only with such a spine surgery simulator. Based on our results, a large variability of instrumentation constructs and levels of fusion exist within experienced surgeons [10,11] and these produce rather different surgical results in some cases. In fact, the spines don't react in the same manner according to the different deformities and instrumentation classes. The smallest variations occurred for case #1 (right thoracic curve) where the resulting main thoracic Cobb angle varied only from 6° to 17°. The other 2 cases produced more significant variations. For example, in case #2, the kyphosis angle varied from 22° to 53°. Of the instrumentation classes simulated, the pedicle screws approach provided the best 3D correction.

This study questions the criteria for optimal configuration and standards to objectively design the best surgical construct. A spine surgery simulator presents a powerful tool to rationalize the surgical operations and thus, to provide optimal surgery results for a specific patient. In the future, it will offer an essential guide to assist surgeons during their preoperative planning of surgical instrumentation of the scoliotic spine.

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Objectives for Correction and Related Instrumentation Strategies in Scoliosis Surgery for Lenke Curve Types 2, 3 and 5

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Abstract. A recent study revealed a large variability among a group of 32 spine surgeons in the pre-operative instrumentation planning for the same 5 AIS patients. It is hypothesized that this variability may be attributed to different objectives for correction. In this new study we analyzed the objectives of correction and the related instrumentation strategies for three different Lenke curve types. Nine experienced surgeons from the Spinal Deformity Study Group were surveyed and asked to assess 11 different geometric parameters describing the spinal deformities for three different Lenke curve types (2, 3 and 5) according to their importance for an optimal 3D correction.These same 9 surgeons were asked to provide their preferred posterior instrumentation planning for three patients with the same curve types. Statistical analyses included: median, interquartile range IQR and Wilcoxon non parametric test. There was an overall agreement that sagittal and coronal balances were the most important parameters for an optimal correction. All other parameters were highly variable depending on the curve-type. Mobility was more important for the Lenke curve types 3 and 5 than for type 2 ($p<0.032$). A comparative analysis based on the coronal curves (Cobb) and the number of unfused vertebrae revealed a significant difference ($p<0.025$) between the correction objectives of the surgeons and their posterior instrumentation planning. In the three curves types analyzed, there is a large variability in scoliosis correction objectives, which is surgeon and curve-type dependent. There is a disagreement between the correction objectives and the instrumentation strategies. Optimal configuration of surgical instrumentation remains a controversial topic.

1. Introduction and objectives

Severe spinal deformities involved in adolescent idiopathic scoliosis (AIS) generally are treated by spinal instrumentation and fusion surgery. The surgical goals in treatment should as well as to reduce the magnitude of the deformities with the fewest instrumented segments and thus achieve good balance in all three planes of the spine. The strategies to obtain these objectives are based on the accurate selection of fusion levels and the optimal application of three-dimensional corrective forces and displacements by the instrumentation devices.

Several procedures can be used to correct scoliosis [1-4]. There is no clear consensus on the preferred instrumentation system to use and even less consensus on the optimal operative plan for each curve type with modern multi-segmental instrumentation systems. The modern multisegmental instrumentation systems provide many spinal fixations and flexible technique options. In turn, the surgical decision-making process has considerably increased in complexity, especially when selecting the fusion levels. So a surgeon's method of treatment is made according to their individual and collective beliefs and previous experience.

Recent report has revealed a large variability in the planning of spinal instrumentation within a group of surgeons for the same patients with AIS [5-6]. In a recent study, thirty-two surgeons of the *Spinal Deformities Study Group* reported the existence of a large variability in the selection of the highest and lowest vertebra and the number of implants used in their surgical procedures treating AIS. Different classes of instrumentation strategies and different fusion levels have been identified. It is hypothesized that this variability may be attributed to different objectives for correction. Therefore the purpose of this study was to analyze the objectives of correction and the related instrumentation strategies for three different Lenke curve types [7].

2. Materials and Methods

The study was divided into 2 parts. The first part of the study aimed at evaluating the correction objectives for three different Lenke curve types, while the second part focussed on analyzing the relationship between the objectives of correction and the surgical instrumentation.

Nine experienced surgeons of *the Spinal Deformity Study Group (SDSG)* agreed to participate in the first part of the study. They were asked to assess 11 different geometric parameters describing the spinal deformities for each of the three different Lenke curve types (2, 3 and 5) according to their importance for an optimal 3D correction (Table 2). The parameters were taken from the Radiographic Measurement Manual [8]. A rating scale of 1 (insignificant) to 5 (very important) was used.

Three females (13, 15 and 16 years) with AIS that were candidate for surgical instrumentation were selected for the second part of the study (Table 1). Curve patterns were as follows: 1 Lenke type 2 (Cobb Thoracic/Lumbar: 62°/43°), 1 Lenke type 3 (Cobb Thoracic/Lumbar: 72°/70°) and Lenke type 5 (Cobb thoraco-lumbar: 64°) (Figure 1).

The same surgeons that responded to the first survey were also asked to provide their preferred posterior instrumentation planning for the patients using the CD Horizon system (Medtronic Sofamor-Danek, Memphis TN).

The folder contained several clinical information of each patient: age, gender, weight, height, Risser grade, preoperative standing postero-anterior (PA) and lateral radiographs, supine side bending radiographs, 3D reconstruction of the spine and Cobb angle measurements (Figure1 and Table 1). The instrumentation planning by each surgeon was done using a graphical worksheet. The surgeon has to specify: 1) the implant types, the screw trajectory and their vertebrae locations, 2) the rods' shape as installed in their initial position before any maneuver, 3) the parameters of the rod installation and any other maneuvers (Figure 2).

The comparative analysis between the correction objectives and instrumentation strategies was based on four parameters: Proximal thoracic curve (Cobb PT), main thoracic (Cobb MT), lumbar curve (Cobb LL) and the number of unfused vertebrae (Mobility). When the importance of these parameters is equal to 4 or 5 (Yes) it is hypothesized that the coronal curves (Cobb) should be instrumented and the mobility should be considered in the surgical strategy, otherwise, they shouldn't be instrumented.

Analyses were conducted using Statistica software (StatSoft, USA). Importance and variability of the correction parameters were evaluated using the median (M) and interquartile range (IQR). The objectives of correction and the surgical instrumentation were compared using a Wilcoxon non parametric test and a level of significance set at 0.05.

Table1: Patient characteristics

	Age (years)	PT	MT	TL/L	Kyphosis	Lordosis
Lenke 2 (P1)	16	45°	62°	43°	46°	37°
Lenke 3 (P2)	15	37°	72°	70°	27°	53°
Lenke 5 (P3)	13	28°	64°	46°	37°	51°

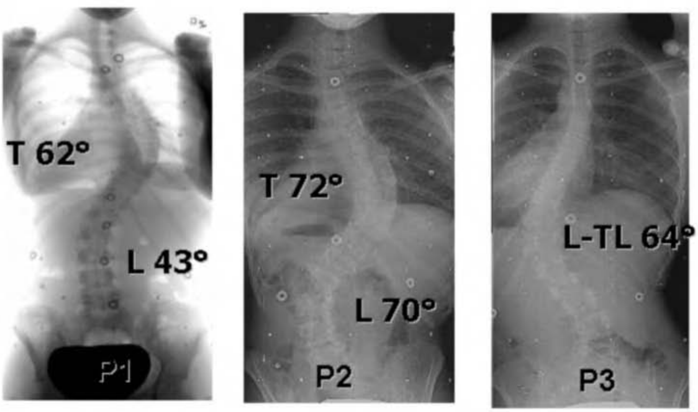

Figure 1: Preoperative standing postero-anterior radiographs (PA) of the three patients

3. Results

The "sagittal balance" and "coronal balance" were considered as the most important parameters for the best post-operative 3D correction for all Lenke curve types (Table 2). The very low iterquartile range indicates that this choice was quite unanimous. In the coronal plan, the correction was more important for type 2 curves than types 3 and 5 ($p < 0.032$). The Cobb MT and TL/L were important for the three Lenke curve types but with a different IQR. This difference of the IQR indicates that the choice depends on the curve type. The Cobb PT curve was more important for type 2 (M=5) than types 3 and 5 (M=2). In the sagittal plan, the kyphosis and the lordosis were more type 3 and 5 than Lenke curve type 2 ($p < 0.032$). The "apical vertebral rotation" of the three curves was highly variable depending on the curve type. Finally, mobility was more important for the Lenke curve types 3 and 5 than for type 2 ($p < 0.032$).

Table2: Evaluation of correction objectives for different Lenke curve types

	Type 2 Double thoracic		Type 3 Double major		Type 5 Thoracolumbar /lumbar	
	Median	IQR	Median	IQR	Median	IQR
Cobb PT	5	0,5	2	0,5	2	0
Cobb MT	5	0	5	1	3	1,5
Cobb TL/L	4	1	4	1	5	0,5
Coronal Balance	5	0,5	5	0	5	0
Thoracic Kyphosis	4	1	4	1,5	4	2
Lumbar Lordosis	3	1,5	4	1,5	4	1
Sagittal Balance	4	1,5	5	1	5	0,5
Apical Vertebral Rotation (PT)	4	1	2	1	2	1
Apical Vertebral Rotation (MT)	4	1	4	0	2	1
Apical Vertebral Rotation (TL/L)	3	0,5	4	0	5	0,5
Mobility (Nb of unfused vertebrae)	1	1	5	1	5	1

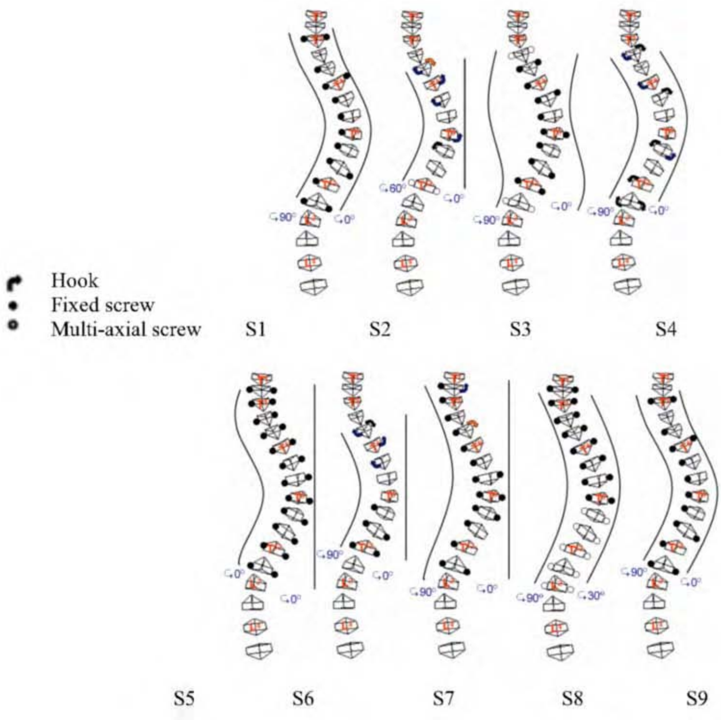

Figure2: Instrumentation configurations proposed by the nine surgeons (S1 to S9) for patient #1 (Lenke 2).

The pertinent results of the second part are summarized in Table 3. Overall, there is a significant difference ($p<0.025$) between the correction objectives of the surgeons and their posterior instrumentation planning. For example, for patient #1 (Lenke 2)

(Figure 2; table 3) six surgeons among nine proposed not to instrument the PT curve and there was complete agreement between surgeons not to instrumented the TL/L curve. This was different than results reported in the first survey. There was an agreement between surgeons to instrument the PT and TL/L curves in type 2 (M=2).

All surgeons agreed to instrument a small number of unfused vertebrae; even they agreed that the mobility parameter wasn't important for surgical correction of type 2.

Table 3: The objectives of correction and instrumentation strategies for different Lenke curve types

	Type 2 Double thoracic		**Type 3** Double major		**Type 5** Thoracolumbar /lumbar	
	Objective	Strategy	Objective	Strategy	Objective	Strategy
Cobb PT	Yes	No	No	No	No	Yes
Cobb MT	Yes	Yes	Yes	Yes	Yes	Yes
Cobb LL	Yes	No	Yes	Yes	Yes	No
Mobility (Nb of unfused vertebrae)	No	Yes	Yes	No	Yes	No

Yes: instrumented curves; No: not instrumented curves

4. Discussion and Conclusion

This study attempted to capture the complexity of the clinical reasoning of experienced surgeons in there decision-making process. To our knowledge, this is the first attempt to analyze scoliosis correction objectives within a sample of experienced surgeons and the related instrumentation strategies. Except for sagittal and coronal balances, the surgeons do not agree on surgical correction objectives related to the best 3D correction in AIS. There is a significant difference between the correction objectives of the surgeons that participated in this study and their instrumentation strategies. This difference reinforces the need to standardize posterior instrumentation strategies in order to determine the instrumentation configuration which optimizes the spine correction for different curve types.

In summary, our study showed a large variability of the correction objectives within a group of experienced spine surgeons. The correction objectives appear to be surgeon- and curve type-dependent. We hypothesize that this variability may be explained by the well documented inter observer variability of current surgical classification systems and by personal surgeon's preferences based on their pervious experience. There is a disagreement between the correction objectives and the instrumentation strategies which reinforces the need of standardized posterior instrumentation strategies.

5. Acknowledgements

Special thanks to the members of the Spinal Deformity Study Group. Funded by NSERC-Canada and by an unrestricted educational/ research grant from Medtronic Sofamor Danek.

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Correction of the Angle of Trunk Inclination Utilizing Apical Wiring Techniques and Concave Rib Osteotomy in Adolescent Idiopathic Thoracic Scoliosis

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Abstract: Improving the angle of trunk inclination (ATI) is important for achieving optimum clinical deformity correction in adolescent idiopathic scoliosis. Three concave apical implant techniques were reviewed in combination with the use of concave rib osteotomies. Rib osteotomy improved the ATI correction significantly when using apical wiring techniques.

Keywords: Adolescent idiopathic scoliosis, rib osteotomies, spinal instrumentation

Introduction

Lasting correction of rotational trunk deformity is an elusive goal [1,2]. Recently, we have recently reported lasting correction [3,4]. We utilized an instrumentation technique emphasizing an anatomical rod- translational load technique [3,5].

For several reasons a variety of concave instrumentation anchor strategies were used. We found hooks very useful in smaller curves, but problematic in larger curves. For these we initially used sub-laminar wires, but soon learned that they did not provide transverse plane rotation correction. To lateralize the transverse load of the wires we began placing them in the sub-pars position, and obtained some transverse plane rotation. To improve the trunk correction we then added concave rib osteotomies [6]. However, our goal was to devise a concave instrumentation anchor strategy that completely avoided the spinal canal, or any potential entry into it. We thus turned to a combined spinous process (for coronal and sagittal translation) plus transverse process (for transverse rotation and posterior translation) wire combination.

The importance of rib-hump severity to the patient and parent alike was well described by Pratt et. al [7]. Their study demonstrated good correlation between the patient's perception of rib-hump severity and clinical asymmetry measurements generated by the scoliometer. Asher et al. also demonstrated good correlation between the maximum angle of trunk inclination (ATI) and more complex surface topographic measurement systems (the Suzuki Hump Scoring system) [8]. Therefore, the ATI correction was determined to be a reasonable measure of trunk deformity change following surgery.

The purpose of this study is to compare differences in correction with these three different concave instrumentation anchor techniques, and in the wire groups to compare them with and without concave rib osteotomies.

Materials and Methods

From December 1996, when the first combined spinous process and transverse process concave wire anchors were used, through December 2001 sixty-one consecutive patients whose main thoracic curve was their largest were treated with the same posterior-only, anatomical rod-apex translational segmental instrumentation. Fifty-six patients (92%), 50 females and 5 males, mean age at surgery 14.9 ± 2.3, had a mean main thoracic Cobb of 63° ± 10° and angle of trunk inclination (ATI) of 17° ± 4°. They were followed a mean of 36.2 ±13.5 (range, 20 to 66) months. The five patients not included because of incomplete follow-up data had not had any major or minor surgical or follow-up complications during follow-ups ranging from 4 to 28 months. Three different concave thoracic anchor techniques were used: Hooks (n=13); Sub-pars wires (n=29); and Spinous process plus sub-transverse process wires (n=14). Multiple concave rib osteotomies were performed in nineteen of the patients who underwent one of the wiring techniques. Angle of Trunk Inclination (ATI) was measured (scoliometer) by a single observer preoperatively and at latest follow-up. At latest follow-up the patients also completed a SRS-22 health related quality of life questionnaire.

Statistical differences were studied with the student-t test, and alpha set at $p < 0.05$. Variance between compared values was determined to avoid type 1 error.

Results

The pre-operative Cobb was significantly larger in the two concave wire anchor groups (Table 1).

Table 1 MAIN THORACIC COBB: Concave hook, sub-pars wire, and spinous & transverse process wire anchors

Anchor Group	Pre-Op. (Degrees)	Bend (Degrees)	Follow-Up (Degrees)	Correction (Percent)
Hooks (n=13)	**56° * ** ± 7.0°**	33° ± 8.7°	**18° † ± 5.4°**	68 % ± 11 %
Sub-pars Wires (n = 29)	**66° * ± 8.3°**	41° ± 10.5°	**23° † ± 6.7°**	65 % ± 10 %
Spinous & Transverse Process Wires (n = 14)	**66° ** ± 11.3°**	44° ± 15.2° (n = 12)	23° ± 8.2°	65 % ± 11.0%

* $p < 0.001$, ** $p < 0.02$ † $p < 0.05$

The main thoracic ATI's pre-operative and at follow-up were similar for the three groups (Table 2).

Table 2 ANGLE OF TRUNK INCLINATION: Concave hook, sub-pars wire, and spinous & transverse process wire anchors

Anchor Group	Pre-Op. (Degrees)	Follow-Up (Degrees)	Correction (Degrees)	Correction (Percent)
Hooks (n=13)	16° ± 3.5°	10° † ± 2.5°	6° ±3.1°	39 % ± 13 %
Sub-pars Wires (n = 29)	17° ± 3.9	11° ± 3.3°	6° ±4.3°	34 % ± 22 %
Spinous & Transverse Process Wires (n = 14)	19° ± 5.3°	11° ± 3.8°	8° ± 18.4	41 % ± 18.4%

Concave rib osteotomies did not improve main thoracic Cobb correction (Table 3).

Table 3 Main Thoracic Cobb: Effect of concave rib osteotomies

Rib Osteotomy Group	Pre-Op. (Degrees)	Follow-Up (Degrees)	Correction (Percent)
Without Rib Osteotomies (n = 24)	63° ± 8.3°	22° ± 9.5°	63% ± 11
With Rib Osteotomies (n = 19)	69° ± 9.7°	21° ± 8.1°	68% ± 8.0°

Concave rib osteotomies significantly improved main thoracic angle of trunk inclination correction (Table 4).

Table 4 Angle of Trunk Inclination: Effect of concave rib osteotomies; wire groups combined

Rib Osteotomy Group	Pre-Op. (Degrees)	Follow-Up (Degrees)	Correction (Degrees)	Correction (Percent)
Without Rib Osteotomies (n = 24)	16° ± 3.3°	11° ± 3.3°	**5° * ± 3.63°**	28% ± 19.7
With Rib Osteotomies (n = 19)	21° ± 4.3°	10° ± 3.5°	**10° * ± 4.2°**	49% ± 13.8°

* $p < 0.001$

Concave rib osteotomies did not improve main thoracic curve correction in either of the concave wire anchor groups. However, concave rib osteotomies significantly improved ATI correction in the sub-pars wire group, 4° without osteotomy and 9° with osteotomy, $p < 0.001$. The same trend was there in the spinous and transverse process wire group, 5° compared to 13°, but the numbers were too small and variance great. (Table 5)

Table 5 Angle of Trunk Inclination: Effect of concave rib osteotomies on the two separate wire groups

Anchor and Osteotomy Groups	Pre-op (Degrees)	Follow-Up (Degrees)	Correction (Degrees)	Correction (Percent)
Sub-pars Wires				
Without Rib Osteotomies n = 15	16° ± 3.8°	12° ± 3.2°	**4° * ± 4.2°**	22% ± 23%
With Rib Osteotomies n = 14	19° ± 3.2°	10° ± 3.3°	**9° * ±2.8°**	47% ± 13%
Sp. & Tran. Process Wires				
Without Rib Osteotomies n = 9	16° ± 2.4°	11° ± 3.6°	5° ±2.4°	34% ±16%
With Rib Osteotomies n = 5	24° ± 5.3	11° ± 4.5°	13° ± 6.2°	53% ±17%

* $p < 0.001$

Health related quality of life, as measured by the total SRS-22 questionnaire score, was high. Forty-four (80%) of the 56 scored 4 or above and the average scores for each subgroup was above 4, there being no difference between them. (Table 6)

Table 6 Health Related Quality of Life at latest follow-up, measured by the total SRS-22 score.

Anchor and Osteotomy Groups	Total SRS-22 Score	Ceiling	Floor	% > 4	% < 4
Hooks (n=13)	4.33 ± 0.42	4.86	3.59	85%	15%
Sub-pars Wires					
Without Rib Osteotomies n = 15	4.32 ± 0.44	4.95	3.57	80%	20%
With Rib Osteotomies n = 14	4.19 ± 0.77	4.95	3	71%	29%
Sp. & Tran. Process Wires					
Without Rib Osteotomies n = 9	4.41 ± 0.38	4.91	3.86	67%	33%
With Rib Osteotomies n = 5	4.47 ± 0.19	4.77	4.32	100%	0

Discussion

Three-dimensional correction of spinal deformity in the operative treatment of adolescent idiopathic scoliosis is a sought after goal of many implant systems and correction sequences described in modern literature. Early reports describing Cotrel-Dubousset instrumentation and the technique of rod derotation provided a foundation for the three-dimensional concept. [9]. More recently, a strong movement towards thoracic pedicle screw constructs with direct apical vertebral rotation has reinforced the focus on obtaining three dimensional correction, especially at the apex of the curve, which is presumed to be the general region of greatest clinical trunk deformity. [10].

Past reports on a smaller group of patients from our group have demonstrated no effect of concave rib osteotomies on complex surface topography measurement systems. [3]. This study group included patients with double curves, which likely accounts for the lack of effect of the osteotomies on overall topographic measurements. The subject group for this study had preoperative main thoracic curves with the ATI measurement generated by the main thoracic transverse deformity.

This study demonstrates the evolution of concave apical anchor techniques utilizing implants other than pedicle screw fixation. The proximity of the spinal cord to the concavity of the curve apex and the size of the thoracic pedicles at the concave apex may require the use of alternative fixation. Both sub-laminar and sub-pars wiring techniques are options, however invading the spinal canal is necessary without significant improvement in correctional based on our series.

The combination of spinous process and sub-transverse process wiring at the peri-apical segments fulfills the goal of avoidance of spinal canal implants. In larger curves, this wiring technique was shown to be as effective as sub-pars wiring when comparing Cobb percent correction. The goal of transverse plane correction using wiring techniques alone was not maximized. The concave rib osteotomy allowed significant improvement in ATI correction when combining both wiring techniques as a group. The ATI correction was significantly greater in the sub-pars group when osteotomies were performed and the same trend was present in the spinous-process/transverse process group, however the group was too small to make a definite conclusion.

One criticism would be our lack of knowledge concerning the effect of the rib osteotomy on verterbral rotation measured by CT. The study group was not subjected to preoperative and postoperative CT scanning, therefore this data point is unavailable. Direct comparisons to rotational correction achieved by other authors would be difficult to perform. [10] We also do not know the effect of the rib osteotomies on pulmonary function in our group. Other studies looking at the surgical method of correction combined with “chest wall disruption” showed short-term decreases in pulmonary function with decreased long-term improvement in values. [11] We do not have the data points to determine this in our group.

Conclusions

Concave hook anchors provided 65% Cobb and 39% ATI correction for the smaller curves mean 56º. Sub-pars wires provided comparable 65% Cobb and 34% ATI correction for significantly larger curves mean 66º. Spinous process plus transverse process wires provided comparable corrections of 65% Cobb and 41% ATI, again for significantly larger curve of 66º, and did not expose the spinal canal contents to possible injury. The addition of concave rib osteotomies to the concave wire anchors significantly improved transverse plane trunk correction, 5º correction (28%) without and 10º correction (49%) with osteotomies.

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The Use of Thoracoplasty in the Surgical Treatment of Idiopathic Scoliosis

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Abstract: Introduction: Rib prominence on the convex side results from vertebral rotation. The cosmetic deformity of the back in scoliosis is only partially corrected by operations on the spine itself, whilst costoplasty addresses the problem directly, and improves the cosmesis.
Purpose: Our experience in convex and concave side thoracoplasty is discussed.
Patients and methods: The selection of the patients for thoracoplasty was done primarily taking into consideration the cosmetic disturbance of the rib hump and the consequences to the psychism of the patient. A total of 35 scoliotic patients (32 females and 3 males) with mean age 18.8 years underwent thoracoplasty in combination with posterior spinal fusion. In 23 patients (3 males and 20 females) convex side thoracoplasty (rib resection at the site of the hump) was done as a first stage procedure (18 patients) or a second stage procedure (5 patients). In the patients with spinal fusion at the same time, the resected ribs were used as bone graft. 12 female patients were treated with concave side thoracoplasty (osteotomies of the medial part of the ribs and elevation of the ribs on the instrumentation rod) as a first stage procedure combined with spinal fusion, while in one 22 female patient both side thoracoplasty was done as a second stage procedure.
Conclusion: Either form of thoracoplasty was an effective and impressive way to improve the patient's appearance although it was not possible to quantify the results. The complications that were presented viz. 4 haemopneumothorax, 2 pneumothorax, 2 pneumonia) were treated successfully.

Keywords: scoliosis, thoracoplasty, rib resection, rib osteotomies

Introduction

Scoliosis surgery, whilst being successful as regards measurement by the Cobb angle, may leave the unsightly rib prominence unchanged or worse, and result in dissatisfaction and disappointment (14) (10). The unilateral rib prominence which is often seen in adolescent idiopathic scoliosis is frequently the main concern of the patient, and may cause social and psychological damage (2). Thoracoplasty may be performed as a preliminary procedure before (30) or at the time of primary surgery for scoliosis (36). Various techniques for thoracoplasty have been described (29), (12), (30), (12), (26), (2), (23), (10). The most common technique is the removal of the prominent ribs at the convex side of the curve (the rib hump) (40) (22) (43) (33) (29). Another alternative is the transposition of the medial part of the ribs (after medial costectomy) of the concave side, on the rod of the spinal instrumentation (8, 28). Our experience in convex and concave side thoracoplasty is discussed.

Patients and methods

The selection of the patients for thoracoplasty was done primarily taking into consideration the cosmetic disturbance of the rib hump and the consequences to the psychism of the patient. Other factors that were taken into consideration were the ability to fit on the back of a chair, and the stiffness of the curve. The forward bending test (Adam's test) was done to evaluate the rib hump. The use of the scoliometer was helpful to have an initial quantification of the deformity. We used radiographs in the forward bending position with caudally-cranial direction of the X-rays to evaluate the rib angle. Patients with a rib angle greater than 10°-15° and a rib prominence at a higher level than the spine were candidates for convex side thoracoplasty. On the contrary patients with a spine at high level (that was a contraindication for convex side thoracoplasty), were candidates for concave side thoracoplasty.

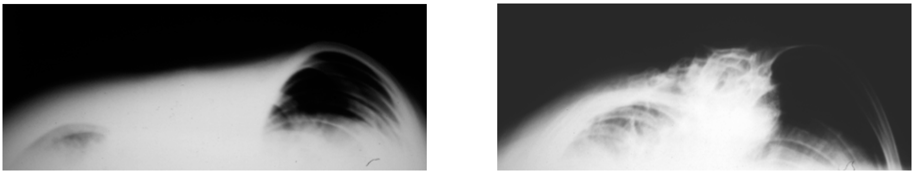

Figure 1: Left: a rib hump in higher level of the spine considers a strong indication for convex side thoracoplasty. Right: a rib hump in same level with the spine is a poor indication for convex side thoracoplasty and concave side thoracoplasty is strongly indicated.

Patients with sharp localized humps were candidates for rib resection (convex side thoracoplasty) while patients with long extended humps, may be treated with concave side thoracoplasty.

A forced vital capacity (FVC) of 40% of the predicted normal was regarded as the minimum necessary respiratory function.

Convex Side Thoracoplasty

23 scoliotic patients with average age 20.7 years underwent convex side thoracoplasty in combination with spinal fusion. 15 females and 3 males, operated in one stage procedure and the resected ribs were used as bone graft. Thoracoplasty was done as a second stage procedure in 5 patients.

Surgical Technique

Through the midline incision used for primary correction of the scoliosis, the lumbar fascia on the affected side is divided longitudinally, the interspace between the latissimus dorsi and the trapezious muscle is identified and the muscles are retracted. The prominent ribs are dissected subperiostealy preserving the segmental vessels and nerves and the underlying pleura. 4 - 7 cm segment of rib is resected and prominent costotransverse joints and transverse processes are trimmed. Costoplasty was carried out on an average of five ribs (4 - 8 ribs) for each patient. The resected ribs are an excellent source of bone graft and this is a strong advantage of this method as one stage procedure.

Before wound closure, saline was poured into the resected rib bed while the lung was fully inflated. Either bubbling or the disappearance of fluid during this “saline test” indicated a pleural puncture which would require the insertion of a chest drain. In the absence of a pleural puncture only the rib bed was drained by a small suction drain.

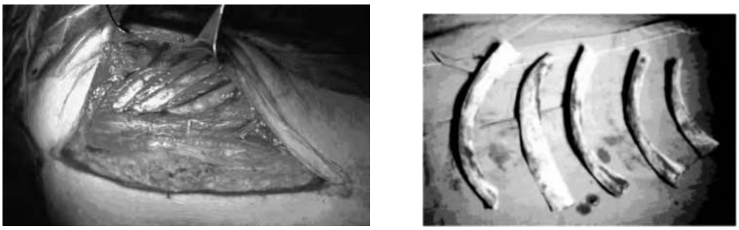

Figure 2: Intraoperative photos of convex side thoracoplasty. Left: preparation of the ribs, Right: the resected ribs are used as bone graft.

Complications

Three hemopeneumothorax and 1 pneumothorax were treated with a chest tube, while 1 patient with respiratory infection (pneumonia) was treated successfully with antibiotics.

Results

Postoperatively all patients were able for immediate mobilization. Pain was successfully controlled with pethidine im. and oral analgesics (lonarid). Physiotherapy and mucosolvant drugs were used in all patients immediately post operatively. All patients overcame the postoperative complications. The cosmetic appearances were markedly improved. Thoracoplasty increased the operation time by an hour and the blood loss by about one unit. The main limitation of the convex side thoracoplasty was the rib prominence to be lower or at the same level with the spine. That probability becomes higher when we consider the Instrumented spine. In such cases concave side thoracoplasty was the procedure of our choice.

Concave Side Thoracoplasty

Twelve female patients with average age 18 years were treated with concave side thoracoplasty.

Surgical technique

The surgical approach was done through the midline incision that was used for the spinal fusion. On the concave side the paraspinal muscles were retracted until there was clear view of the costovertebral joints (Figure 3). Then the medial part of the ribs (7-8 ribs), was dissected in a length of 2-3 cm and cut close to the transverse process. The ribs then are repositioned on the rod of the concave side and secured with stitches. “Saline test” was performed to exclude pleural tear.

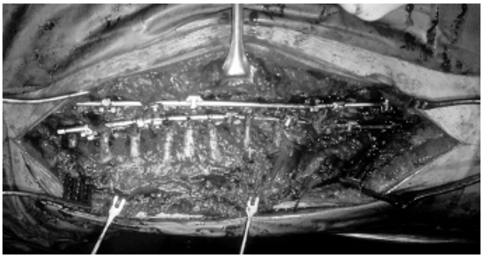

Figure 3: intraoperative photo of concave side thoracoplasty. The osteotomized ribs are placed and secured over the concave side rod.

Complications

The 3 patients who presented with pneumohaemothorax were treated with a chest tube and the one patient who had respiratory infection (pneumonia) was treated successfully with antibiotics.

Results

All patients had cosmetic improvement. The postoperative treatment was identical with the group of the concave side thoracoplasty. The increase of intraoperative time and blood loss was equal with the one stage procedure convex side thoracoplasty group. There was no source of rib bone graft in this procedure.

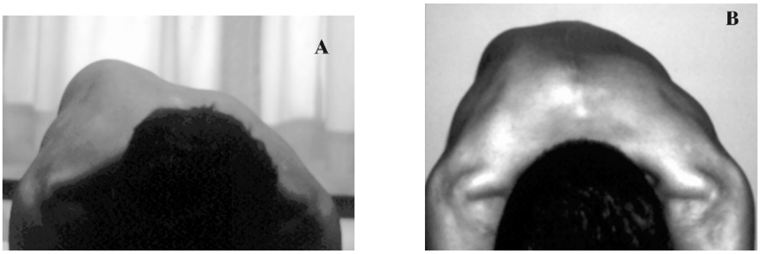

Figure 4: Preoperative (A) and postoperative (B) photo of a patient who underwent posterior spinal fusion combined with convex side thoracoplasty.

Discussion

Thoracoplasty seems to be an effective method to improve the cosmetic appearance of the scoliotic patient in combination with spinal fusion. In our department we used both convex and concave side thoracoplasties and we think that both methods are effective. Good patient satisfaction after costoplasty has been reported (29, 36, 30), but no objective measurements have been described and it is difficult to compare the results of different methods, sites of rib resection, and the timing of surgery. Various objective measurements of the rib hump have been described (37, 38). We tried to have an

objective measurement for the correction of the rib hump, but that was not easily reproducible because we noticed differences due to the patient position.
One must be carefully in the selection of the patients for convex side thoracoplasty. When the rib angle is greater than 15°, there is strong indication for thoracoplasty (8). Less strong indications for thoracoplasty are rib angle > 10°, thoracic curves greater than 60°, curve correction <20° and intraoperative correction <50% (8). Convex side thoracoplasty has no indication if the spine (alone or Instrumented) is more prominent than the rib hump (10). In very extreme rotation, the bodies of the vertebrae may cause the prominence (2) such cases will not benefit from costoplasty, as is shown on radiographic silhouette views. Other benefits of convex side thoracoplasty in combination with spine fusion as one stage procedure referred to be increased spinal correction (30) and a great source of bone graft (2,8,30,43)
Concave side thoracoplasty can be applied with no actual limitations about the level of the convex rib hump and the Instrumented spine. Increasing curve flexibility in adult scoliosis has been reported in clinical experience with concave rib osteotomies (8, 28).
Satisfactory lung function is essential (10) and patients those FVC (forced vital capacity) of less than 40% of predicted normal should be excluded. Our patients did not show a significant decrease in lung capacity. That finding may be explained by the fact that we don’t stabilize the remaining part of the ribs as it is reported by others (10, 30). It is referred to be a significant reduction in the peak expiratory flow rate following preliminary costectomy and instrumentation. Steel (36) found a temporary reduction in pulmonary function. On the other side other authors (Barret 1993) report intact lung capacity postoperatively (2)

Recurrence of the rib prominence in young patients with immature skeleton has been reported (10, 29). Others report that the correction achieved by thoracoplasty does not appear to reduce with time (4). We noticed no recurrence of the hump because our patients were near or after the epiphyseal closure. Rib reformation, is a common finding without clinical significance (2).
Excess resection of ribs that leads in a posterior concavity of the thorax wall has been reported (8). We did not record such a concave deformity in our patients.
The complications of thoracoplasty may be serious or annoying. Small trauma to major vessel or lungs is the most dangerous, and parietal pleura tears are not uncommon. Because of this some surgeons propose the use of a chest tube in all cases of thoracoplasty (16). We used a chest tube only in confirmed cases or pleura tears. Trauma of the costal nerves may be responsible for painful neuroma that makes the patient a continues complainer(10). Even partial palsy of brachial plexus has been reported (10). We noticed no neuralgia, but a slight hypoesthesia or numbness of the overlying skin that relieved spontaneously. Trauma of the costal vessels is a cause for haemothorax or wound hematoma. Respiratory infections are not uncommon and they are caused by the inhibition of the normal inhale due to the pain. That fact can be worse due to initial effect of scoliosis on the lung capacity (7, 6, and 11). It is important to control the postoperative pain, and start early respiratory physiotherapy. Mucosolvant drugs and adequate dehydration are useful to avoid or minimize such infections.

Conclusions

Either form of thoracoplasty is an effective and impressive way to improve the patient's appearance.

Convex side thoracoplasty removes the rib prominence from the convex side and provides rib bone graft. It can not be applied in cases that the Instrumented spine is equal or most prominent of the rib hump.
Concave side thoracoplasty transfers the medial part of the ribs on the rod of the concave side. There are no limitations due to the spine prominence, but no bone graft is provided.
With careful selection of the patients and proper surgical technique complications can be minimized or treated effectively.

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Chapter 6

Quality of Life

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Validity and Reliability of SRSI and SF-36 in Japanese Patients with Scoliosis

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Abstract. We have examined the validity and reliability of Japanese SRS-24 and SF-36 in patients with scoliosis. 278 patients with scoliosis were recruited. Their average age was 24.8 years (range 17-84 years) and 83% of patients had idiopathic curves. The major coronal curve averaged 43° (range 10° -114°). Questionnaires surveyed were SRS-24 and SRS-22, and SF-36. Only domains applicable to untreated patients were analyzed. Scale level analysis was evaluated by the ceiling and floor effect. The Cronbach α and item-scale correlations were calculated as representatives of internal consistency reliability and item internal consistency, respectively. Most domains of SF-36 had large ceiling effects. Both the SRS questionnaires had limited ceiling/floor effects. SRS-22 had a better internal consistency than SRS-24. Low item-scale correlations (<0.25) were found in question14, 15, and 18 of SRS-22. The Japanese version of SRS-22 was the most useful measure for patients with scoliosis. However, some questions have low item-scale correlations, lowering reliability of the Function domain.

Keywords. Scoliosis, Outcome, validity

Introduction

The patient-based outcome is the primary endpoint of any treatment. There are two types of scales: generic and disease-specific. Measurement of both scales is recommended [4]. Short Form-36 (SF-36) is a representative generic measure used in various diseases. Among instruments specific to spinal disorders, the Scoliosis Research Society (SRS) Instrument has been applied to many spinal problems including adolescent idiopathic scoliosis, spondylolisthesis [8], and adult deformities [3]. The first version called SRS-24 reported by Haher and colleagues [7] consists of five domains including postoperative status, which raises difficulties for the assessment of the patients having no treatment. Asher and colleagues proposed a modified version, SRS-22 [1]. It incorporated the mental facet from SF-36 and was widely analyzed by its originators for its validity.
Translation of these scales from English into other languages is daunting, especially into Asian languages such as Japanese which has a different type of grammar and a non-western culture. The Japanese official version [5] of SF-36 has been widely applied to many clinical trials. Though not available in an official version, the Japanese

version of SRS-24 has been introduced by several Japanese surgeons [10, 11]. The Japanese Scoliosis Society had planned to translate SRS-22 into an official Japanese version, and this final version is now available.

The purpose of this study was to examine the validity and reliability of SRSI and SF-36 in patients with scoliosis in the Japanese population.

1. Materials and Methods

278 patients with scoliosis were recruited: 234 (84.2%) were idiopathic, 16 (5.8%) were of a neuromuscular type including Chiari-malformation, 16 (5.8%) were congenital, 5 (1.8%) had neurofibromatosis, and 5 (1.8%) displayed other entities. 62 patients had a post-operative status. There were 191 female and 43 male subjects with an average age of 23.7 years (13.1 to 34.3 years). Curve angle mean was 42.8 degrees (25.3 to 60.3 degrees) measured using the Cobb method.

Patients were asked to fill in the questionnaire sheets in the outpatient clinic. The questionnaire set consisted of any of the combination of SRS-24, SRS-22 and SF-36 version The SRS-24 used was the private version [10] which was modified from the previous author's translation [11]. The SRS-22 was the final version proposed by the Japanese Scoliosis Society. The Japanese official version [5] of Short-Form 36 was used with approval. Only domains applicable to untreated patients were analyzed: Physical Function (PF), Role Physical (RP), Bodily Pain (BP), General Health (GH), Vitality (VT), Social Functioning (SF), Role Emotional (RE), and Mental Health (MH) of SF-36; Pain, Image, Function, and Action of SRS-24; Pain, Function, Image, and Mental Health of SRS-22. The questionnaire sheets were filled by 162 patients for SRS-24, 87 for SRS-22, and 235 for SF-36.

Scale level analysis was evaluated by the floor and ceiling effect. Cronbach Alfa of SRS-24 and SRS-22 was calculated as an index of the internal consistency reliability. Item-scale correlations of SRS-24 and SRS-22 as item internal consistency were analyzed.

2. Results

2.1. Scale level analysis (Table 1)

Table 1. Scale Level Analysis

SF36	Ceiling	Floor	SRS24	Ceiling	Floor	SRS22	Ceiling	Floor
Physical Function	51.5%	0%	***Pain***	3.0%	0%	***Pain***	23.0%	0%
Role Physical	77.4%	0%	***Self-Image***	0%	0%	***Self-Image***	0.0%	0%
Bodily Pain	77.4%	0%	***Function***	5.2%	0%	***Function***	1.1%	0%
General Health	4.7%	0%	***Activity***	58.2%	0%	***Mental Health***	5.7%	0%
Vitality	6.0%	0%						
Social Function	79.6%	0%						
Role Emotional	66.0%	0%						
Mental Health	8.9%	0%						

Table 2. Internal Consistency (Cronbach α)

SRS24		SRS22	
Pain	**0.687**	***Pain***	**0.860**
Image	**0.657**	***Image***	**0.722**
Function	**0.514**	***Function***	**0.608**
Action	**0.613**	***MentalHealth***	**0.801**

Large ceiling effects were found in the SF-36 domains: PF 51.5%, RP 77.4%, BP 77.4%, GH 4.7%, VT 6.0%, SF 79.6%, RE 66.0%, MH 8.9%. The median of five domains (PF, RP, BP, SF, and RE) was the full score.

Small ceiling effects were found in the SRS-24 domains except the Activity domain. In the Activity domain, 58% of the patients had the full score (no limitation of activity). The three other domains (Function, Image, and Pain) had a small percentage of the full score.

Small ceiling effects were found in the SRS-22 domains except the Pain domain. In the Pain domain, 23% of the patients had the full score (no pain). The three other domains (Function, Image, and Mental Health) had a small percentage of the full score.

2.2. Internal consistency (Table 2)

The domains of SRS-24 also had moderate scores of Cronbach α (0.51 to 0.69). The three domains (Pain, Image, and Mental Health) of SRS-22 showed an excellent internal consistency with a moderate score (0.61) in the Function domain.

2.3. Item internal consistency (Table 3)

Most items of SRS-24 showed moderate correlations with the appropriate domains. Low correlations (<0.2) were found for question11 (relating to personal relationships) and question 12 (relating to financial considerations).

Most items of SRS-22 showed excellent correlations with the appropriate domains. Question15 (relating to financial considerations), question14 (relating to human relationships), and question18 (going out considerations) of SRS-22 less than 0.25 in their item-scale correlations.

3. Discussion

Patient-based outcomes are now the primary endpoint both for patients and physicians. But, among thousands of measures, only a small number are reliable and robust. They must satisfy validity, reliability, and responsiveness. The latter demonstrates the effectiveness of treatment, but also demands additional study design and was therefore not considered in this paper. Validity and reliability signify the appropriateness of a measure as a psychometric tool. Our study examined scaling validity and internal reliability of the two measures that have usually been used in spinal deformity.

Table 3. Item Internal Consistency

SRS24	Item Scale Correlation	Alfa If Removed	SRS22	Item Scale Correlation	Alfa If Removed
Pain			***Pain***		
question1	0.518	0.623	question1	0.788	0.790
question2	0.572	0.589	question2	0.852	0.767
question3	0.363	0.667	question8	0.657	0.826
question6	0.641	0.580	question11	0.565	0.587
question8	0.502	0.643	question17	0.561	0.855
question11	0.240	0.698			
question18	0.024	0.711	***Self-Image***		
			question4	0.372	0.725
Self-Image			question6	0.595	0.619
question5	0.386	0.668	question10	0.621	0.611
question14	0.533	0.475	question14	0.279	0.733
question15	0.506	0.515	question19	0.551	0.637
Function			***Function***		
question7	0.348	0.374	question5	0.649	0.352
question12	0.231	0.596	question9	0.371	0.476
question13	0.406	0.263	question12	0.391	0.460
			question15	0.122	0.652
Action			question18	0.224	0.554
question4	0.388	0.543			
question9	0.448	0.463	***Mental Health***		
question10	0.427	0.506	question3	0.531	0.773
			question7	0.641	0.739
			question13	0.443	0.800
			question16	0.780	0.696
			question20	0.528	0.777

Scaling validity will demonstrate an instrument's capacity for covering various types of targeted disorders. When a measure scale does not cover the distribution, a significant number of cases are at either end of the scale; termed the floor/ceiling effect. We think that moderate ceiling effects found in some domains of the SRS-24 and SRS -22 were acceptable in the recruited population, which included patients with relatively small curves. In contrast, a large ceiling effect for most domains of the SF-36 casts some doubt on its usefulness when applied to young patients with scoliosis. As SF-36 is a generic scale, it must cover normal to severe conditions. This wide coverage may lead to less sensitivity of the narrow-range conditions of the specific disease. Previous reports have indicated superiority of disease-specific measures over generic measures for validity and responsiveness [6, 9].

Our results questioned the internal reliability of SRS-24. Internal reliability (internal consistency) indicates correlation between items of the same domain. As for internal consistency (Cronbach α), 0.7 is usually regarded as acceptable. No domain of SRS-24 could satisfy this criterion. Three of the four domains of SRS-24 consist only of three questions. Therefore, the results of the item-scale correlations (item internal consistency) were nt possible to interpret because the α, after removing one question, was calculated only from the other two questions.

All domains of SRS-22 except the Function domain scored over 0.7. Analysis of item internal consistency showed three unsuitable questions: question14 (relating to personal relationships) of the Image domain, question15 (relating to financial considerations) of the Function domain, and question18 (going out considerations) of the Function domain. Though severe deformity may prevent social activity, it depends on the personality of patients with mild to moderate deformity as to whether their self-image affects personal relationship. The Japanese health insurance system, which covers all citizens, might lower the significance of the financial management for patients and made this question15 unrelated to the Function domain. Asher et al [2] recommended deletion of question15 in such circumstances.

4. Conclusion

SRS-22 had the best validity and reliability among the SRS-24, SRS-22, and SF-36 measures. However, the Function domain had limited internal consistency and some questions had only moderate item-scale correlations. SRS-24 displayed a low Cronbach α in all domains. The usefulness of SR-36 was hindered by high ceiling effects in many domains.

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Current Methods for Management of Scoliosis. Treatment or Malpractice?

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Abstract. Bracing and spine instrumentation are the universally used methods for the treatment of scoliosis used during the last half century. This now demands an objective evaluation of the long-term outcome of treatment in order to determine our contemporary attitude to these unique in medicine, time-resisting therapeutic paradigms. This is essential, with the need to report ambiguity of results of bracing and the accumulated evidence of high morbidity, with sometimes severe complications, of instrumentation. It is also mandatory with regard not only to the demands for the continuous development of scientific principles, based on effective methods for treatment with less side effects to the maximum benefit of the patient, but also from an ethical point of view in accordance with existing moral axioms and requirements for professional integrity.

1. Introduction

Orthotic devices such as the Milwaukee brace introduced by Blount in 1958 and other types of braces, based on the same principles but developed later, are widely used for treatment of early progressive scoliosis with a Cobb angle of approximately 30°-45°. Posterior instrumentation, combined with spine fusion as introduced by Harrington in 1962, and other technically more demanding surgeries, developed to achieve better correction and to avoid postoperative bracing, are currently used worldwide for the treatment of scoliosis.

2. Current experiences

2.1. Bracing

Random reports of the results of bracing in Table 1 show that the long term outcome of the treatment is *i)* ambiguous *ii)* psychosocially compromising the young patients, *iii.)* that approximately one third of braced patients ultimately undergo spinal fusion and iv) that it includes significant risk for development of the degenerative vertebral changes.

3. Spinal instrumentation

Reported results of spinal instrumentation are largely satisfactory, at least with regard to the effect of surgery on the deviation of the spine in the coronal and sagittal planes.

Table 1. Reported results of bracing.

* No significant effect : [9,10]
* Some degree of correction: [5,13]
* Success in arresting the progression: [12]
* Progression after accomplished treatment: [7]
* Psychosocial implications: [2,1,16]
* Increased risk for degenerative vertebral changes: [14,7]
* Rate of operation despite bracing :15 % [7]
  22 % [13]

Reported peroperative and postoperative complications are mainly related to technical issues concerning the procedure itself. Nonetheless, although extensive surgery is associated with complications and sometimes severely disabling neurological deficit, including blindness [8], there are few reports on the long-term overall rate of complications shown in some random consecutive series of patients operated on by four different methods. (See Table 2).

Table 2. Reported incidence rates of complications associated with spinal instrumentation by four different methods. (Percentages in brackets ; x = no information)

Method	Harrington	Zielke	Cotrel-Dubouset	Isola
Author / nr of refer	17	15	16	4
Patients /n	370 + 22 *	66 **	582 ***	179 ****
Average age / y	15. .3	26. 3	21	14. 6
Average follow-up / y	3	2	> 2	6.1
Death	0.25	x	x	0
Wound compl.	2 (0.5)	3 (4.5)	4 (0.7)	2 (1.0)
Nevromuscular compl.	5 (1.3)	18 (27.3)	0	0
Technical failure	x	24 (36.3)	16 (2.8)	24 (13.4)
Pleural compl.	12 (3.6)	2 (3.0)	x	1 (0.6)
Pseudarthrosis	7 (2.0)	2 (3.0)	3 (7.5)	7 (4.0)
Other compl.	x	13 (20.0)	x	x
Reoperation	4 (1.0)	2 (3.0)	20 (3. 4)	17 (9.5)

* in 22 cases only convex rib resection on earlier fused patients
** in 33 cases anterior and posterior fusion
*** 448 cases with AIS (average age < 21y); 124 adults
**** in 73 cases supplemental procedure

The total percentage of complications, including re-operations in Table 2 is 7.5% for Harrington, 85% for Zielke, 7.5% for Cotrel-Dubouset and 28.5% for Isola instrumentation. The results of the latter study "compare favorably with those of the 1994-1999 SRS Morbidity and Mortality reports" [4], unfortunately not accessible to non-members of the Society.

These rates are by no means intended to represent the incidence of complications of these methods in general ; only to show that all are accompanied by significant hazards.

4. Ethical and scientific aspects

The ethical rules underlying the practice of medicine have been determined by society from ancient times [11] to the present [18]. All focus on the physical and the psychosocial well-being of the patient. With regard to treatment, the decision of a physician shoud be governed by the ipsissima verba "*primum non nocere est*", and he/she " … *will abstain from whatever is deleterious and mischievous*" [11]. On the other hand, stagnation in development of new methods for treatment, attributed to uncritical use of current methods, as opposed to "science", one of the three cornerstones of Medicine defined as " … *investigation and experimentation aimed ... to revision of accepted theories and laws in the light of new facts*…".

5. Discussion and Conclusions

The results of spinal instrumentation are largely satisfactory with regard to achieved correction of the spinal deformity. Nonetheless, extensive, but not life- saving, surgery exposes healthy children to a high rate of complications including death, neurological deficit of varying degrees, infection, pseudarthrosis and a 10 to 25% lifetime risk of re-operation [6]. Finally, spinal fusion always results in permanently impaired function of the spine, psychosocial side effects and, in the long-term perspective, increased risk of developing disabling degenerative changes below the fused vertebral segment.

Further use of current methods for management of scoliosis has led to prolonged stagnation in the development of new methods for treatment using scientific methods, i.e., " … *investigation and experimentation aimed ... to the revision of accepted theories and laws in the light of new facts*", while, with obtaining a half-a-century long experience, it denotes "*dereliction of professional duty, or failure of professional skill, or learning that results in injury, loss or damage*" i.e. malpractice with ethical and legal implications.

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Research into Spinal Deformities 5
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Deformity Related Stress in Adolescents with AIS

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Abstract. A new questionnaire (The Bad Sobernheim Stress Questionnaire BSSQ) has been developed to assess the psychological stress scoliosis patients develop as a consequence of their deformity. The aim of this study was to determine this stress level in a sample of adolescents with scoliosis.
Materials and methods. 206 Patients were recruited to the study and completed a questionnaire (8 items). The average age was 15.7 years with an average Cobb angle of 35.8°. All subjects returned a fully completed questionnaire. Plausibility of the results was assessed by examining for consistent responses to two plausibility questions.
Results. The average stress value was 19.97 / 24, which can be regarded as "low stress".
The average stress value in the group meeting the plausibility threshold (n = 155) was 21 / 24 while the average stress value in the group not meeting the threshold (n = 51) was 15.9 / 24, regarded as "medium stress". This correlated negatively with the Cobb angle ($r = -.54$; $p < 0{,}001$). The Cobb angle / test value correlation was highest in thoracic curves (n = 87; $r = -.49$; $p < 0{,}001$) and lowest in double major curves (n = 46; $r = -.27$; $p = 0{,}03$).
Conclusions. Adolescents with scoliosis have on average only "low stress" associated with their deformity. Not fulfilling a plausibility threshold seems to be a predictor for more stress associated with the scoliotic deformity.

Keywords. Adolescent Idiopathic Scoliosis, Deformity related stress, Bad Sobernheim Stress Questionnaire (BSSQ)

Introduction

Quality of life seems to be an important issue for patients with scoliosis. Frequently the SF-36 questionnaire is used to assess health related quality of life (HRQL) but this has to be regarded as a general instrument which ia used for a variety of diagnoses. In a study related to scoliosis it has been applied alongside two other questionnaires [1]. Women with idiopathic scoliosis were questioned with the help of an age adapted set of questionnaires containing questions referring to the health related quality of life (SF-36, BFW, STAIK). The results were compared to the norm values and examined in uni- and multivariat procedures (MANOVA) in order to find out whether age or Cobb angle have an impact on quality of life issues. In comparison to the norm random sample, the adolescent female scoliosis population showed a less positive point of view towards life and were more liable to be subject to depression. Adult patients with scoliosis have shown a reduced HRQL both in the psychological and in the physical field (SF-36). The results were largely independent of the Cobb angle or patients' age. The results of this study indicated that idiopathic scoliosis in children, adolescents and adults has to be regarded as a risk factor for the impairment of health related quality of life.

The SRS-22 questionnaire has been developed as an instrument which is specifically aimed at cases with spinal deformities. It has been compared to the SF-36 recently [2]. This study showed that SRS-22 Mental Health and Pain domain scores can be accurately calculated from correlating SF-36 domain scores. SRS-22 Function scores can be fairly well predicted from correlated SF-36 domain scores. However, Self-Image and Management Satisfaction/Dissatisfaction domain scores cannot be approximated from SF-36 domain scores.

The SRS-22 HRQL questionnaire is reliable, with internal consistency and reproducibility comparable to SF-36. In addition, it demonstrates concurrent validity when compared to SF-36. It is shorter and more focused on the health issues related to idiopathic scoliosis than SF-36 [3].

However the SRS-22 takes more than 20 min. for completion and not all questions seem suitable for patients treated conservatively. Our aim was to establish a short and concise questionnaire related to psychological issues of scoliosis patients, which can also be used in our out-patient practice. Therefore a new questionnaire was developed to assess the psychological stress in scoliosis patients consequential to their deformity [4] termed the Bad Sobernheim Stress Questionnaire (BSSQ). 8 questions are provided, focussed on scoliosis with two questions included to test plausibility. Maximum score values of 24 can be achieved. We have proposed a subdivision of the score values as follows: 0-8 (high stress), 9-16 (medium stress) and 17-24 (low stress). The BSSQ was shown to have a good repeatability (r = 0,95) and sufficient criterion validity (r = 0,78); however Cronbach α of 0,7 was not reached [4] due of the small number of items [5].

The aim of this study was to determine the level of stress present in adolescents with scoliosis which might be related to their deformity.

Material and Method

The questionnaire - The following items have been provided:

1. I feel embarrassed by the appearance of my back.
2. I find it hard to show my back in public.
3. I feel embarrassed in situations, in which other people can see my bare back.
4. *I don't feel embarrassed showing my back.*
5. I try not to get too close to other people to avoid their becoming aware of my scoliosis.
6. When deciding what kind of clothes to wear or how to fashion my hair, I take care to ensure my back is hidden.
7. *Scoliosis is a part of m; people have to accept me the way I am.*

8. Because of my scoliosis, I avoid activities/hobbies which otherwise I would love to do.

The following rating was applied to the individual questions:

0 completely true
1 nearly true
2 hardly true
3 not true at all

The following rating was applied to the plausibility questions (4 and 7):

3 completely true
2 nearly true
1 hardly true
0 not true at all

206 Patients were recruited to the study and completed the German original version of the Bad Sobernheim Stress Questionnaire (BSSQ). Plausibility of the results was assessed from consistent responses to the two plausibility questions. To be plausible the ratings of the plausibility questions should not differ more than 1 point from the reference questions (3 and 5 respectively).

The average age was 15.7 years and the average Cobb angle was 35.8°. All patients returned their fully completed questionnaires.

Results

The average stress value was 19.97 / 24, which can be regarded as “low stress”.The average stress value in the group meeting the plausibility threshold (n = 155) was 21 / 24 correlating slightly negatively with the Cobb angle (r = -.19; p = 0,008). The average stress value in the group not fulfilling the plausibility threshold (n = 51) was 15.9 / 24, which has to be regarded as “medium stress”, correlating clearly negatively with the Cobb angle (r = -.54; p < 0,001). The Cobb angle / test value correlation was highest in those with a thoracic curve (n = 87; r = -.49; p < 0,001) and lowest in double major curves (n = 46; r = -.27; p = 0,03)

Discussion

The SRS-22 HRQL questionnaire successfully discriminates between cases with no scoliosis or moderate scoliosis and large scoliosis. It does not discriminate between cases with single, double, or triple curves. Self-image and, to a lesser extent, pain and function domain scores correlate with radiographic and trunk asymmetry severity. The SRS-22 HRQL questionnaire may be useful in choosing non-surgical versus surgical treatment in borderline cases [6].

Spinal deformity correlates well with the SRS-22 quality of life questionnaire responses whereas trunk deformity magnitude does not. This finding is somewhat surprising as it is the trunk deformity that the patients see themselves [7].

The BSSQ seems to have a certain sensitivity to trunk asymmetry because the test value correlated more to the Cobb angles in a single thoracic curve pattern than in a double curve pattern which, from the cosmetical point of view, are commonly regarded as less disturbing.

As the BSSQ is short and not time consuming, it can easily be completed by patients in an out-patient clinic. However, further research is needed in order to specify the appropriate age at which the BSSQ should be used. The BSSQ already has been modified (BSSQbrace) to assess the psychological stress suffered by scoliosis patients in a brace; however, this questionnaire needs to be reworked [8]. Nevertheless both questionnaires have already been applied at other centres with results comparable to those presented in this report [9].

Not fulfilling the plausibility criteria threshold seems to be a predictor for more stress in scoliosis. This finding may help to quantify any decision making process affecting the patient. Like the SRS-22, the BSSQ may be useful in choosing non-surgical versus surgical treatment in borderline cases

It has already been shown that HRQL (SF-36, BFW, STAIK) can be improved during a course of Scoliosis Intensive Rehabilitation (SIR) [10]. It is intended to try and answer the question as to whether the BSSQ values vary during a course of Scoliosis Intensive Rehabilitation (SIR).

Conclusions

Adolescents with scoliosis at average seem to have only “low stress” associated with their deformity. Not fulfilling a plausibility criteria threshold seems to be a predictor for more stress associated with a scoliosis. Different curve patterns are seen as impairing self -image differently cosmetically. This seems in accordance with objective criteria (lateral deviation, rib hump, decompensation) which describe the deformation.

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The Influence of Brace on Quality of Life of Adolescents with Idiopathic Scoliosis

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Abstract. Traditionally, the effectiveness of brace treatment on adolescents with IS is based on curve magnitude and to some extent on vertebral rotation and rib hump. QoL has been introduced in the recent years in order to evaluate the effectiveness of brace treatment. The aim of the study is to determine the influence of brace on quality of life (QoL) of adolescents with idiopathic scoliosis (IS).
Thirty-six patients with a mean age of 13,9 (range 12-17) years old, a mean Cobb angle 28,2° (range 19-38°) and a mean angle of trunk inclination (ATI) 7,8° (range 4°-17°) who were treated conservatively with a modified Boston brace for a minimum of 2 years, filled the form of Brace Questionnaire (BrQ). BrQ is a validated, disease specific instrument, its score ranges from 20 to 100 and higher BrQ scores mean better quality of life. Correlations were determined by the Pearson correlation coefficient, with $p<0.05$ considered significant.
Mean overall score of BrQ was 73,8 (SD 15. 8). Lower scores were observed in physical functioning (55,4, SD 15,9) and vitality (55, SD 25,9). School activity (98, SD 4,4) was affected less. The Cobb angle correlated significantly only with school activity ($p<0,02$). The ATI correlated significantly with social functioning (thoracolumbar ATI, $p<0.038$; lumbar ATI, $p<0.035$). There were no significant correlations between either Cobb angle or ATI with BrQ overall scores.
Cobb angle and ATI significantly influenced school activity and social functioning respectively, but not general health perception, physical functioning, emotional functioning, vitality, bodily pain and self-esteem and aesthetics.

Keywords. Idiopathic scoliosis, brace, quality of life, Brace Questionnaire, brace influence on quality of life

Introduction

Braces in Adolescent Idiopathic Scoliosis (AIS) treatment are reported to produce stress [1, 2, 3, 4, 5] although there is a controversy whether health related quality of life HRQoL of brace treated scoliotics is negatively affected [3, 6, 7, 8, 9]. Although questions of whether bracing is considered an effective way of altering the natural history of progression of curves in growing children have been raised [10, 11] orthotic therapy for AIS is widely accepted [12].

AIS is a chronic condition that affects the body configuration of the adolescent leading to certain alterations in lifestyle as a consequence. Brace wear has a quantifiable impact on several aspects of child and family functioning [2, 13]. Factors that contribute negatively in regard to coping with the orthoses include the length of time the brace must be worn, the failure of the brace [14] or previous poor behaviour adjustment [15, 16].

The impact of the brace to the self and body image of the adolescent is reported as the main contributory factor for stress production [17, 18, 19, 20, 21, 22, 23, 24]. Different psychological reactions, such as panic when patients realize the implications of the diagnosis [21] negative mood, depression, anger, or feelings of responsibility for illness during the initial adjustment period [25, 26] and emotional disturbances of body image, self-esteem, and sexual attitudes [1, 27] have also been reported.

Traditionally, the effectiveness of brace treatment on adolescents with AIS was based on curve magnitude and to some extent on vertebral rotation and rib hump. HRQoL has been introduced in the recent years in order to evaluate the effectiveness of brace treatment. The aim of the study is to determine the influence of brace on HRQoL of adolescents with AIS.

Material-Method

The Patients

Thirty-six patients, attending the Scoliosis Clinic of the Orthopaedic Department of Thriasio General Hospital at Athens, Greece, were included in the study. There were 32 girls and 4 boys, with a mean age of 13,9 (range 12-17) years, a mean Cobb angle of 28,2^o (range 19-38^o) and a mean angle of trunk inclination (ATI) 7,8^o (range 4^o-17^o). All the patients who were treated conservatively with a modified Boston brace with antirotatory blades [28], wore the brace for 23 hours per day for a minimum duration of 2 years. Evaluation of self reported HRQoL was performed by Brace Questionnaire (BrQ) [29].

The Questionnaire

BrQ is a validated, disease specific instrument, its score ranges from 20 to 100 and higher BrQ scores mean better quality of life. It consists of eight specific domains, namely a) general health perception, b) physical functioning, c) emotional functioning, d) self-esteem and aesthetics, e) vitality, f) school activity, g) bodily pain and h) social functioning, Correlations were determined by the Pearson correlation coefficient, with $p<0.05$ considered significant. The SPSS v.11 statistical package was used for the statistical analysis.

Results

The results from the statistical analysis are summarized in **Table 1** and **Table 2**.

The mean overall score of BrQ was 73,8 (SD 15. 8). Lower scores were observed in physical functioning (55,4, SD 15,9) and vitality (55, SD 25,9). School activity (98, SD 4,4) was affected less, **Table 1**.

The Cobb angle correlated significantly only with school activity ($p<0,02$). The ATI correlated significantly with social functioning (thoracolumbar ATI, $p<0.038$; lumbar ATI, $p<0.035$). There were no significant correlations between either Cobb angle or ATI with BrQ overall scores, **Table 2**.

Table 1. The mean BrQ overall and domain scores (SD= Standard Deviation)

BrQ Domains	Mean score
General health perception	80,0 (SD 18,86)
Physical functioning	55,4 (SD 15,89)
Emotional functioning	68,2 (SD 26,84)
Self esteem and aesthetics	68,0 (SD 29,74)
Vitality	55,0 (SD 25,93)
School activity	98,0 (SD 4,45)
Bodily pain	84,4 (SD 12,91)
Social functioning	83,1 (SD 16,29)
BrQ overall score	73,8 (SD 15,8)

Table 2. Correlation between BrQ overall and domain scores with Thoracic Cobb angle, Lumbar Cobb angle, Thoracic Angle of Trunk Inclination (ATI), Thoracolumbar ATI and Lumbar ATI. *Correlation is significant at the 0,05 **level**

BrQ Domains		Thoracic Cobb	Lumbar Cobb	Thoracic ATI	Thoracolumbar ATI	Lumbar ATI
General health perception	Pearson Correlation	-0,352	-0,160	-0,027	-0,194	-0,094
	p value	0,319	0,658	0,941	0,592	0,797
Physical functioning	Pearson Correlation	0,183	-0,170	0,059	-0,313	-0,274
	p value	0,613	0,639	0,871	0,379	0,444
Emotional functioning	Pearson Correlation	-0,130	-0,205	-0,015	-0,382	-0,317
	p value	0,720	0,570	0,967	0,276	0,373
Self esteem and aesthetics	Pearson Correlation	-0,277	-0,210	-0,188	-0,412	-0,297
	p value	0,438	0,561	0,603	0,236	0,405
Vitality	Pearson Correlation	0,039	-0,109	0,137	-0,075	-0,108
	p value	0,914	0,765	0,705	0,837	0,767
School activity	Pearson Correlation	0,218	0,717*	0,189	-0,164	0,238
	p value	0,545	**0,020**	0,602	0,650	0,508
Bodily pain	Pearson Correlation	0,006	-0,378	-0,362	-0,587	-0,433
	p value	0,986	0,281	0,304	0,075	0,212
Social functioning	Pearson Correlation	-0,005	-0,548	-0,443	-0,659*	-0,667*
	p value	0,989	0,101	0,199	**0,038**	**0,035**
BrQ overall score	Pearson Correlation	-0,049	-0,285	-0,140	-0,454	-0,383
	p value	0,893	0,425	0,700	0,187	0,275

Discussion

It has been suggested that AIS may lead to multiple physical and psychosocial impairments depending on its severity [6]. The results of the present study indicate that the influence of the modified Boston brace on adolescents' HRQoL was moderate. The brace affected mainly the physical functioning and vitality of these patients, a finding which may imply that the brace's stiffness and rigidity may play a more important role than brace-wearing itself. The psychological impact of the brace on adolescents, as it is recorded by the scores of emotional functioning and self-esteem and aesthetics was moderate, while social functioning and school activity seemed to be affected less. Bracing was not associated with pain in our studied population.

Although the initiation of brace treatment is a critical period regarding the psychological stress [2, 27], in the course of time, patients seem to cope with orthotic therapy. This may explain why patients who are still into brace wearing period become less aware of a social and psychological problem than a physical functioning problem.

Cobb angle and ATI significantly influenced school activity and social functioning respectively, but not general health perception, physical functioning, emotional functioning, vitality, bodily pain and self-esteem and aesthetics. The positive influence of thoracolumbar and lumbar ATI improvement while wearing the brace may be interpreted as an expression of the patient's satisfaction and expressed as improvement in social activity, either at school or with the family and the friends.

All the examined variables were not statistically significant in the model of the BrQ overall score, including other clinical and radiographic data, such as ATI and Cobb angle, which do not seem to exert an influence on the quality of life of adolescents with AIS. These findings are in accordance with Negrini et al [30], who concluded that technical matters, such as rib hump or radiographic lateral alignment and rotation, are secondary outcomes and only instrumental to primary outcomes that is what they need for their future (breathing function, needs of further treatments in adulthood, progression in adulthood), and their present too (aesthetics, disability, quality of life).

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Research into Spinal Deformities 5
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Associations between Quality-of-Life and Internal or External Spinal Deformity Measurements in Adolescent with Idiopathic Scoliosis (AIS)

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Abstract: In theory, quality-of-life measures should correlate with impairments such as spinal deformity. The goal was to determine the ability of the SRS-22 and surface topography measures to predict internal deformity. Data from 227 females with AIS were collected. Correlations and regression were used to predict Cobb angle or category. In subjects treated conservatively, the Cobb angle correlated with pain, self-image, satisfaction and total score. Only self-image correlated with surface topography. In subjects having had surgery, Cobb angle correlated with self-image, mental health, satisfaction and total scores. The cosmetic score was the only external deformity measure to correlate with the SRS-22. Function, self-image and trunk-twist predicted subjects within 3 categories (Cobb <30°, 30-50°, >50°) with 57% accuracy compared to 53% when using self-image only. Accuracy in predicting subjects with curves smaller or larger than 50° was 79% (using self-image, trunk-twist) or 72% (self-image only). Correlations between quality-of-life and deformity measures were low. However, it was possible to predict subjects within clinically meaningful categories of internal deformity using SRS-22 scores.

Keywords. Predictive value, SRS-22, surface topography, curve severity (Cobb)

1. Introduction

Questionnaires have been developed to assess health-related quality-of-life in patients with scoliosis. Questionnaires can be used to detect changes over time, or as a result of interventions and to guide clinical decision by predicting subjects in greatest need of aggressive care or with the most severe scoliosis[1]. Asher et al. proposed the Scoliosis Research Society-22 questionnaire (SRS-22)[2-4] to improve on previous questionnaires[5]. The SRS-22 has good to excellent internal consistency[2,5-7], very-good test-retest reliability[2,6,7], has showed some discriminative validity[3,6] and showed concurrent validity with the SF-36[2,5,6], SF12[7] and Oswestry[7] questionnaires. However, in a previous study, we found high ceiling effects (the proportion of subjects obtaining the maximum score) in using the SRS-22 with younger subjects, treated conservatively or long after surgery (3-35%[2,5-8]). High ceiling effects may limit the SRS-22's discriminative and predictive ability.

Beyond discrimination validity the SRS-22 should also have some predictive validity. The theory of the International Classification of Functioning Disability and Health (ICF) suggests that different quality-of-life domains could be associated with the severity of impairments such as internal and external deformity[9].

In adults with and without surgery, no significant correlations have been observed between the SRS-22 and radiographic parameters[6]. In teenagers treated non-surgically, significant correlations were observed with the Cobb angle[3,10-12]. However, SRS-22 scores correlated significantly only with the Hump index from a number of external deformity measures[11,12]. To date, the strongest correlations have consistently been observed for the function or the self-image domain[3,11,12] or in subjects with single thoracic curves[12]. Correlations with measures of impairments have been in the expected direction, varied between samples and, at best, were moderate in strength. There is still controversy about which domains correlate significantly with deformity impairments, especially with external deformity measures.

The objectives of this study were: (1) To determine the correlation between SRS-22 domains and indicators of scoliosis severity. (2) To determine the ability of SRS-22 scores, alone or with surface topography (ST) indices, to predict internal curve severity.

2. Methods

Between April 2004 and May 2005, 383 patients completed the SRS-22 during their consultation at a scoliosis clinic or an orthopedist office and 227 met our inclusion criteria: age between 8 and 20 years old (clinic), all ages (office); female gender; referred for assessment and treatment of AIS. Subject with trauma (n = 2); scoliosis secondary to congenital or specific causes (n = 120); or with incomplete questionnaires (n = 2) were excluded. Data from 32 males were also excluded because they did not allow a sufficient representation within each sub-group. Ethical approval was provided by the local hospital's review committee.

Descriptive, radiographic, ST and questionnaire assessment was completed. Data were collected in a database with an interface facilitating the standardization of the data entry. Diagnosis and treatment status were collected during the consultation. Maximal curve size, as measured by the Cobb angle[13] was determined from postero-anterior radiographs taken using a standard positioning frame[14].

Cosmetic scores, trunk-twist, and decompensation measurements were derived from a ST exam. A single camera system and custom software was used to scan the patient using the positioning frame[15]. Decompensation measures the lateral displacement of the C7 spinous process relative to a point midway between the posterior superior iliac spines. Trunk-twist measures the degree of relative rotation between maximally rotated upper and lower aspects of the torso. The cosmetic score is a summary parameter combining a waist asymmetry measure with the shoulder and scapula angles[16]. (Figure 1.) Higher ST scores signify more severe asymmetries. ST parameters can detect post-operative changes[17], have content validity[16] and are reproducible[15,18].

The SRS-22 questionnaire is self-administered in 2-3 minutes and contains 22 questions assessing 5 domains: function (n = 5 questions), pain (5), self-image (5), mental health (5) and satisfaction with management (2). Domain and total scores calculations were done as per Asher et al[5]. High scores represent good quality-of-life.

Simple correlations between SRS-22 scores and measures of internal and external spinal deformity were assessed using Spearman's coefficients. The ability of the SRS-22 scores with or without ST parameters to predict curve severity sub-groups membership (Cobb >30°, 30-50°, >50°) was assessed using stepwise multinomial regression. Models were obtained to predict subjects with Cobb angles above or below thresholds set at 40°, 45°, and 50°. These thresholds were selected because patients with curves larger than these values are at greater risk for progression or meet the indications for bracing or corrective surgery[19,20].

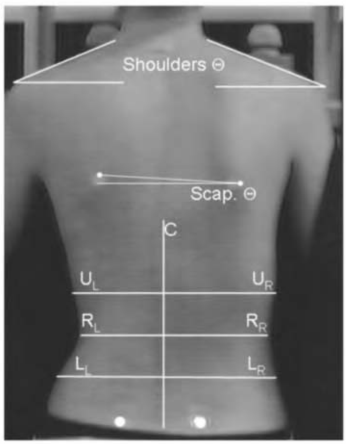

Figure 1. The shoulder angle (shoulder Θ) and scapula angle (Scap. Θ) are shown. Waist asymmetry is calculated as $(R_L * U_L * U_R) / (R_R * L_R * L_L)$ where the reference distances (R_L, R_R) are, respectively, the minimum left and right distances between the edge of the trunk and a vertical line crossing the midpoint between the posterior superior iliac spines. The distances to the edge of the trunk at 10% of the trunk height above (U_L and U_R) and below (L_L and L_R) the reference are also used in the calculation.

3. Results

The mean age of the 227 females was 18.6 ± 9.2 years and the mean maximal Cobb angle in this sample was 37 ± 16°.

For subjects without surgical correction, correlations with the Cobb angle reached significance ($p < 0.05$) for the pain (Spearman's rho= -0.19), self-image (-0.43), satisfaction (-0.20) and total scores (-0.24). Only self-image correlated significantly with external deformity measures (cosmetic score -0.29, trunk-twist -0.20). (Table 1).

Table 1. Correlation between SRS-22 and deformity in subjects without corrective surgery

Spearman rho		Maximal Cobb Angle	Age	Cosmetic Score	Decompensation Score	Trunk-twist
	n	153	156	130	128	132
Function	156	-0.06	**-0.29**	-0.04	-0.03	0.01
Pain	155	**-0.19**	**-0.31**	-0.02	-0.04	-0.02
Self Image	155	**-0.43**	**-0.25**	**-0.29**	0.00	**-0.20**
Mental Health	156	-0.05	**-0.17**	-0.01	0.09	0.02
Satisfaction	155	**-0.20**	**-0.36**	-0.06	0.09	-0.07
Total	156	**-0.24**	**-0.33**	-0.11	0.02	-0.07

Bold values are statistically significant at α = 0.05

Table 2. Correlation between SRS-22 and deformity in subjects having had corrective surgery

Spearman rho		Maximal Cobb Angle	Age	Cosmetic Score	Decompensation score	Trunk-twist
	n	57	60	47	46	47
Function	60	-0.11	**-0.39**	-0.12	-0.03	0.04
Pain	61	-0.13	**-0.43**	-0.08	0.09	-0.09
Self Image	60	**-0.30**	-0.22	-0.13	-0.02	0.01
Mental Health	61	**-0.36**	-0.15	**-0.43**	-0.13	-0.10
Satisfaction	60	**-0.38**	-0.17	**-0.30**	-0.08	-0.12
Total	61	**-0.30**	**-0.37**	-0.26	-0.04	-0.03

Bold values are statistically significant at α = 0.05

In subjects who had corrective surgery, significant correlations were observed between the post-operative Cobb angle and self-image (Spearman's rho = -0.30), mental health (-0.36), satisfaction (-0.38) and total score (-0.30). Correlations using measures of external deformity reached significance only between cosmetic score and mental health (-0.43) or satisfaction (-0.30). (Table 2).

Entering all SRS-22 and ST scores in a stepwise multinomial regression analysis, only function, self-image and trunk-twist were retained to predict subjects belonging to 3 Cobb angle categories with 57% overall accuracy (Cobb <30° = 53%, 30-50° = 63%, >50° = 52%, pseudo-R^2=.36). When using only SRS-22 measures, self-image predicted Cobb categories' membership with 53% accuracy (Cobb <30° = 39%, 30-50° = 68%, >50° = 53%, pseudo-R^2=.28). Predictive models for Cobb angles above or below thresholds of 40°, 45° and 50° were compared. The accuracy or predictive models of subjects with curves smaller or larger than 45° or 50° was the same: 79% (using self-image and trunk-twist, pseudo-R^2= .27) or 76% (using self-image only, pseudo-R^2= .20). In contrast, the model predicting subjects with curves larger or smaller than 40° had lower accuracy (60% self-image only vs. 68% for self-image and trunk-twist).

4. Discussion

This study provided some evidence of predictive validity for the SRS-22 questionnaire. The self-image domain showed a moderate ability to predict subjects belonging to different categories of curve severity for which clinicians recommend different treatment courses. The predictive validity of the SRS-22 was partially supported by low to moderate significant correlation with the internal and external deformity measures in subjects with and without corrective surgery.

The ICIDH theory suggests that quality-of-life domains of questionnaires like the SRS-22 could be associated with the severity of impairments such as measures of deformity[9]. The strength of the correlations with curve severity (Cobb angle) observed in our non-surgical subjects (-0.19 to -0.43 for pain, self-image, satisfaction and total scores), is similar to that reported by others in non-surgical (-0.27 to -0.50 function[3,11,12], pain[3], self-image[3,11], mental health[3] and total scores[3,11]), and mixed samples (with and without surgery -0.16 to -0.43 all domains[10]). As in the current study, in non-surgical subjects correlations were highest with self-image[3]. No other studies investigated correlations between SRS-22 and deformity measures in samples of surgical subjects. In such samples we found the strongest correlations with different domains than for non-surgical subjects (satisfaction, mental health).

The direction and low magnitude of the correlations between SRS-22 and external deformity measures in the current study (-0.20 to -0.29) are consistent with previous findings using different ST measures(-0.30 to -0.47)[3,11,12]. Most studies also found correlations between external deformity and self-image but some also observed correlations with function (Hump Index)[11,12], pain and total scores (angle of trunk inclination)[3] in subjects with more severe scoliosis. Numerous other ST measures did not correlate consistently with the SRS-22[11,12].

Correlations with the severity of deformity measures have been shown to be strongest (-0.46; -0.60) in subjects with single thoracic curves[12]. Therefore, stronger correlations between deformity and quality-of-life may have been observed if subjects curve types had been considered. Alternatively, the relatively low strength of the correlations observed between deformity and quality-of-life may be due to nonlinearity. Nevertheless, the direction of the correlations was in the expected direction with poorer quality of life being associated with more severe internal and external deformities.

This hypothesis was the basis for our regression analysis. With or without using ST parameters in conjunction with SRS-22 scores prediction accuracies were 57% or 53%, respectively. Most the difficulty appeared to be in trying to predict subjects with curves above or below the Cobb threshold used to recommend bracing (≈30°)[19,20]. This observation suggested that we investigate predictive models for subjects above or below the higher curve severity threshold typically used to identify subjects with greater risk of progression or candidate for surgery[19,20]. Models performed best (accuracies >75%) when using a 45° or 50° threshold rather than 40°.

The sample size was adequate to conduct the predictive validity analysis with adequate power (>10 subjects/variable). Selection criteria led to a homogeneous sample in terms of gender and diagnosis. The subgroups compared were selected on the basis of their clinical relevance and represented categories of curve severity for which different clinical decisions are recommended.

5. Conclusion

Partial evidence of the SRS-22 predictive validity was provided with all domains except function showing low to moderate correlations with measures of the internal or external deformity. SRS-22 also predicted with as much as 79% accuracy, subjects within different categories of curve severity. Models performed best when predicting subjects with curves larger than 45° or 50° suggesting that there may be a threshold above which the quality-of-life of persons with scoliosis begins to deteriorate.

6. Acknowledgments

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Chapter 7

Electronic Poster Presentation

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Research into Spinal Deformities 5
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Evaluation of Torso Shape and Asymmetry Associated with Scoliosis

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Abstract. This paper presents a technique for evaluating torso shape and asymmetry in scoliosis using indices of point-set data obtained from torso surface scans. Point-set data are the maximum curvature points of a surface scan and contain key shape information. The centroids, distributions and densities of point-set data are indices of shape and asymmetry. The mean-squared deviations of the centroids per-cross-section from the medial plane are indicative of asymmetry. The distribution and density of point-set data are indicative of shape. Evaluations using point-set data indices were 100% in accord with those based on the cosmetic score. Indices of point-set data have more degrees of freedom and were able to distinguish between scans that have similar cosmetic scores.

Keywords. Scoliosis, Torso Shape, Asymmetry, Range Scans, Cosmetic Score

Introduction

The study of the external deformity associated with scoliosis pre-dates modern investigations of spinal deformity using radiographs [1]. Continued interest in the external deformity is justified by the fact that many patients worry more about their external shape than about their spinal deformity [2]. Also, many patients initially seek treatment for scoliosis because they are not satisfied with the appearance of their torsos and view improvement in torso shape as a measure of the success of scoliosis treatment [2].

Since the advent of the use of back shape imaging for the assessment of scoliosis (with systems such as Moiré topography [3]), several research groups have developed scores to quantify torso asymmetry based on indices like scapular angle differences and back surface rotation obtained from images of the back. These scores include: posterior trunk symmetry index (POTSI) [4], [5]; cosmetic score [6]; integrated shape imaging system (ISIS) index [7]; and Quantec score [8]. They are computed from indices that are not linearly independent basis vectors in shape space. This makes them untenable to multidimensional analysis of shape and asymmetry. Thus, it is very possible to see two patients who have the same deformity score and yet present widely different manifestations of torso asymmetry. There is a need to develop more descriptive measures of torso asymmetry based on multi-dimensional analysis of torso shape and asymmetry in shape space.

This paper presents a technique for evaluating torso shape and asymmetry in scoliosis based on descriptors of the major features of torso deformity: twist, bend and asymmetry (Figure 1). The descriptors are indices of point-set data obtained from torso surface scans.

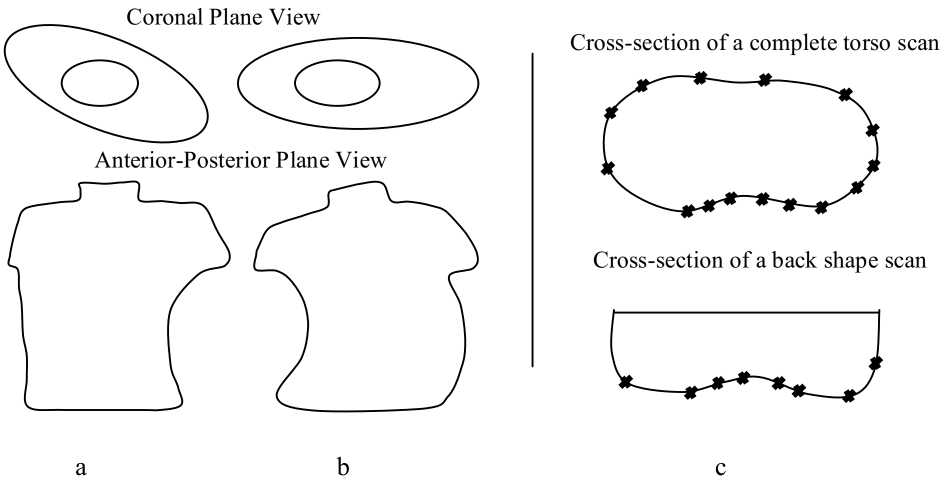

Figure 1. A. Twisted torso shape. B. Bent torso shape. C. Points of high curvature on cross-sections of a complete torso scan and a back shape scan of a human torso.

Point-set data are the maximum curvature points of surface scans and contain key shape information. The centroids, distributions and densities of point-set data are indices of shape and asymmetry. The mean-squared deviations of the centroids per-cross-section from the medial axis are indicative of asymmetry. The distribution and density of point-set data are indicative of shape. The technique was modelled from 30 back shape scans of scoliosis patients and tested on another 18 back shape scans of scoliosis patients.

Point-set Data

A. High Curvature Points

Edges and points of high curvature play an important role in the perception of shape. Research in human cognition and shape recognition suggest that when presented with objects, the human visual system pays much attention to points of high curvature [9]. Davis [10] developed an approach that detects angles and sides at various degrees of coarseness to construct a hierarchy of angles that describe the curve at any desired level of coarseness. The approach was to aid the incorporation of curvature information in descriptions of plane shapes. It can be extended to the description of 3D shapes by representing the 3D shapes by a finite set of cross-sections. In this paper, high curvature points are called point-set data.

B. Application to Assessing Scoliosis

As human torso scans are 3D shapes, point-set data can be used to assess the torso shape and asymmetry associated with scoliosis. The range of deformity patterns produces various distributions of point-set data. The torso surface is divided into six regions (Figure 2) and centroids of point-set data in each region computed. The difference between the mean-square deviations from the medial plane of the centroids in the two halves of the torso is a measure of asymmetry. The centroid distributions are indicative of overall twist and bend.

Figure 2. Back shape views of (from left to right) mild, moderate and severe patients showing centroids of the distribution of point-set data of the six sections.

Materials and Methods

Back shape scans of 30 female idiopathic scoliosis patients whose torso deformity run the gamut seen in our scoliosis database (containing over 1000 entries) were used to calibrate the deformity- and symmetry-space of the twist, bend and asymmetry indices. The patients were diagnosed as having idiopathic scoliosis and were between 10 and 18 years old (average age 14.5 years). Each index ranged from 0 to 10 with '0' corresponding to no deformity and '10' corresponding to the maximum found in our database. To obtain an overall score, the three indices were modeled as orthonormal vectors in 3D shape space. The deformity index was the Euclidean norm of the magnitude of the indices. Mild, moderate and severe torso deformity mapped to values of 1-3, 3-5 and 5-10 respectively.

To evaluate the correspondence of the technique to other measures of torso deformity like the cosmetic score [6], 18 torso scans of female scoliosis patients whose demographics matched the earlier group were selected from our scoliosis database (age range, 12-18 years; average age 14.9 years). The torso deformity present in the back shape scans were classified using the proposed technique and compared to the classification obtained using the cosmetic score.

Results

Table 1 shows the results obtained from classifying 18 scans of female scoliosis patients based on the distribution of their point-set data and a comparison with the cosmetic score classification. Evaluations using point-set data indices were 100% in accord with those based on the cosmetic score. Indices of point-set data have more degrees of freedom and were able distinguish between scans that have similar cosmetic scores. They are a superset of clinical descriptions similar to the cosmetic score.

Table 1: Classification of back shape scans of 18 female scoliosis patients

	Age	Cosmetic Score		Point-set Data	
		Score	Classification	Score	Classification
1	13.8	1.0	Mild	2.3	Mild
2	18.0	1.6	Mild	2.5	Mild
3	17.0	1.8	Mild	2.2	Mild
4	14.4	2.6	Moderate	4.7	Moderate
5	13.8	3.5	Severe	6.3	Severe
6	14.2	1.5	Mild	2.3	Mild
7	12.8	2.5	Moderate	4.3	Moderate
8	17.4	3.1	Moderate	3.6	Moderate
9	16.2	3.1	Moderate	3.7	Moderate
10	15.0	1.9	Mild	2.6	Mild
11	14.8	2.1	Moderate	4.4	Moderate
12	16.1	3.4	Severe	6.5	Severe
13	14.6	1.9	Mild	1.8	Mild
14	12.7	3.3	Moderate	3.8	Moderate
15	16.4	4.9	Severe	7.1	Severe
16	14.1	1.0	Mild	1.0	Mild
17	13.3	1.1	Mild	1.2	Mild
18	15.1	1.9	Mild	1.6	Mild

Discussion

The proposed technique can be used on back shape data (as in this paper) or on complete torso data [11]. The classifications obtained were in accord with classification based on the cosmetic score. As shape and asymmetry characterize the external deformity of scoliosis, the technique could be applied to monitoring changes in torso shape in progressive scoliosis. Future work will focus on validating the technique on a larger dataset of patients.

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Assessment of Brace Local Action on Vertebrae Relative Poses

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Abstract. Bracing is a widely used treatment of scoliosis, but there is still no consensus about its actual effect. Previous studies were based on global descriptors of the spine shape (Cobb angle, plane of maximal deformity, *etc.*). We present a new method to analyze braces effects at a finer scale and to find which vertebral levels are significantly affected by this treatment. The proposed method compares a group of patients treated with a brace and a control group. The 3D spine geometry of the patients from the two groups was digitized on two separate occasions: with and without brace (first group) or two times without brace (control group). The modifications of the vertebrae relative poses (combination of relative translation and rotation between consecutive vertebrae) were then extracted from 3D reconstructions. Centrality and dispersion measures of the relative poses modifications were computed using a method that take into account the non-linearity of the rotation matrix. Then, finally, multivariate hypothesis tests were used to compare the centrality and dispersion of the two groups. The method was applied to 28 untreated scoliotic patients and 41 patients treated with a Boston brace. Significant differences ($p<0.01$) between the centrality and dispersion measures of the relative poses modifications were respectively found from T1 to T6 and from T8 to L1. Those significant differences concords with the back flattening effect and the spatially limited correction found in other studies; however the proposed method offers a more specific evaluation of the localization of those effects.

1. Introduction

Bracing had become a well accepted treatments for mild cases of adolescent idiopathic scoliosis (AIS) because it is non-invasive and it does not pose risks to the patient's health. However, the actual effect of such treatment is difficult to measure because the modifications of the spine geometry are small and there is no consensus about the localization of that effect.

The conventional method used to measure the effect of a brace is to compute clinical indices (such as the Cobb angle, the apical rotation, the plane of maximal deformity, etc) and to compare the progression of those indices for a control group and a group of patients treated with a brace [1,2,3].

However, this method of evaluation has many drawbacks. First of all, most of the clinical indices used are solely based on an anterior-posterior radiograph, thus discarding the three dimensional nature of the spine curvature. Second, the information gathered using those clinical indices is dependant of the shape of the whole spine and do not offers well localized information about the action of the treatment. Finally, the interpretation of the results could be difficult because the indices are usually not independent.

Moreover, previous studies were only concerned with the mean deformation caused by the brace and not with its variability. However, a modification of the variability could be an indication that the correction is more or less important for large curves than it is for smaller curves (for example) which would be valuable clinical information.

To circumvent those drawbacks and limitations, we propose to apply an hypothesis testing procedure directly to the spine geometry without computing any intermediate index. The spine geometry will be described using the relative poses (relative positions and orientations) that separates the local coordinates systems of neighbouring vertebrae. A similar approach was proposed by Petit et al. [4] to compare two surgical instrumentations. However, only the mean position of the center of rotation was studied. The proposed method will be applied to the relative poses used to describe the geometry of the spine. Furthermore, the hypothesis tests will not only compare the mean effect on the spine shape, but also the variability of this effect.

2. Method

The proposed method can intuitively be subdivided in three steps. First of all, the modification of the vertebrae's relative poses is computed. This modification takes the form of a vector of rigid transforms (combination of a rotation and a translation). Then, the mean and variability of those rigid transforms is computed. Finally, a hypothesis testing procedure determines if there is significant differences between patients treated with a brace and patients from a control group.

2.1. Vertebrae Relative Poses Computation

The spine geometry was described using the relative poses that separate the local coordinates systems of neighbouring vertebrae. Furthermore, the effect of a brace on the spine geometry is simply modeled by the set of rigid transforms that must be applied to the relative poses computed without the brace to obtain the relative poses computed when the patient is wearing his brace.

In other words, the spine geometry is described by the relative poses T_1, T_2, *etc.* and the effect of the brace is modeled by the rigid transforms ΔT_1, ΔT_2, *etc.* illustrated at Figure 1.

The relative poses computation is achieved by reconstructing a 3D model of the spine from a pair of calibrated radiographs [5] and then rigidly registering each vertebra to its first upper neighbour.

2.2. Mean and Covariance Computation

The rigid transforms used to model the effect of a brace are composed of a rotation and a translation. Computing the mean value of the translation is easy, since translation is described by three real numbers (it belongs to R^3). However, the rotation is more difficult to manipulate, because rotations cannot by added or multiplied by a scalar (they naturally belongs to a Lie group). Thus, just summing a set of rotation matrices and dividing the total by the number of elements might not produce a valid rotation matrix and the result would not be invariant with respect to a change of coordinates system.

Those difficulties can be solved by using the Fréchet mean, which is a generalization of the conventional mean. This generalization is based on the minimization of the distances between the elements of a set. Moreover, its computation is easy if one knows the exponential and log maps associated with the chosen distance function. Furthermore, the variability of the rigid transforms can be captured by computing a covariance matrix in the tangent space of the Fréchet mean (the equations needed to compute the Fréchet mean and the covariance on rigid transforms can be found in [6]).

2.3. Hypothesis Testing

After computing the mean and variability from a group of patient treated using a brace and a control group, the next important step is to determine if they differ significantly. This can be achieved by using multivariate hypothesis testing. Thus, the Hotelling's T^2 test will be used to compare the mean of spine shape deformation and the variabilities will be compared using the Box's M test.

However, these two tests assume a normal distribution of the measures (details about the derivations and the underlying assumptions of those two tests can be found in Rencher et al. [7]). Therefore, we have to assume that both sets of rigid transforms are normally distributed in the tangent spaces of the Fréchet mean of the two sets. This assumption is generally justifiable in the case of braces effects because the deformation of the spine and its variability are small.

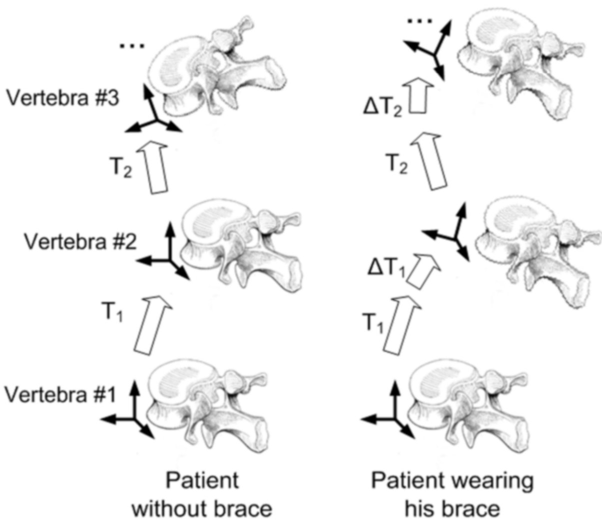

Figure 1. The action of a brace expressed as rigid transforms (ΔT_1, ΔT_2, *etc.*) on the spine geometry expressed using relative poses (T_1, T_2, *etc.*)

2.4. The Case of the Boston Brace

To demonstrate the practical significance of the method described in this article, two groups of patients were selected for comparison. The first group was composed of 39 scoliotic patients that were treated using a Boston brace. All the patients of this group had received two stereo radiographic examinations: one without brace and one while wearing their brace (both examinations were performed on the same day). The second group (which is the control group) was composed of 26 scoliotic patients that did not received any orthopaedic treatment and had received two stereo radiographic examinations (for ethical reasons, the two examinations were conducted six months apart).

The stereo radiographic examinations were used to reconstruct 3D spine models and the method described in the previous subsections was used to compare the mean modification of the spine shape as well was the variability of the spine shape modification for the two selected groups.

3. Results

The mean modifications of the spine shape (see Figure 2) along with the rotational and translational variabilities were computed for the group treated using the Boston brace and the control group. The variability of the Boston brace effect appeared to be more important in the lower part of the thoracic spine (approximately from T7 to L1, with a maximum at T11). Moreover, the mean curve in frontal view as well as the kyphosis and lordisis found in the sagittal view seemed to be reduced by the treatment.

Hypothesis tests were also performed to detect statistically significant differences between the control group and the group treated with the Boston brace. The results of those tests are presented in Table 1. In this table, p-values lower than 0.01 are marked with a star ("*"), p-values lower than 0.001 are marked with a two stars and p-values lower than 0.0001 are marked with a three stars.

4. Discussion and Conclusion

The comparison of the group treated using the Boston brace and the control group outlined two significant differences. First of all, there was a significant difference between the mean deformations of the spine geometry from T1 to T6. This suggest a systematic effect of the Boston brace on the geometry of the thoracic spine of all patients treated with it regardless of strength and shape of the curvature caused by scoliosis. This effect could be associated with what was described in earlier studies as the "flat back" effect of the Boston brace.

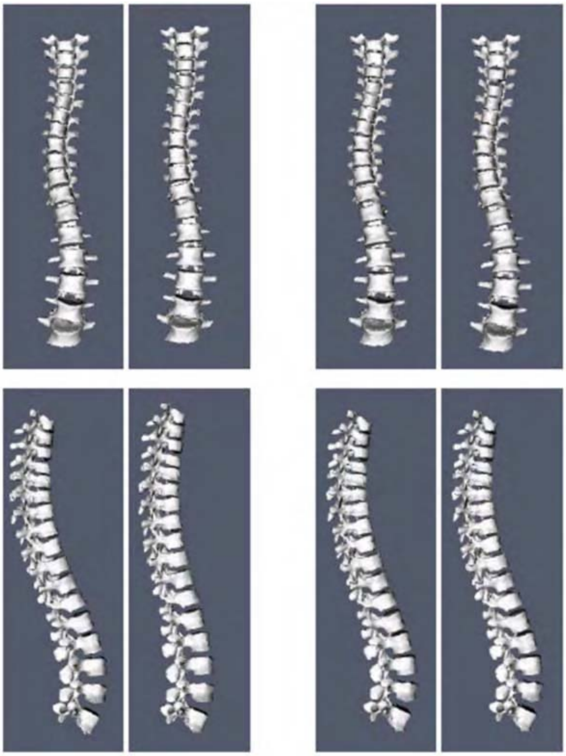

Figure 2. From left to right: mean shape without brace, with the brace, of the control group at the first acquisition and of the control group at the second acquisition Top : Frontal view. Bottom: sagittal view

	Mean		Covariance	
T2 → T1	2.5e-4	**	1.1e-1	
T3 → T2	1.7e-3	*	5.6e-2	
T4 → T3	8.4e-9	***	1.4e-2	
T5 → T4	2.1e-3	*	1.8e-1	
T6 → T5	6.8e-3	*	1.7e-1	
T7 → T6	2.5e-2		1.3e-1	
T8 → T7	5.9e-2		4.3e-2	
T9 → T8	5.2e-1		7.5e-6	***
T10 → T9	2.3e-1		5.2e-4	**
T11 → T10	3.6e-1		2.3e-5	***
T12 → T11	8.2e-1		4.4e-6	***
L1 → T12	6.7e-1		5.3e-4	**
L2 → L1	9.3e-1		2.9e-1	
L3 → L2	3.4e-2		2.9e-1	
L4 → L3	3.0e-2		7.3e-2	
L5 → L4	3.1e-1		1.3e-2	

Table 1. Statistical significance of the difference between the means and the covariance matrices of a control group and a group of patients wearing a Boston brace.

The second significant difference between the two groups of patients was observed between the variabilities from T8 to L1. A significant difference between variabilities is an indication that the Boston brace brings scoliotic spines closer to a `` healthy " spine shape (which is the goal of the treatment). More serious scoliotic cases were submitted to larger corrections than mild cases which lead to larger variabilities. Therefore, this difference suggests that most of the therapeutic effect of the Boston brace is localized in the region from T8 to L1.

One of the limitations of the proposed method is that the assumption of normality needed to apply the T^2 and M test is quite restrictive. For example, for larger deformations the non-linearities related to the rotation could lead to asymmetric distributions (for which the normality assumption would be hard to justify).

Finally, a method to assess the local effects of a brace was presented. The proposed method was applied directly to a representation of the spine geometry (the vertebrae's relative positions and orientations) which lead to results that are more precisely localized than those found in previous studies. The proposed method was used to compare a control group with a group of patients treated with a Boston brace and significant differences were found between the mean modifications of the geometry in the upper thoracic spine and between the geometry modification variabilities in the lower part of the thoracic spine. Those results concord with previous results about the “flat back” effect and the idea that the Boston brace might not have a therapeutic effect on the whole spine but on a relatively small part of the spine. Furthermore, the proposed method could also be used in various contexts such as motion or posture analysis or studies about the effect of corrective surgeries.

Acknowledgement

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Design of a Minimally Invasive Non Fusion Device for the Surgical Management of Scoliosis in the Skeletally Immature

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Abstract. Current management of scoliosis in the skeletally immature focuses on prevention of curve progression. Progressive curves require surgical instrumentation without fusion with periodic lengthening of the construct, continuous bracing and ultimately fusion of the curve when control is lost at the adolescent growth spurt. This treatment regime has a major negative impact on the childs biopsychosocial profile and yields relatively poor longterm results. The aim of this study was to define the ideal characteristics of a growing rod and design a novel implant based on these characteristics.

The method used was logical thought to define the desired implant characteristics and then design an implant which approximated the theoretical model as closely as possible.

An ideal growing rod would grow with the spine, correct the deformity as growth occurred, leave no residual deformity at maturity, not require activity restriction/bracing, not require fusion at maturity and be compatible with a minimally invasive surgical technique.

The ideal growing rod (IGR) is modular consisting of a number of units linked together which conform to the shape of the deformed spine. Each unit spans a disc space and consists of a telescopic rod with one end attached to the vertebra above and the other to the vertebra below. The rod is pushed apart by the force of growth but can only elongate in a predetermined direction resulting in a three dimensional realignment of the instrumented spinal segments with growth.

In conclusion it is possible to design a growing rod with theoretical advantages over current constructs.

Keywords. Scoliosis, spinal deformity, skeletally immature, young child, growing rod, minimally invasive, non fusion, surgery

Introduction

The current management of scoliosis in the skeletally immature is conservative with the use of localiser casts and braces to delay curve progression until the child is old enough for definitive treatment by instrumentation and fusion of the curve. [1] Cases where conservative therapy fails are managed by a variety of surgical procedures including convex epiphysiodesis, stapling of the convex side of the curve, short segment fusion, and posterior growing rod systems such as the, Harrington rod, ISOLA growing rods or Luque trolley system. [2]

The posterior growing rod systems such as the Luque Trolley often result in spontaneous fusion of the spine as it is exposed subperiosteally for insertion of the device. ISOLA growing rods are inserted in such a way as to cause fusion of a small segment of spine proximally and distally to give a solid anchor for the rods. The rods do not control the sagittal profile adequately and obtain their correction by distraction alone. Also they require repeated reoperation at 6 monthly intervals to lengthen the rod construct. At the end of treatment the patients go on to fusion as a definitive management of their scoliosis and often do not achieve good correction of their deformity. Insertion of posterior growing rods and the final fusion procedure are relatively major surgical procedures especially if a thoracotomy is required for anterior release of the curve prior to insertion of the growing rods[1, 2].

The factors responsible for the development of scoliosis in the skeletally immature vary considerably from idiopathic to neuromuscular causes etc. However once a curve becomes established a secondary element comes into play. Growth at a growth plate is accelerated by traction across the growth plate and reduced by compression of the growth plate (Heuter-Volkmann Law). Once a scoliosis curve develops the biomechanics of the spine are altered resulting in compression of the growth plates on the concave side of the curve and reduced pressure or traction on the growth plates on the convex side of the curve. This results in asymmetrical growth of the vertebral body exacerbating the deformity[1, 2]..

Logically use of an implant to change the curve biomechanics and allow compression of the convex side and application of traction to the concave side thus reshaping the growing vertebra should eliminate the curve. Currently there is no implant system available which applies these principles to the correction of early onset scoliosis [3-5].

The aim of this paper is to describe a new concept of implant for the management of early onset scoliosis applying the principle of altering spine biomechanics to reshape the deformed growing vertebral body thus eliminating the deformity and obviating the need for fusion at skeletal maturity.

Method

The method used was logical thought to define the desired implant characteristics and then design an implant which approximated the theoretical model as closely as possible.

An ideal growing rod (IGR) would grow with the spine, correct the deformity as growth occurred, leave minimal residual deformity at maturity, not require activity restriction/bracing, not require fusion at maturity and be suitable for minimally invasive use.

The IGR must therefore conform to the deformed spine, spontaneously extend with growth, be capable of effecting a three dimensional correction with extension, be strong enough to resist fatigue failure in an adult and be suitable for thoracoscopic insertion and not significantly interfere with the structure of the spine.

Results

One potential design of the ideal growing rod (IGR) is a modular rod system consisting of a number of units linked together which conform to the shape of the deformed spine. Each unit spans one or more disc spaces and consists of a telescopic rod with one end attached to the vertebra above and the other to the vertebra below. The rod is pushed apart by the force of growth but can only elongate in a predetermined direction which results in a three dimensional realignment of the instrumented spinal segments with growth.

Figure 1 shows a unit of the modular rod viewed from the anterior aspect of the spine. The two halves of the telescopic rod are attached to the superior and inferior vertebrae respectively via vertebral body screws on the convex aspect of the scoliosis deformity. The vertebral body growth plates are the endplates of the intervertebral discs. As growth occurs the vertebral body screws are pushed apart resulting in distraction of the telescopic rod which due to its curvature in the opposite direction to the spinal deformity in the coronal plane results in a correction of the coronal plane spinal deformity.

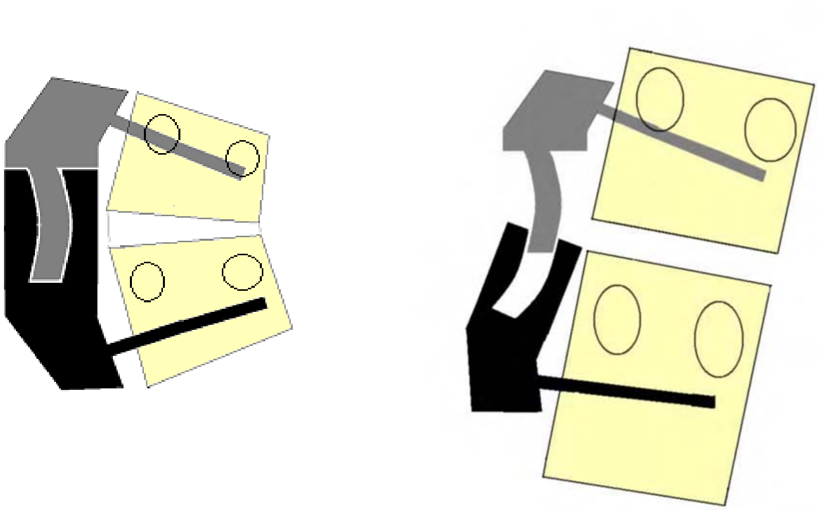

Figure 1. A unit of the IGR attached to two adjacent vertebrae in a scoliosis deformity viewed from the front. The illustration on the left shows the device immediately after insertion and the illustration on the right shows the device after growth has occurred resulting in coronal plane deformity correction at that spinal motion segment.

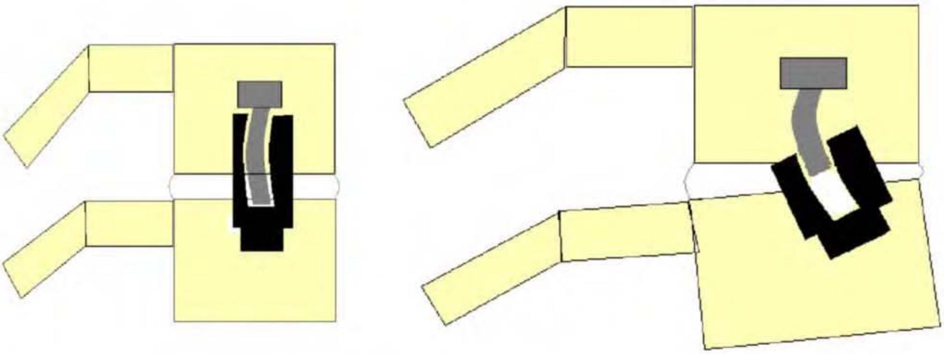

Figure 2. The same unit of the IGR attached to the same two adjacent vertebrae in the scoliosis deformity in figure 1viewed from the side. The illustration on the left shows the device immediately after insertion and the illustration on the right shows the device after growth has occurred resulting in sagittal plane deformity correction at that spinal motion segment.

Figure 2 shows the same vertebrae and unit of the IGR viewed from the lateral aspect of the spine. As growth forces the vertebral body screws apart the telescopic rod is distracted which due to its curvature in the opposite direction to the spinal deformity in the sagittal plane results in correction of the sagittal plane spine deformity.

Figure 3 shows the same vertebrae and unit of the IGR viewed from the superior aspect of the spine. As growth pushes the vertebral body screws apart the telescopic rod is distracted which due to its spiral in the opposite direction to the rotational spinal deformity results in correction of the rotational plane spine deformity.

Figure 4 shows multiple units linked together to form the IGR. The different units independantly correct the deformity at each level, the overall effect being a three dimensional correction of the entire spinal deformity with growth. The superior and inferior screw attachment members of the individual units are angled relative to each other in the coronal, sagittal and rotational planes to facilitate fitting the units to the deformed spine. The telescopic rod functions as a low friction bearing and is orientated in such a way as to provide both angular correction of the deformity in three planes and translation of the vertebrae in the deformity back towards the midline. Thus the IGR functions as an extendable internal splint that corrects the deformity with growth. The use of a spring in the lumen of each IGR unit may be beneficial in accelerating the rate of deformity correction with this device. The ends of the telescopic rod in the units can be tapered to prevent over correction of deformity with growth and to allow movement in the instrumented levels after deformity correction has occurred while preventing recurrance of the deformity.

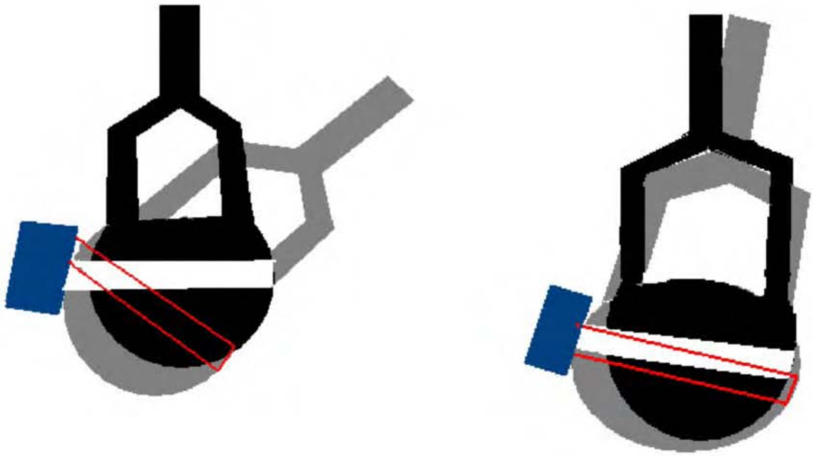

Figure 3. The same unit of the IGR attached to the same two adjacent vertebrae in the scoliosis deformity in figure 1viewed from the top. The illustration on the left shows the device immediately after insertion and the illustration on the right shows the device after growth has occurred resulting in correction of the rotational deformity at that spinal motion segment.

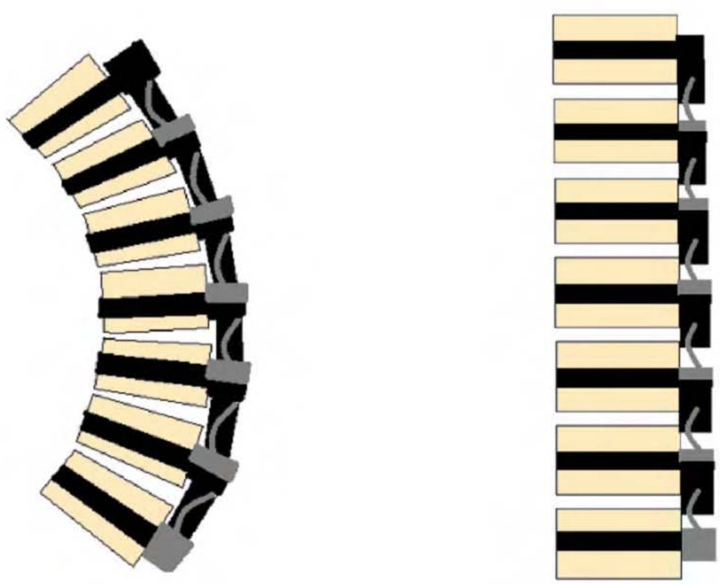

Figure 4. The IGR applied to a right sided scoliosis deformity viewed from the posterior aspect. It consists of multiple units linked together to form the growing rod. The illustration on the left shows the device immediately after insertion and the illustration on the right shows the device after growth has occurred resulting in three dimensional correction of the spinal deformity by the mechanisms described in figures 1-3.

A number of implant prototypes have been built which confirm that the conceptual telescopic rod model with arcs of different curvatures in planes at 90 degrees to each other and a spiral can produce the desired three dimensional correction necessary for the IGR to work.

Discussion

Current growing rod constructs involve initial major surgery to implant the device followed by repeated minor surgical procedures at 6 monthly intervals to extend the rod to allow for growth and require the wearing of a brace during the treatment period which may be many years. These growing rod constructs do not give a 3 dimensional correction of the curve but aim to give some correction and to prevent further deterioration of the deformity. Control of the deformity is typically lost during the adolescent growth spurt and further major surgery is necessary at that stage to fuse the spinal deformity. The overall outcome is often less than satisfactory from a cosmetic viewpoint and the adverse impact of this treatment regimen on the child from a biological, social and psychological perspective is enormous[1, 2].

The IGR can be used to treat spinal deformities in those in which sufficient growth potential remains. It offers a single non fusion minimally invasive surgical procedure, complete correction of deformity, no bracing requirement and no need for further surgery at maturity. The IGR represents a major advance in the treatment options for scoliosis in the skeletally immature. For the first time an implant can utilise residual spinal growth to correct spinal deformity.

High residual growth potential (HRGP) is the most important prognostic indicator in determining the likelihood of progression of scoliosis. Hence HRGP is currently regarded as a bad thing by those managing scoliosis in the skeletally immature. The dilemma in treating these patients is that it is necessary to allow growth to occur to avoid cardiorespiratory compromise but necessary to prevent curve progression as this will ultimately compromise cardiorespiratory function more than if no growth was permitted[1, 2].

The IGR is the first implant to allow HRGP to be controlled and used to correct the spinal deformity. It represents a new departure in the management of scoliosis in the skeletally immature and demands a change in attitude towards HRGP by those treating this condition. The IGR has turned HRGP into an asset in the management of scoliosis. Hence a new philosophy is required by those treating scoliosis in the skeletally immature, in which HRGP is regarded as a good thing and utilised to correct the deformity.

The IGR provides a partial correction of the deformity at the time of application, as do other growing rods. However with growth it acts to gradually correct the spinal deformity which is theoretically safer on the neurological structures than the multiple acute corrections obtained by repeated surgical manipulation of current growing rod constructs. The IGR acts to gradually derotate the spine and the rib cage theoretically allowing restoration of normal respiratory mechanics and eliminating the rib hump. The reversal of the initial deforming forces, by the implant will promote remodeling of the ribs in addition to the mechanical derotation that occurs with growth. This combination of rib derotation and remodeling would be expected to restore the rib cage to near normal, eliminating the rib hump which is usually the major cause of cosmetic deformity. No other treatment method offers as comprehensive a restoration of respiratory mechanics and complete elimination of the rib hump and the rib hollow on the concave side.

There has recently been increasing interest in minimally invasive non fusion technologies to treat adolescent idiopathic scoliosis [3-5]. To date these therapies have consisted of stapling and tethering procedures which do not unload the concave side of the deformity and so do not correct the deformity but may prevent it from progressing [3-5]. The IGR represents the logical next step in this process as it redistributes the force generated by growth to unload the concave aspect of the deformity promoting correction with growth. The IGR is a minimally invasive procedure and so may be considered in selected cases where non compliance with brace treatment is an issue in progressive adolescent idiopathic scoliosis.

The IGR takes us into a new era in scoliosis surgery where high residual growth potential for the first time becomes an advantage in the treatment of spinal deformity. The implant may be inserted by a minimally invasive approach, which combined with its non-fusion technology takes scoliosis treatment in the skeletally immature to new levels.

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Etiologic Theories of Idiopathic Scoliosis: The Breaking of Bilateral Symmetry in Relation to Left-Right Asymmetry of Internal Organs, Right Thoracic Adolescent Idiopathic Scoliosis (AIS) and Vertebrate Evolution

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Abstract. In the search to understand the etiology and pathogenesis of adolescent idiopathic scoliosis (AIS) some workers have focused on mechanisms initiated in embryonic life including a disturbance of bilateral (left-right or mirror-image) symmetry highly conserved in vertebrates. The normal external bilateral symmetry of vertebrates results from a default process involving mesodermal somites. The normal internal asymmetry of the heart, major blood vessels, lungs and gut with its glands is also highly conserved among vertebrates. It results from the breaking of the initial bilateral symmetry by a *binary asymmetry switch* mechanism producing asymmetric gene expression around the embryonic node and/or in the lateral plate mesoderm. In the mouse this switch occurs during gastrulation by cilia driving a leftward flow of fluid and morphogen(s) at the embryonic node (nodal flow) that favors precursors of the heart, great vessels and viscera on the left. Based on the non-random laterality of thoracic AIS curves, the hypothesis is suggested that an anomaly of the binary asymmetry switch explains the excess of right/left thoracic AIS. Some support for this hypothesis is the prevalence of right and left scoliosis curve laterality associated with *situs inversus.* There is recent evidence that vertebrates within their bilateralised shell retain an archaic left-right asymmetric visceral body organization evident in thoracic and abdominal organs.

Key words. Scoliosis, etiology, bilateral symmetry, situs, vertebrae, ribs, evolution

1. Introduction

In the search to understand the etiology and pathogenesis of adolescent idiopathic scoliosis (AIS) two groups of workers have focused on mechanisms initiated in embryonic life including a disturbance of bilateral symmetry. This involves a dissection of the clinical, embryologic, molecular, genetic, and evolutionary basis of laterality [1].

1.1 Idiopathic scoliosis as a complex growth disorder involving bilateral symmetry

Burwell et al [2], finding abnormalities of general body growth and skeletal symmetry in the upper limbs, suggested that the fundamental causes of idiopathic scoliosis may be genetic/environmental (nature/nurture) factors acting directly or indirectly on developing skeletal primordial in early embryonic life. They wrote: "Implicit in this hypothesis is that the abnormalities so created may not become evident in the growing skeleton until months or years after birth." This embryologic model for the etiology of idiopathic scoliosis was developed further by Burwell and colleagues [3-5].

1.2 Idiopathic scoliosis as developmental instability

Goldberg et al [6-8] reviewed left-right directional asymmetries in AIS and reported new observations on handedness, language lateralisation, dermatoglyphics and fluctuating asymmetry (FA). Goldberg wrote [8]: "….scoliosis is not a disease or group of diseases but a symptom or sign of environmental stress, significant enough to overwhelm the intrinsic stability of the morphological genome. As such, there is no specific etiology but a large number of precipitating stressors…." Dangerfield et al [9] reported an increase in FA about the head and hands with increasing curve severity in IS.

1.3 Two embryologic mechanisms that determine symmetry

1.3.1 The *normal external phenotype bilateral symmetry* of vertebrates results, evidence suggests, from a default process involving mesodermal somites [10,11]. Bilateral symmetry may have its origin as an intrinsic property of the oocyte that is induced by its activation [12]

1.3.2 The *normal internal phenotype asymmetry* of the heart, major blood vessels, lungs and gut with its glands is highly conserved among vertebrates and termed *'handed (or chiral) asymmetry'* [10]. It results, evidence suggests, from the breaking of symmetry by a *binary asymmetry switch* mechanism [10,11,13].

The invariant internal left-right asymmetry of vertebrate body plans raises questions not only in cell and developmental biology but also in neurobiology and evolution [14], and the etiology of AIS.

2. Embryologic Origin of Vertebrate Left-Right Internal Asymmetries

2.1 Breaking symmetry in embryos to create 'handed (or chiral) asymmetry'

The theoretical and seminal paper of Brown and Wolpert [10] proposed a model to explain how across all vertebrates early bilateral symmetry of the embryo is broken to create *'handed asymmetry'*. The fundamental determining feature is a *special* *mechanism* to distinguish 'leftness' from 'rightness' defined with reference to the other two axes – anteroposterior (AP) and dorsoventral (DV) [10,11,15]. The left-right axis is the dependent axis, existing only relative to the previously established AP and DV axes; errors in its proper patterning are believed to lead to congenital defects of the heart and abdominal viscera [1].

2.2 The cilia model in mouse gastrulation

According to Capdevila et al [13] experimental evidence indicates that the *special mechanism* in mice during gastrulation involves a specialised cluster of monocilia present on the ventral surface of the mouse node [16-19] – the mammalian equivalent of the organizer region; by rotating, these cilia create a leftward flow of extra-embryonic fluid in the node region (nodal flow); there, by causing a left-right difference in one or more extra-cellular inducers (morphogens), it is translated into asymmetric gene expression around the node and/or in the lateral plate mesoderm [19]. Tanaka et al [17] describe small membrane-bound particles termed *nodal vesicular parcels* that are carried to the left side of the node where they are considered to break the left-right symmetry [18].

2.3 Kartegener's syndrome, primary ciliary dyskinesia and situs inversus

The cilia model of left-right determination in the embryo receives strong support from Kartegener's syndrome (bronchiectasis, chronic sinusitis, and *situs inversus*); this syndrome belongs to a range of ciliary defects which at the structural level result in the clinical presentation including *situs inversus*, respiratory disease and male infertility. These ciliary defects are collectively called *primary ciliary dyskinesia, or immobile cilia syndrome,* in which *situs inversus* occurs in about 50% [20, 21].

3. The High Prevalence of Right Thoracic AIS – is it linked to the binary asymmetry switch and nodal flow of morphogens that lead to the internal asymmetry ('handed asymmetry') of vertebrates?

3.1 Explanations for the excess of right thoracic AIS

Several explanations relating to postnatal structure and function have been invoked to explain why AIS thoracic curves are predominantly convex to the right, including handedness, the heart, aorta, larger right lung and the diaphragm [22].

3.2 Side distribution of curve types by level – thoracic spine non-random

Examination of the side distribution of curves in our school screening study for 1993-99 shows the expected excess of right/left thoracic curves: apex T3-T11 curves 39/6 but a random distribution of the lower curves, apex T12-L3 36/39 [23]. It is concluded that in our sample the mechanism(s) that determined curve laterality for the upper spine differed from that for the lower spine.

3.3 The normal external phenotype bilateral symmetry of vertebrates results from a default process

It is evident that genetic/environmental factors can disturb the default symmetry control of the external phenotype and determine some human limb length inequalities (e.g. Russell-Silver syndrome). It is theoretically possible that it may also occur in AIS [24] but there is no evidence that such a mechanism may determine the skeletal asymmetries of AIS, in the axial and appendicular skeleton.

3.4 The normal internal phenotype asymmetry results from the breaking of the initial bilateral symmetry by a binary asymmetry switch involving nodal flow

There is no experimental evidence that the skeletal precursors of the vertebrate external phenotype are affected *normally* by embryonic nodal flow. But may this occur as an anomaly in the early embryonic development of some humans and be expressed later as AIS?

3.5 Embryologic hypothesis involving nodal flow for right thoracic AIS

Should the leftward nodal flow of morphogens - that affects precursors of the heart, great vessels and viscera to create *'handed asymmetry'* - be extended by anomalous genetic/environmental factors to *left-sided mesodermal precursors of vertebrae and ribs (and in particular their physes),* an asymmetric skeletal anomaly may be imprinted. Such an anomaly, not expressed phenotypically until puberty, may lead to relative left costo-vertebral physeal overgrowth that triggers right thoracic AIS in girls and anomalous upper limb length asymmetry [23,24].

Some support for this hypothesis is the report that in the practice of Dr Robert Winter MD of his 16 patients with dextrocardia about 50% had curves convex to the right [25] as in primary ciliary dyskinesia [20,21].

This hypothesis for the laterality of upper spine scoliosis does not explain the random side distribution of the lower spine scolioses. The evidence suggests that there may there be another mechanism.

4. Evolutionary Origin of Vertebrate Internal Left-Right Asymmetries

In the last few years, an understanding has emerged of the developmental mechanism for the consistent internal left-right structure of major organs, termed *situs* that characterizes vertebrate anatomy [26] (Figure).

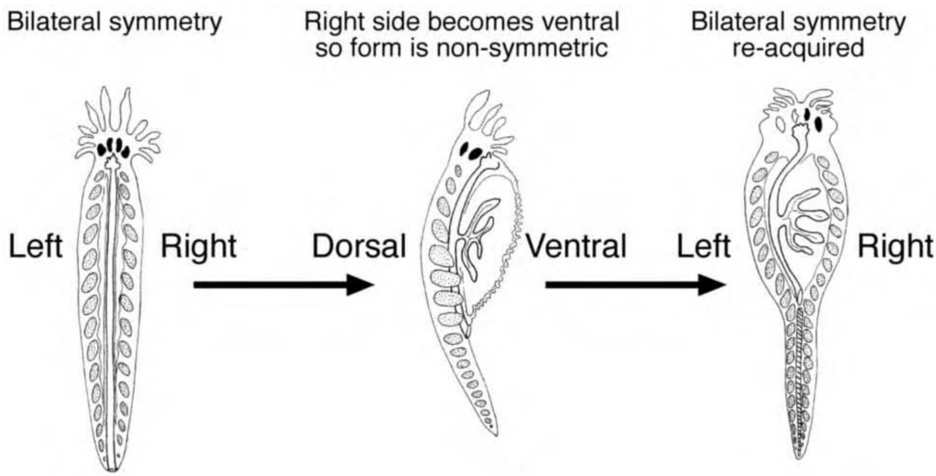

Figure. Bilateral (mirror-image) symmetry of vertebrates: evolutionary origin by re-acquisition (see text, re-arranged from Cooke [26])

Cooke [26,27] adduces evidence (1) that a remote chordate ancestor lost bilateral symmetry when its original right-hand side became ventral, (2) then passed through a non-symmetric stage as a 'visceral' animal, and (3) secondarily re-acquired a symmetrised locomotor-skeletal-neural system. Vertebrates within their bilateralised shell retain an archaic left-right asymmetric visceral body organization evident particularly in thoracic organs. The vertebrate dorso-ventral midline plane is not descended from the original one. This scenario takes account of evidence from comparative developmental anatomy of extant forms, comparative gene expression and molecular taxonomy, but does not take account of fossil evidence.

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Etiologic Theories of Idiopathic Scoliosis: Enantiomorph Disorder Concept of Bilateral Symmetry, Physeally-created Growth Conflicts and Possible Prevention

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Abstract. The detection of anomalous extra-spinal left-right skeletal length asymmetries in the upper limbs, periapical ribs, ilia and lower limbs of subjects with adolescent idiopathic scoliosis (AIS) raises questions about skeletal bilateral symmetry of vertebrates in health and disorder, its origin and control. The vertebrate body plan externally has mirror-image bilateral symmetries that are highly conserved culminating in the adult form. The normal human body can be viewed as containing *paired skeletal structures* in the axial and appendicular skeleton as 1) *separate left and right paired forms* (eg long limb bones, ribs, ilia), and 2) *united in paired forms* (eg vertebrae, sternum, skull, mandible). Each of these separate and united pairs are mirror-image forms – *enantiomorphs.* Left-right asymmetries of growth plates (physes) may cause (1) in long bones length asymmetries, (2) within one or more vertebral physes putative growth conflict with distortion as deformity, and (3) between ribs and vertebrae putative growth conflict that triggers thoracic AIS suggesting preventive surgery on spine and ribs. There is evidence of a possible role for environmental factors in AIS development. Genes and the environment (nature/nurture) may interact pre- and/or post-natally to explain both the deformity of AIS and its association with widespread anomalous skeletal length asymmetries. If substantiated there may ultimately be a place for the prevention of AIS in some subjects.

Keywords. Scoliosis, bilateral symmetry, etiology, vertebrae, growth plates, enantiomorph, environment

1. Introduction

The detection of anomalous extra-spinal left-right skeletal length asymmetries in the upper limbs [1-4], periapical ribs [5], ilia [6] and lower limbs [6,7] of subjects with adolescent idiopathic scoliosis (AIS) begs the question of whether these asymmetries are unconnected or in some way connected with pathogenesis [8]. In basic terms the observations raise questions about skeletal bilateral symmetry of vertebrates in health and disorder, and a possible etiologic role for environmental factors in etiology.

2. The Vertebrate Body Plan and Its Origins in Embryonic Life

2.1. External phenotype symmetry

The vertebrate body plan externally contains highly conserved *mirror-image bilateral symmetries* that culminate in the adult form [9,10]. We suggest the word *enantiomorph* for these *mirror-image bilateral symmetries* (Gk=opposite form). This symmetric pattern is determined in embryonic life by a *default process* [9,10].

2.2. Internal phenotype asymmetry

The vertebrate body plan internally has left-right asymmetries of heart, great vessels, lungs and gut [9,10]. The pattern is determined in embryonic life from a *binary asymmetry switch* that establishes visceral and vascular asymmetry [9,10].

2.3. The possible relation of these embryonic mechanisms to AIS etiology and the evolution of vertebrate bilateral asymmetries is considered elsewhere [11].

3. Enantiomorph (mirror-image) Bones in the Normal Appendicular and Axial Skeleton

3.1. Separate left and right paired forms

Separate left and right paired forms are found in the limb bones, ribs (axial skeleton) and hip bones (appendicullar skeleton).

3.2 United paired bones

United paired bones include the vertebrae, sternum (of appendicular origin [12], skull and mandible.

4. Growth-plates (physes) Can Create Left-right Asymmetries During Development (Figure 1)

4.1. Separate left and right paired enantiomorph forms

Longitudinal growth from endochondral ossification that is left-right asymmetric evidently lead to skeletal length asymmetries as detected in AIS subjects in their upper limbs, ilia and lower limbs.

4.2 United paired enantiomorph forms may lead to putative growth conflicts

Longitudinal growth from paired enantiomorph endochondral ossification if not symmetric may putatively lead to growth conflict. In vertebrae such growth conflicts may occur in relation to both neurocentral synchondroses and vertebral body physes. The latter process was suggested by Coillard and Rivard [13] and termed "unsynchronized bone growth". The latter process may be left-right (in the transverse plane) or front-back (in the sagittal plane).

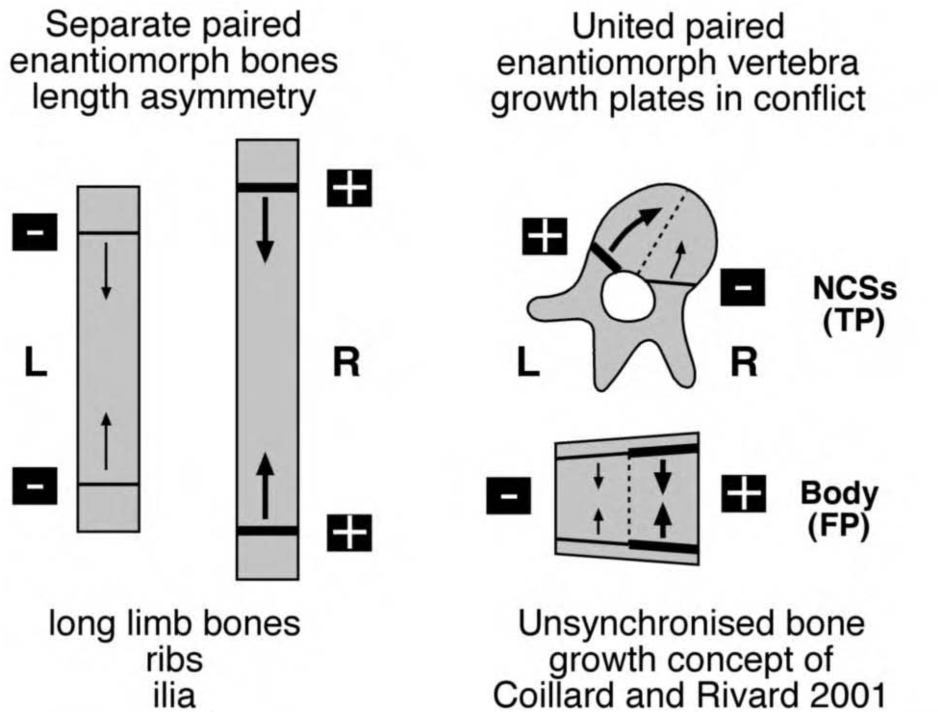

Figure 1. Hypothesis: growth plates (physes) create left-right asymmetries in enantiomorph bones with different effects (TP = transverse plane, FP= frontal plane).

5. Putative Growth Conflicts in Vertebrae and Ribs; Combined Preventive Surgery?

Elsewhere in this Meeting we report a statistically significant correlation between apical vertebral rotation and upper arm length asymmetry in patients with thoracic scoliosis [4]. Interpretation of this finding using the enantiomorph disorder concept leads to the suggestion of possible preventive surgery.

6. Enantiomorphic Vertebral Body Growth-plates (physes) Pre- and Post-natally (Figure 2)

It is evident that human vertebral body growth plates – like other physes – during their years of functional activity liberate cascades of physeal cells that respond symmetrically to successive hormones during growth. Hormones are secreted as post-natal development proceeds; in a) fetal life, insulin and IGF-1, b) early post-natal life, growth hormone, and c) from puberty, steroids including estrogen and androgens [14,15]. Receptors on the cell surface, or nucleus respond to these hormones.

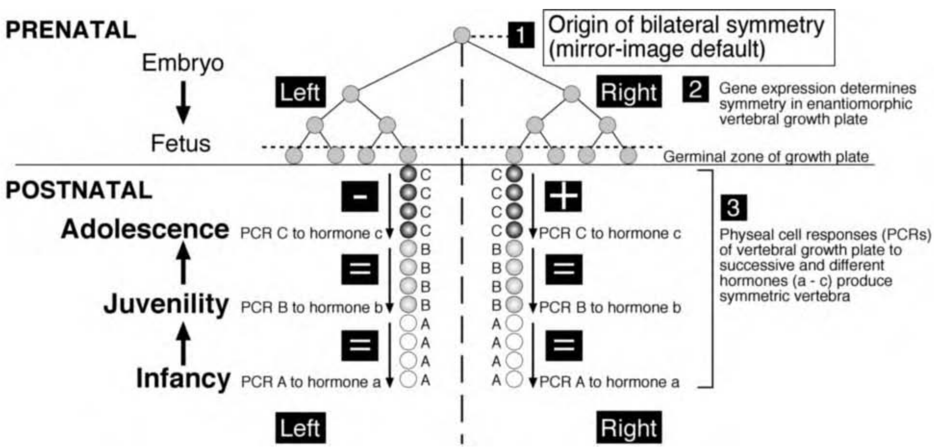

Figure 2. Normal enantiomorphic vertebral body growth plate: cascades of left-right physeal cells respond symmetrically to successive hormones a, b & c. For a possible origin of right thoracic AIS see [11].

Figure 2 illustrates the process in a vertebral body growth plate (physis). Bilateral symmetry is shown to originate from the midline as a default mechanism in the plate stage of embryonic life. Gene expression evidently determines symmetry in enantiomorphic vertebral physes. Physeal cell responses (PCRs) of vertebral growth plates, if symmetric to successive and different hormones through development, evidently contribute to the production of normal symmetric vertebrae.

7. Genetic and Environmental Factors May Disturb Symmetry Control in Separate and United Enantiomorph Bones

7.1. Idiopathic scoliosis as a complex growth disorder arising prenatally

In idiopathic scoliosis (IS) the finding of abnormalities of general body growth and skeletal symmetry in the upper limbs led to the suggestion that the fundamental causes of IS may be genetic and/or environmental factors acting directly or indirectly on developing skeletal primordial in early embryonic life [1,2]. Burwell et al [1] wrote: "Implicit in this hypothesis is that the abnormalities so created may not become evident in the growing skeleton until months or years after birth…. This hypothesis interprets idiopathic scoliosis as resulting, at least in some patients, from a complex disorder of differential growth (or allometric) growth in the skeleton." This basic embryologic model for IS etiology was developed further by Burwell and colleagues [3,16] and Goldberg and colleagues [17-19].

7.2. Left-right fluctuating asymmetry and stress

Fluctuating asymmetry (FA) is characterized by randomly directed deviations from perfect symmetry, with most individuals having little or no asymmetry [20]. It is widely used in humans especially about the hands and head, in the diagnosis of congenital defects. It is claimed that FA is the most sensitive indicator of a child to cope with stresses during development [21,22]. Growth velocity and FA are negatively correlated [20,23].

7.3. Developmental instability concept for idiopathic scoliosis

Goldberg et al [17-19] reviewed left-right directional asymmetries in AIS and reported new observations on handedness, language lateralisation, dermatoglyphics and fluctuating asymmetry (FA). Goldberg [19]: wrote "….scoliosis is not a disease or group of diseases but a symptom or sign of environmental stress, significant enough to overwhelm the intrinsic stability of the morphological genome. As such, there is no specific etiology but a large number of precipitating stressors…." Dangerfield et al [24] reported an increase in FA about the head and hands with increasing curve severity in idiopathic scoliosis.

7.4. Idiopathic scoliosis, spinal asymmetry, stress, chemical, and dietary risk factors

McMaster et al [25] reported evidence that some infants exposed to indoor swimming pools in the first year of life show an association with progressive AIS and in controls vertical spinous process asymmetry [26]. She drew attention to the possibility of chemical risk factors to scoliosis in humans and also in salmon fry [27]. Golding [28] reported an epidemic of idiopathic scoliosis in Jamaica from 1965-83 and attributed it to some dietary factor, possibly the addition of endocrine additives to the food of livestock.

8. Fetal Origins Hypothesis in Relation to Systemic Diseases of Adult Life and Symmetry Control in Children

8.1. Fetal origins hypothesis in relation to systemic diseases of adult life

Barker and colleagues [29] and others [30,31] have shown that the origins of important chronic systemic diseases of adult life – including coronary heart disease, stroke and type 2 diabetes, as well as rates of aging – may lie in fetal responses to the intra-uterine environment. It is termed the *'fetal origins hypothesis'*. It has led to national medical research projects being developed in the UK (Biobank) and USA (Genes and Environment Initiative, and the Genetic Association Information Network-GAIN) to gather information on how human genes and environment interact over the years to cause disease [32,33]. A recent conference discussed Environmental Genomics, Imprinting and Disease Susceptibilility [34]. Hopes for new therapies are emerging by using supplements to restore gene function by methylation in mice with kinky tails [34] and antibodies to TGF-b for Marfan-like mice [35]. Methyl groups can cause epigenetic changes to DNA in the mouse brain altering the way genes are expressed [36].

8.2. Fetal origins hypothesis in relation to skeletal symmetry control in children

In view of the findings outlined above of Burwell and colleagues [1-3], Goldberg et al [17-19], McMaster [25,26], Barker et al [29] and others we suggest that a wider evaluation is needed of the possible role of environmental factors acting pre- and/or post-natally to initiate enantiomorphic disorders of the human skeleton including limb bone length asymmetry [37] and idiopathic scoliosis. Intra-uterine growth retardation can be associated with limb length asymmetry [38]. In a review of patients with disturbances of normal laterality there was a significant association between laterality defects and anomalies of the spine and other midline structures [39].

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Bilateral Intra-Annular Spinal Compressive Stresses *In Vivo*

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Abstract. The purpose of this pilot study was to determine if compressive stresses in the annulus of the intervertebral disc vary with activity in a quadruped and are affected by treatment with an implant. Pilot *in vivo* tests were conducted on skeletally immature domestic pigs (approved by IACUC). One pair of sensors was implanted within the annulus of T10-11, and the second pair at T8-9. A staple was them implanted across the right side of T8-9. Wires were routed subcutaneously and exited at the dorsal cervical region. Sensor signals were acquired before and after staple implantation, post-operatively during normal activities, and biweekly under anesthesia. After 8 weeks, spines were harvested and imaged. Early results from 2 sensors during walking and sitting, post-op day 5, clearly showed cyclic stresses during gait. Stresses were attenuated at the stapled vertebra compared to the unstapled vertebra.

Keywords. *In vivo* spine mechanics, compressive stress, microelectromechanical sensors, growth modulation

Introduction

Several recent studies have shown that spine growth may be altered unilaterally [e.g. 1]. Development of an increasing compressive stress gradient is presumably the predominant mechanism of observed changes to vertebrae, growth plates, and discs. Prior *in vivo* studies have reported hydrostatic pressure in the fluidic disc nucleus using small needle-based transducers. Thin, flat, transducers are required, however, to test for side to side differences in the longitudinal component of the compressive stress within the annulus, in order to allow for solid contact conditions and for orienting the sensing surface parallel to the transverse plane. Microelectromechanical systems (MEMS) suitable for this configuration are commercially available and inexpensive, but the end-user must complete the packaging of the sensors. Early versions of MEMS sensors for bilateral intra-annular disc compressive stresses have been designed, fabricated, and calibrated.

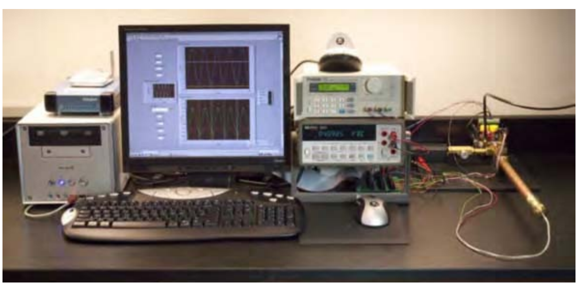
In vivo pressure measurements have been reported in several anatomic locations. In the knee, for example, *in vivo* forces in the anterior cruciate ligament were determined to vary with gait in a goat model [2,3]. In the spine, *in vivo* pressure [4,5,6] strain [7], and force [8] have been measured in lumbar vertebral bone and nucleus; new methods continue to be developed to measure pressure in the nucleus pulposus. Prior *in vivo* spine mechanics studies, however, have not attempted to determine the chronic static compressive stress differential, i.e. the baseline compressive stress gradient over a relatively long time period across the annulus. *In vivo* measurements, while very difficult, are essential to defining and translating *in vitro* test conditions to the level of the whole organism, and to correlating measures between species. Knowledge of *in vivo* stress histories has been defined as the first of five basic principles of functional tissue engineering [9].

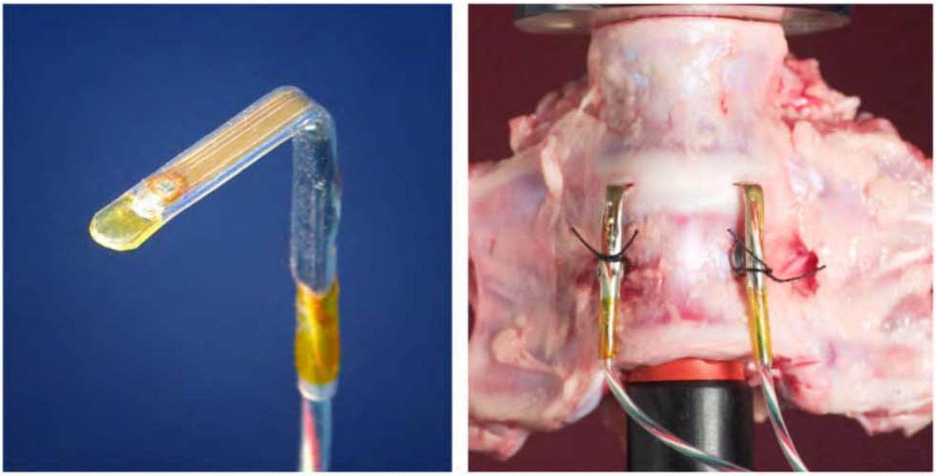
The purpose of this pilot study was to determine how physiological compressive stresses in the annulus of the intervertebral disc vary with activity in a quadruped, and the compressive stress on the disc due to staple implantation. A secondary goal was to assess the feasibility of maintaining the *in vivo* system for up to 8 weeks.

Methods

Piezoresistive pressure sensors were chosen for size, range, and ability to be placed remotely from signal conditioning circuitry. Commercial sensor dies in a full Wheatstone bridge configuration (SM5108: 0.65 mm^3, Silicon Microstructures Inc., Milpitas, CA) permitted absolute pressure measurements at physiological levels. Carriers of various lengths and pad sizes were tested to define the thinnest structurally sound device. The sensors were incorporated into a metallic package (2.5 mm width, 12.5 mm length, 0.8 mm thickness) to withstand dynamic *in vivo* stresses and to allow for firm attachment to vertebrae. Sensors were electrically connected to the carriers in a clean room facility (Class 10) using ultrasonic wire-bonding techniques.

Each sensor was calibrated in fluid (hydrostatic pressure) and then under solid contact stress. The first calibration system used a nitrogen chamber (range: 0-1.6 MPa), a commercial reference sensor, digital control and signal acquisition instrumentation. The solid contact compression tests were performed with custom fixtures in a materials test system. Sensors were calibrated before and after immersion in fluid for 1 week, with continuous monitoring of zero drift. *In situ* tests were then performed to correlate sensor output with total joint compression. Both sensors were placed into the annulus of porcine vertebral motion segments mounted in the MTS.

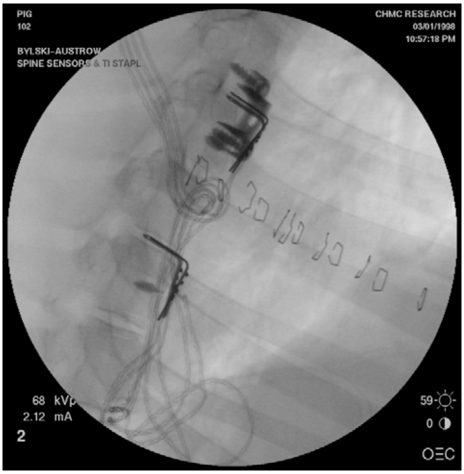




In five skeletally immature domestic pigs (approved by IACUC), a right lateral thoracotomy was used to implant 4 sensors and a custom spine staple [1]. One pair of sensors was implanted within the annulus of a mid-thoracic vertebra, then the second pair were placed 2 levels away. One staple was driven across the right side of one disc. Wires were routed subcutaneously and out the posterior cervical region. Placement was documented with fluoroscopy. Sensor signals were acquired before and after staple implantation, post-operatively during normal activities, and biweekly under anesthesia. After 8 weeks, spines were harvested and scanned using CT and micro-CT systems (ImTek, Knoxville TN).

Results

Early results from 2 sensors during walking and sitting, post-op day 5, clearly showed cyclic stresses during gait. Stresses were attenuated at the stapled vertebra compared to the unstapled vertebra. In this case, peak stress in gait was 0.57 MPa, while stress levels cycled over a range of 0.05 MPa during quiet sitting, right). After 8 weeks, staples and right side sensors remained well positioned. Dynamic physiological stresses of 3 MPa have been measured, and impact stresses of 2 MPa were measured under the staple during the process of staple implantation.


PIG
102
BYLSKI-AUSTROW
CHMC RESEARCH
03/01/1998
10:57:18 PM
68 kVp
2.12 mA
2
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0
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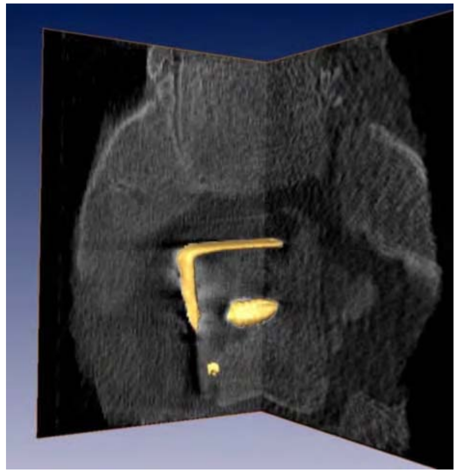
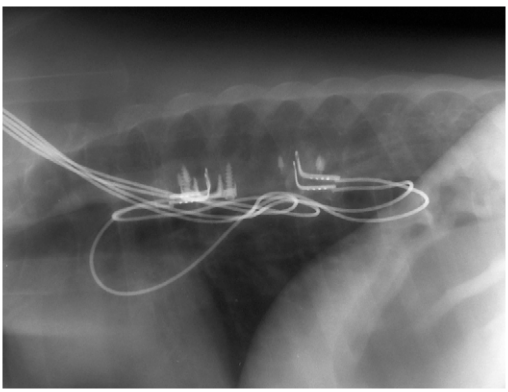
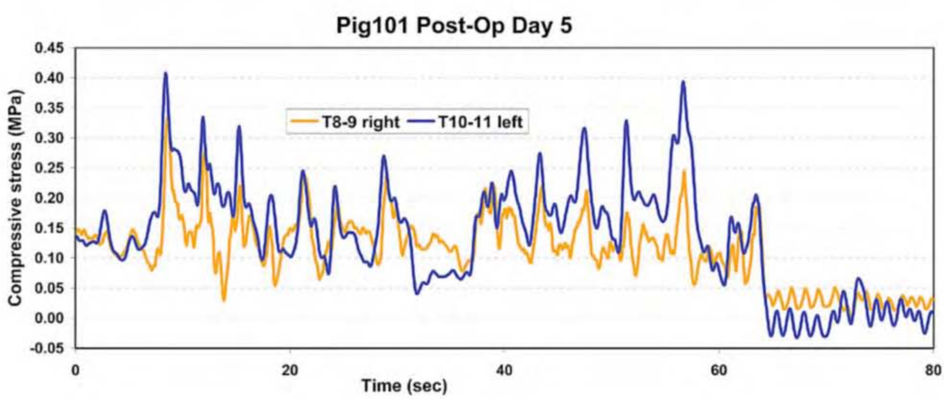
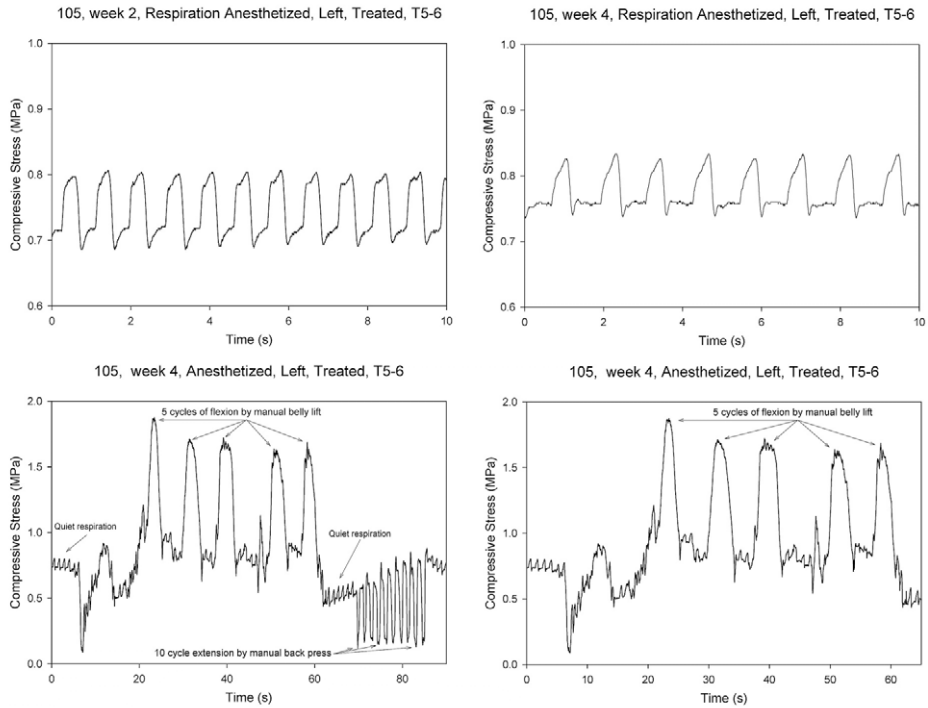





Pig101 Post-Op Day 5
T8-9 right
T10-11 left
Compressive stress (MPa)
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
0
20
40
60
80
Time (sec)



Conclusion

Novel subminiature compression sensors were successfully fabricated, packaged, and calibrated both as isolated transducers and in situ in the annulus of intervertebral discs. Sensor output correlated with peak joint load. While durability remains an important factor, *in vivo* applications appear possible. Physiological stresses have been measured for up to 6 weeks *in vivo*, indicating the potential for determining changes in coronal plane loading gradients across vertebral discs and growth plates over longer time periods. Limitations include quadruped model, sensor sensitivity to device location and intervetebral joint motion, and the effects of the sensors themselves on discs and joint motion over time.

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Postural Differences in the Shoulder Girdle During Normal Locomotion in Treadmill vs. Over Ground Walking

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Abstract: In a clinical setting, most musculoskeletal assessment related to gait is undertaken using a treadmill which is additionally widely used during gait and neurological rehabilitation. Although previous studies have reported the range of motion of gait characteristics during running, there is a paucity of information on normative walking data applicable to clinical assessment. Movements and posture of the shoulder girdle is an important indication of back and upper extremity function. While studies indicate that shoulder girdle kinematics are changed during shoulder dysfunction there is little information on the postural relationship between the shoulder and pelvis. The present investigation aims to create a normative database for kinematics during treadmill walking by examining the differences between the treadmill and over ground walking patterns. Additionally, the research will also assess shoulder girdle posture and to establish its relationship with the pelvic complex which will contribute to further understanding scoliotic posture and movement. 14 normal subjects walked over ground at a self-selected speed followed by walking on the treadmill at a speed matched to each subject's respective average over-ground speed. Three-dimensional kinematic data was captured using a passive marker based motion analysis system (Vicon Peak, UK). Angular and temporal kinematic parameters were estimated. The results indicate differences in angular kinematics between over-ground and treadmill locomotion. These differences should be considered when treadmill kinematics are used for clinical evaluation as opposed to over ground ambulation is scoliosis and other conditions.

Keywords: Treadmill walking, kinematics, Gait

Introduction

Gait and posture analysis forms an important part of clinical evaluation and rehabilitation in conditions associated with gait disturbances. While previous research on gait include assessments using normal and pathological subjects [1], the common spatio-temporal parameters used within these studies include walking speed, stride time and length, step time and length and durations of stance and swing phase [2]. Although several studies outline general temporal data for normal gait and spatial information for lower limb joints [3, 4], there is a relative paucity of information on the upper body segments.

While the angular motion of the pelvis is indicated as an important factor in gait [5], pelvic obliquity and pelvic rotation is regarded as major determinants of gait [6]. Although there is an ongoing conflict questioning the importance of these gait determinants [7], studies have attempted to quantify the relationships and measurement reliability of pelvic movement during gait [8,9,10].

Pathological gait could be defined as a deviation from the normal pattern of movement and reports indicate that abnormal gait patterns could be the result of any neurological or musculo-skeletal disorder [4]. Studies have examined effect of lumbar supports on pelvic kinematics and reported significant differences in rotations. However, no differences were reported in the sagittal and transverse planes [11]. The assessment and rehabilitation of human locomotion is frequently assisted by a treadmill to simulate overground walking. Previous investigations indicate differences in kinematics when comparing treadmill to overground walking, raising questions on the use of treadmills [12]. Furthermore, treadmill compared to overground running has produced conflicting results regarding the temporal and angular kinematics [13].

Most of overground to treadmill gait comparisons commonly follow the temporal and angular parameters of the lower limbs. Although the treadmill has been described as advantageous in comparative studies because of its convenience and ease of control [14], results have indicated a smaller range of movement in the frontal and transverse planes for the pelvis whilst walking on the treadmill compared to overground. Furthermore, while discussing changes in variability and local stability for treadmill walking, Dingwell et al [15] conclude that treadmills may produce deceptive results.

Movements and posture of the shoulder girdle is an important indication of back and upper extremity function. While studies indicate that shoulder girdle kinematics are changed during shoulder dysfunction, there is little information on the postural relationship between the shoulder and pelvis. The present investigation, part of a wider comprehensive study, aimed to create a normative database for kinematics during treadmill walking by examining the differences between the treadmill and over ground walking patterns. Additionally, the research also assessed shoulder girdle posture in order to establish its relationship with the pelvic complex, which in turn will contribute to further understanding scoliotic posture and movement.

A previous study attempting to characterise the physiological pattern of trunk and shoulders movements during walking, with a view to provide a reference for further studies on spine deformities [16], indicated that the segmental movements analysed were smaller than 5° during gait, with an exception of the angle of proximal curvature in the frontal plane, shoulder rotation, and angle between shoulders and pelvis. These were recorded well below their possible ranges of motion. Furthermore, this study indicated that quantitative data on upper body kinematics as a complement to gait analysis can help understanding movement disorders and compensation strategies in several pathologies.

Methods

A sample consisting of 8 males (aged 22.1 (±3), mass 70 (±6) kgs, height 180.2 (±6.9) cms) and 6 females (aged 22.8 (±3.1), mass 58.4 (±4.1) kgs, height 165 (±5.9) cms) were recruited from university students. All participants were familiar with treadmill walking and reported no known musculoskeletal pathologies. Each subject wore their own trainers either with shorts leaving the anterior (ASIS) and posterior (PSIS) superior iliac spines uncovered or ones that were skin tight (female participants wore tight gym tops).

The study was conducted in a gait laboratory with a walkway of 9m. Timing gaits were used to establish over ground walking speed, which was inputted into the treadmill. The study employed a Vision Fitness treadmill (T9700HRT) and the kinematics were recorded using a 8 camera digital motion analysis system (Vicon Peak, UK). Data sampled at 100Hz with reflective markers positioned using a whole body marker set.

The same researcher performed all marker placements to avoid inter-tester variability. Each participant performed overground then treadmill walking on the same day to avoid the reapplication of markers.

Anthropometric data for each subject was collected and a subject calibration was performed using this data. Participants were allowed to get accustomed to the lab environment and instructed to walk with their normal cadence. Each subject performed ten over ground walking trials. The treadmill was then positioned in the same direction as the walkway and the average speed, calculated from overground walking, was set as the speed for data collection. The subjects initially walked for one minute before the ten trials were captured.

While estimating other gait parameters as part of the wider study, the total range of movement for the pelvic and shoulder girdle were calculated.

Results and Discussion

The average overground walking speed was 1.51m/sec +/- 0.1 for both females and males. Significant differences ($p<0.05$) were identified for the mean temporal values in both condition and gender comparisons, apart from foot off percentage (Table. 1). Treadmill means for the percentage in the stance period were greater than overground percentages.

Figure 1 shows representative data for the total range of movement in the shoulder and pelvis. Figure 2 indicates the angular difference between the pelvis and shoulder girdle.

Average range of motion for the shoulder girdle across the subjects is 5.97 and 4.54 degrees during overground walking and treadmill walking respectively. The average range of motion for the pelvic girdle is 9.34 degrees during overground walking and 5.77 degrees during treadmill walking.

Average angular difference between the pelvic and shoulder girdle is 14.18 degrees in over ground walking as opposed to 8.61 degrees in treadmill walking.

Table. 1. Temporal values comparisons

*SD – Standard deviation F – Female M – Male Both – Female and Male data (p<0.05) * Significant*

		Over ground		Treadmill		Comparison	
		Mean	SD	Mean	SD	P value Condition	P value Gender
Cadence (steps/min)	Both	114.92	5.79	98.70	6.14	.000*	.031*
	F	115.82	5.88	101.74	5.65		
	M	114.24	5.82	96.42	5.63		
Stride time (secs)	Both	1.04	0.53	1.22	0.79	.000*	.031*
	F	1.03	0.05	1.18	0.07		
	M	1.05	0.05	1.25	0.08		
Foot off (% of gait cycle)	Both	62.61	1.72	68.27	1.17	.000*	.818
	F	62.17	1.20	68.81	1.28		
	M	62.94	2.00	67.85	0.92		

The results indicate differences in angular kinematics between over-ground and treadmill locomotion. Angular difference between the shoulder and pelvic girdle is much higher in ground walking than in treadmill walking. Further studies are currently being carried out to substantiate these findings. The differences should be considered when treadmill kinematics are used for clinical evaluation as opposed to over ground ambulation in scoliosis and other conditions.

Fig 1 Total Range of Movement

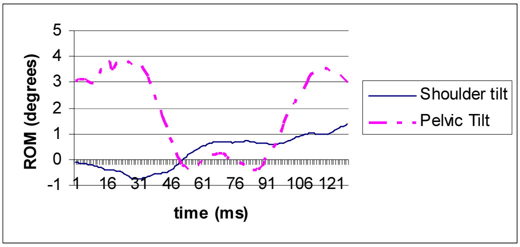
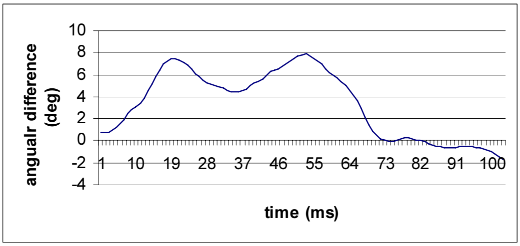


Fig 2 Angular difference



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Balance Lower Limb Loads and 3D Spine Modifications after Total Hip Joint Replacement: Effects of Leg Length Discrepancy Correction

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Abstract: Following total hip joint replacement (THJR), the durability of a prosthesis is limited by: wearing of frictional surfaces and loosening and migration of the prosthesis-cement-bone system. Literature review witnesses biomechanical studies focused mainly/only on hip functional state while none of them approached leg length discrepancy (LLD), posture unbalancing or spine related problems after THJR. Conversely, these latter could be critical elements for surgery and rehabilitation success, given the possible induction of asymmetric loading patterns. This study presents the results obtained by using a recently proposed methodology, to measure 3D subject posture balance and spine morphology and to evaluate its usefulness in individual therapy tuning/follow up. 3D subject's posture has been measured by means of 3D opto-electronic device, force platform and baropodography. 90 subjects after THJR have been included in this study. The subjects have been evaluated in two different epochs: 3 weeks after surgical intervention and after 3 months. 77/90 patients presented a LLD, pelvic obliquity and posture unbalancing. More than 90% of this group showed an overall postural re-balancing induced by the use of simple underfoot wedge. 70/77 patients needed wedge under the healthy side showing the surgical intervention produced a leg lengthening. 60/90 (52 LLD) patients underwent up to now to control and patients who wore the suggested wedge (63.4%) presented an improvement over all the considered quantitative parameters. Patients who wore a shorter than suggested wedge (23.1%), or that did not wear the suggested wedge (13.5%) presented a moderate or significant worsening of their postural balancing respectively.

Introduction

Following THJR, the durability of a prosthetic implant depends on many factors but is generally limited by two types of damage: wearing of frictional surfaces of the acetabular and femoral component as well as the loosening and migration of the "prosthesis-cement-bone" system. Contact forces in the hip joint must be known for tests on strength, fixation, wear and friction of implants, for optimising their design and materials by computer simulation and for giving guidelines to patients and physiotherapists about which activities should be avoided after a replacement. Several studies focus their attention on failure causes and particular importance is recognised to post-operative care programmes as well as to following patient's life habits. In any case literature review witnesses biomechanical studies focused mainly/only on hip functional state while none of them (to authors knowledge) approached leg length discrepancy, pelvic obliquity, posture unbalancing or spine related problems such as low back pain and spine deformities after THJR. Conversely, these latter could be hypothesized to be critical elements for surgery and rehabilitation success, given the possible induction of asymmetric loading patterns and/or negative influence on normal daily activities (for example back pain generally limits movement activity). Bergmann et al. [1] reported in vivo measurements on nine different activities which are assumed to cause high hip joint loads and occur frequently in daily living. Even if the results of this study cannot be fully generalised, given the fact the reported data are obtained from only 4 patients and a high inter-individual variability has been found, it provides stimulating elements to take into account when hip prosthesis loading patterns during daily life activities have to be considered. The highest loads have been found in walking activity and in stairs climbing. The average peak forces during normal walking at about 4 km/h were between 211% and 285% of BW. The averaged force curves during the stance phases of walking and going upstairs look very similar at first glance. However, the implant torque is larger when going upstairs. Downstairs the peak force slightly exceeds that from going upstairs. Standing up from a chair loads the hip joint more than sitting down but much less than walking. Surprisingly Standing on one leg let the contact force rise to nearly the same peak value as walking. Knee bends contact forces is about 25% less than standing on one leg. On a study on the duration and frequency of every day activity on THJR patients [2] Morlock et al. reported the most frequent activity during day was sitting (44,3% of the time) followed by standing (24,5%), walking (10,2%), lying (5,8%) and stair climbing (0,4%). As it can be noted, standing activity is more than twice the walking one and it provides comparable load stress. Hundreds per year of THJR patients are usually treated at our rehabilitation centre. On clinical investigation the majority of them often showed unbalanced standing posture as well as typical prosthesised leg knee flexed posture during standing indicating a sort of leg length discrepancy compensation. Moreover many of them reported back pain problems during follow up, From the above we decided to study standing posture characteristics after THJR in deep detail. The aim of this study is to present the results obtained on 90 THJR patients analysed by using a new proposed methodology, measuring 3D global skeleton subject posture balance and spine morphology by using a 3D opto-electronic approach. The evaluation of this approach and its usefulness in individual therapy tuning/follow up, as well as in medium and long term spine problems prevention after total hip joint replacement (THJR) is discussed.

1. Materials and Methods

The methodological approach is to evaluate each subject's posture by means of 3D opto-electronic device, force platform and baropodographic measurements. Ninety (90) subjects after THJR aged 24 to 78 (μ=66.5 ± 9.3) years have been included in this study, all of whom signed an informed consent. The subjects have been evaluated in two different epochs: after about 10 days when they were allowed to load prosthesised lower limb and after 3 months since they were discharged from our centre. All the patients underwent 3 to 4 weeks of in-hospital rehabilitation treatment, after which they went back home. The experimental recordings are based on the VICON-Mx[1] opto-electronic system; anyway this approach is a very general one and it can be indifferently applied to any stereo-photogrammetric recording system, provided that this latter would be able to supply all the required landmarks three-dimensional co-ordinates. The usual raw measurement data consists of a set of 3D Kinematic measurements acquired at 100Hz sampling rate. The 3-D spatial positions of a total of 27 passive markers have been measured to identify and reconstruct the whole skeleton [3,4]. In particular, the vertebral column is identified by 11 markers placed on the spinous processes from C7 down to S3 every second vertebra, while the head, chest, pelvis and legs are identified by placing markers on the zygomatic bones, chin, sternum, ASIS, PSIS, knees and heels. In order to proceed to a correct quantification of subject's posture, a statistical approach has been taken into account [3,4]. At least 5 different 1 second lasting measurement per each orthostatic standing position are performed. So a minimum of 500 3D measurements are averaged per each postural attitude. For each obtained kinematic average, the spinal curves identification and the related Cobb and Kyphosis-Lordosis angles have been computed (mean value and s.d.) [3,4]. In order to describe patient's postural behaviour, three summarising postural parameters have been selected. To describe trunk and global unbalancing, *averaged spinal offset* (average of spine markers displacements with respect to the vertical line passing through the S3 vertebra) and *averaged global offset* (average of spine markers displacements with respect to the vertical line passing through the middle point between the heels see figs. 1,2) have been used [3,4,5], while *Cobb angle of main spine curve* has been used to enlighten major modifications in spine morphology on the frontal plane. In such a way, when postural unbalancing is present due to leg length discrepancy, it is possible to control the modification induced by underfoot wedges both at pelvis level, and at spine and global posture level. The optimal wedge size has been determined as the one which induced the best posture re-balancing and spine deformities reduction [3,5]. Global posture balancing/unbalancing and spine stiffness information have been correlated to clinical outcomes and used to individualise post-operative care programmes after THJR, including strategies for mobilisation, early weight bearing, gait retraining, posture conditioning and re-balancing. Patients who needed leg length discrepancy to be compensated have been suggested to wear a simple underfoot wedge.

2. Results and Discussion

In the evaluated sample 77/90 patients (85.6%) presented a LLD, pelvic obliquity and posture unbalancing. More than 90% of this group showed an overall postural re-balancing induced by the use of simple underfoot wedge (μ=16.5 ±8.1mm). 70/77 patients (90.9%) needed wedge under the healthy side showing the surgical intervention produced a leg lengthening. 60/90 (52 LLD) patients underwent up to now to control and three different patient's subgroups have been classified: patients who wore the suggested wedge (63.4%, group A); patients who wore a shorter than suggested wedge (23.1%, group B); patients who did not wear the suggested wedge (13.5%, group C); Group A presented a well balanced stabilised posture, improving all the considered quantitative parameters (100% improvement) and showing the

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correctness of the re-balancing principle in order to prevent dangerous lower limb load discrepancy and undesired spinal deformities. In the group B, a similar behaviour can be observed, but a percentage of the subjects paid the incomplete lower limb discrepancy correction with a worsening of spinal curve (66.7% improvement). This latter was only partially reduced at the control evaluation when the correct wedge was applied. Group C presented a generalised significant worsening of their postural balancing, mainly due to an increase of spinal deformity (16.7% improvement). Subjects belonging to this group could still be able to benefit from an optimal underfoot wedge application, but with less efficacy than in groups A and B. Prosthesis settlement was found not to be unusual. 28/52 (53.8%) patients presented such phenomenon and their wedge size had to be changed accordingly: wedge size reduction (μ=5.3± 3.1 mm.).

Table 1: Patient's Postural Improvements Induced by Wedge at first and second evaluations, listed by Postural Parameters

	# of considered Parameters			
Time of evaluation	3	2	1	None
First Evaluation – 77/90 (85.6%) Subjects	60%	32.5%	7.5%	---
Control Evaluations (after 3 months 60/90 (52Wedged)) Subjects	*# of considered Parameters*			
Group A: After wearing correct wedge (33/52 = 63.4%) Subjects	100.0%	0.0%	0.0%	0.0%
Group B: After wearing shorter wedge (12/52 = 23.1%) Subjects	66.7%	33.3%	0.0%	0.0%
Group C: After not wearing a wedge (7/52 = 13.5%)	0.0%	33.3%	50.0%	16.7%

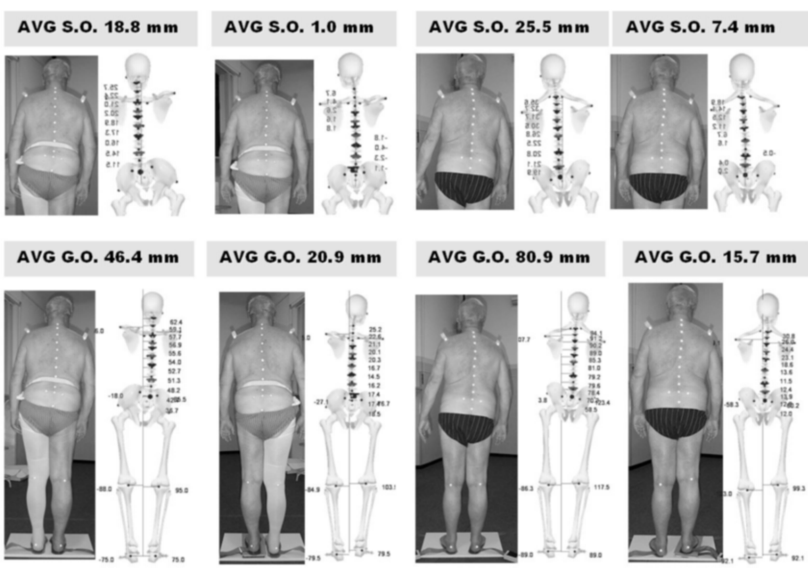

Figure 1.Group C, 3D Posture and Spine morphology comparison between first evaluation and follow up with and without wedge (2.5cm in this case)

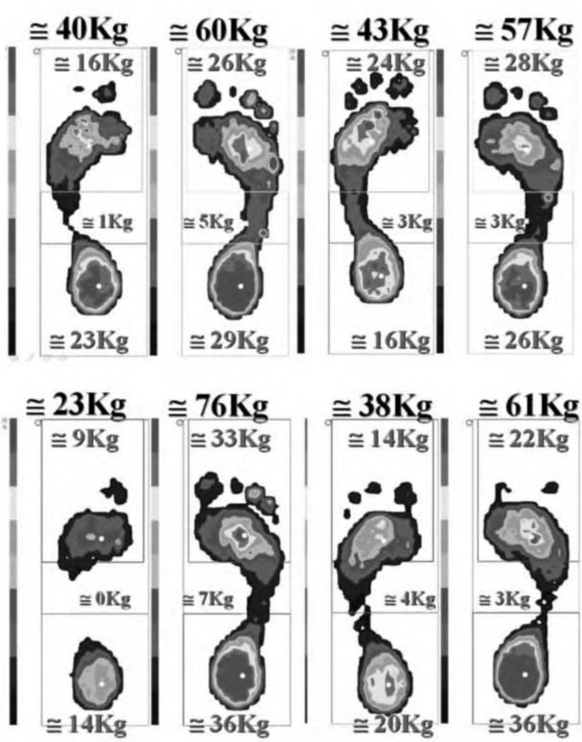

Figure 2a,b.Underfoot Loads and pressure maps comparison between first evaluation (upper panel) and follow up (lower panel) with and without wedge (2.5cm in this case)

All the patients who wore the correct size wedge (Group A) resulted to perform a well balanced symmetrical gait (visual evaluation) at the control, while unbalancing and/or asymmetrical gait was detected in the other groups. Moreover Group A patients did not report any back pain episode during the monitoring period while some patients belonging to the other groups reported both some back pain episodes and/or pain to prosthesised limb or to the contra-lateral knee. Some patients belonging to Group C and presenting relevant leg length discrepancy (i.e. more-equal than 2cm) in addition to increased spinal curves presented also some paravertebral muscular blocks and/or asymmetrical muscular hypo/hypertrophy, both painful or asymptomatic (see fig. 2). Further studies are needed to quantify all the above mentioned aspects in order to allow a proper statistical analysis.

3. Conclusions

3D quantitative posture measurement appears to be an encouraging technique to be usefully applied in individualised therapy tuning and follow up after THJR. Posture and spinal morphology/stiffness quantitative parameters demonstrated to be useful tools to better individualise post-operative care programmes. In particular spinal and global unbalancing quantification resulted to grant important information to better equalise lower limbs load discrepancies. Case by case quantitative description and statistical comparison allow to control the outcomes and efficiency of applied therapy. Some important findings arise from results. After THJR more than 85% of our sample presented a leg length discrepancy that had to be compensated. The induction a correct re-balancing seems to be a useful approach in order to reduce risks of lower limb load disparity, asymmetric locomotion and spinal deformities generation. This has been proved to be obtainable with simple inexpensive leather/cork underfoot wedges Moreover, it seems very important to approach postural re-balancing as soon as possible after THJR; in fact, from results of all groups it appears that even if postural re-balancing can still be efficiently induced after a longer period, the recovering of a correct spinal shape and attitude is not as good as immediately after THJR. Finally more than 50% of patients showed a prosthesis settlement indicating the necessity of follow up.

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Biomechanical Modeling of Anterior Spine Instrumentation in AIS

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Abstract. This study is part of a larger project regarding the development of a *Spine Surgery Simulator* (S3), which has shown good results for posterior instrumentation surgeries. The aim was to develop a biomechanical model for the anterior instrumentation of the scoliotic spine. A biomechanical model using flexible mechanism was developed and surgical manoeuvres (instrumentation, rod installation and compression) were reproduced. Validation of the model was done by comparing the results for the instrumented part of the spine to the post-operative data (analytical Cobb angles in the frontal and sagittal planes, plane of maximum deformity, etc.). To date, surgeries of four patients operated by thoracotomy were reproduced. Preliminary results show that anterior instrumentation of the scoliotic spine can be adequately modelled using pre-operative geometric data and using mechanical properties from literature. Once validated with a larger sample of cases, the anterior instrumentation model could be implemented into S3 and used by orthopaedic surgeons to test various instrumentation strategies in virtual reality before performing the actual surgery.

1. Introduction

Anterior instrumentation of the scoliotic spine is known for its possibility to save distal levels from fusion, and since the 1990's, for the possibility to use minimal invasive techniques. Recent instrumentation designs and technique are more complex and require detailed preoperative planning. However, as for posterior surgeries, optimal configuration of anterior instrumentation is still very controversial[10]. Relying solely on is experience and knowledge, the surgeon has to take decisions regarding the spinal segment to be fused, number of implants and rods to be used etc. Correction obtained is rarely optimal and numerous residual deformations are reported. To address this problem, a *Spine Surgery Simulator* (S3) is currently being developed and has shown good results for posterior instrumentation surgeries. The aim of this study was first to develop a biomechanical model to simulate anterior instrumentation of the scoliotic spine and eventually, to contribute to extend the range of instrumentation configurations offered by *S3*.

2. Methods

The biomechanical model of the patient's spine was defined using the flexible mechanism approach developed by Poulin et al.[9]. It was implemented with ADAMS 2003 software. The model is composed of rigid bodies (non-deformable) corresponding to the vertebrae and of flexible elements representing the intervertebral structures. Position, orientation and specific geometric representation of each vertebra were obtained using a 3D multi-view reconstruction method and a free-form deformation (dual kriging) technique[4]. Flexible elements used for the intervertebral structures are mathematically represented by a 6x6 stiffness matrix, which contains translational and rotational preload values[1]. Relations between displacements are chosen to be linear.

The mechanical properties of the spine model were adapted from published data[5,8]. Screws and nuts were modeled as rigid bodies. The rod was represented by a composition of deformable beam elements formulated according to the Timoshenko theory[7]. The 4.5 mm diameter rod was considered flexible with the mechanical properties of titanium.

Boundary conditions were imposed to represent the behavior of the anesthetized patient on the operating table. Six degrees of freedom (DOF) were allowed at the lowest vertebra in the model (L5) using a stiffness matrix with coefficients representing the mechanical properties of the disc between L5 and the sacrum. T1 was constrained in the transverse plane to allow lengthening of the spine and was free to rotate.

The following surgical maneuvers of an anterior instrumentation procedure, starting after the spine has been exposed, were then reproduced.

(1) Discectomy and insertion of the bone graft were simulated by modifying the coefficient in the stiffness matrix of the intervertebral elements.

(2) Position and orientation of the screws in the vertebral bodies were obtained from the postoperative radiographs (figure 1). Each link between a screw and the vertebra was modeled by a stiffness matrix without coupling effects. Mechanical properties were adapted from published data considering bi or unicortical fixation and screws major diameter[2,3,6,11].

(3) The rod was attached to each implant starting at the lowest instrumented vertebra. Translation and rotational constraints were created between each implant and the closest rod segment to simulate the attachment. Once the rod is inserted in the implant a cylindrical joint is created between the implant and the rod to allow axial translation and rotation.

(4) Compression started at the lowest instrumented vertebra. Forces were applied on each adjacent implant. Nuts were created and then tightened to eliminate all DOFs between the rod and the implants.

Once the model was completed, the surgeries of four scoliotic patients who underwent open anterior instrumentation surgery were reproduced. Simulations results were then compared to post-operative data.

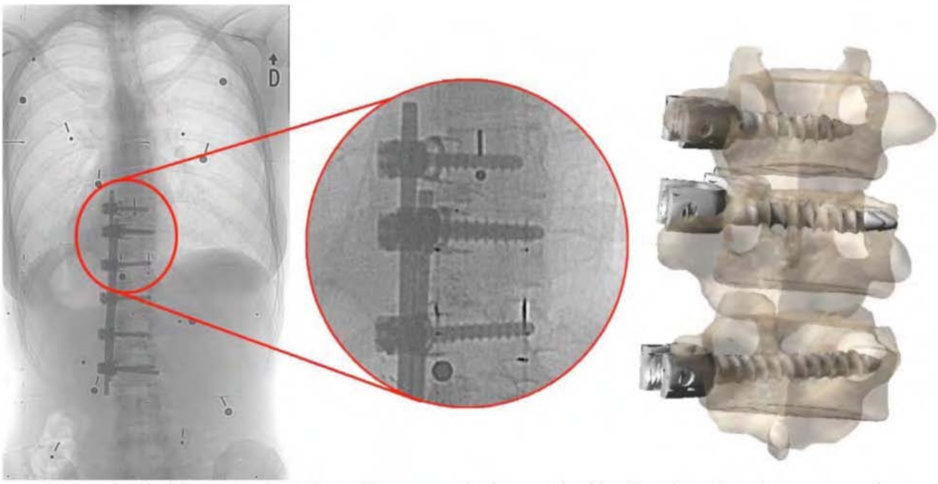

Figure 1 : Position and orientation of the screws in the vertebral bodies viewed on the postoperative radiographs and in the biomechanical model prior to the attachement to the rod.

3. Results

Preliminary simulation results show a maximum difference between simulated and 3D post-operative geometry of 4° for the Cobb angle in the frontal plane and 2° in the sagittal plane. The average difference in the 3D position of the vertebrae compared to the post-operative data was 3 mm.

Figure 2 shows the pre and post-operative radiographs of one of the scoliotic patients used in this study. Beside each radiograph 3D reconstruction of the preoperative geometry of the patient spine and 3D geometry obtained after surgery simulation can respectively be seen.

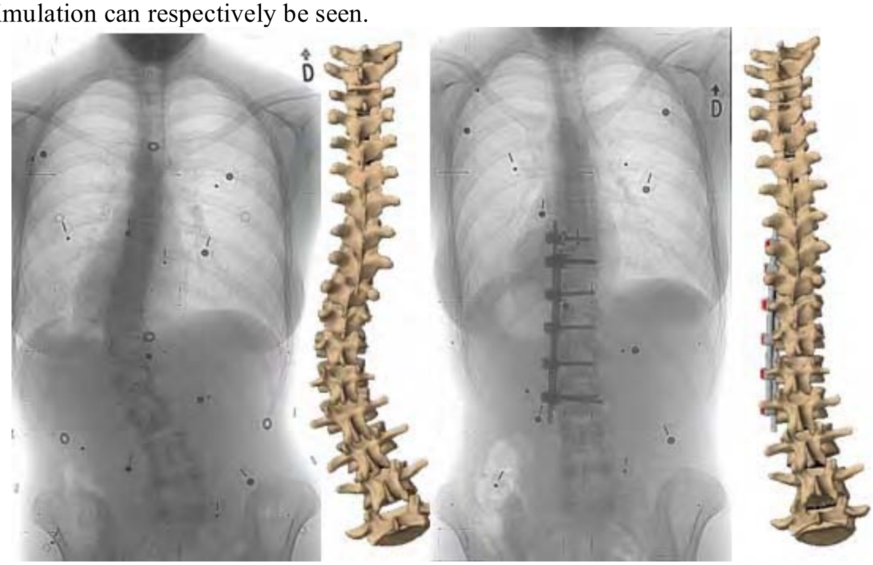

Figure 2: Pre and post-operative radiographs of a scoliotic patient and geometry of the model before and after simulation of the surgery

4. Discussion and Conclusion

A portion of the differences between the simulations and post-operative data could be attributed to the approximation of the surgical maneuvers. For instance, because implants were positioned in the vertebral bodies according to the information given by the post-operative radiograph, positioning errors could easily have occurred. Also, since no accurate values for the compression between each instrumented segment was available, forces were applied until vertebral end plate were considered parallel or according to what could be seen on the post-operative radiographs. In the model straight rods only were inserted but sometimes in situ rod bending was done during surgery which could have affected the results of the simulations. All these possible sources of errors have to be investigated by sensibility studies which will help to determine their effects on the results.

The preliminary results obtained with the biomechanical model previously described demonstrate the possibility to predict the correction of the spine that can be obtained by an anterior instrumentation surgery. More cases have to be simulated to confirm the results already obtained and to validate this new approach. Development of such models is very relevant for the enhancement of S3 in order to make it a powerful and complete tool for preoperative planning and prediction of correction outcomes.

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Towards an Automatic Classification of Spinal Curves from X-Ray Images

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Abstract. The objective of this research was to describe a multi-resolution technique for segmentation of the spinal curve on postero-anterior radiograph. Global features from the radiographs were first identified. From this approximate region, local regions of the spine curvature were iteratively filtered using diffusion and shock filters to enhance the boundaries of each vertebral body from radiographic noise. The spine curve going through the centroid of the vertebral bodies was successively identified for clinical classification of spinal deformities.

Keywords. Segmentation, Classification, Radiography, Adolescent Idiopathic Scoliosis

1. Introduction

Diagnosis from visualization of radiographs in Adolescent Idiopathic Scoliosis (AIS) is paramount in the evaluation of curve severity and in providing insights about the surgical strategies to adopt. The assessment of spine deformity is usually performed using the 2-D frontal radiograph of the trunk. X-rays are routinely diagnosed by orthopedic surgeons and, when available, archived in a Picture Archive and Communication Subsystem (PACS) architecture. Annotation of radiographs can be saved and consulted at a later time but is a time-consuming task, which render large-scale retrospectives studies (before PACS) difficult to perform.

Semi-automated classification software was first proposed by Stokes *et al* 0. The anatomical landmarks were first manually identified on the radiograph. A rule-based algorithm was introduced to analyze the segmentation and to infer King curve types 0. Statistical inference of King classification was also investigated using first and second derivatives as features computed from a database of two hundred and fifty five manually digitized spine curves 0. However, the amount of training data was relatively low when considering each class separately and thus might not generalize well the patterns observed in AIS. Moreover, the time-consuming task of manually marking radiographs is not suitable for a clinical use. To overcome mislabeling while acquiring lung radiography, Luo *et al* 0 proposed to classify automatically the view (postero-anterior or lateral view) from lung radiographs. In the field of spinal deformities, where details are located inside the chest area, few approaches were proposed to automatically segment the spinal column. Deschenes *et al* suggested the uses of wavelet analysis, statistical templates and deformable contours to semi-automatically segment the spinal 00. Although achieving good results, it cannot be executed for instance on a large-scale retrospective studies. The aim of this study was to propose an automatic, multi-resolution segmentation scheme designed to detect the spinal curve on the postero-anterior radiography in order to automatically provide adequate indexation for both clinical and research purposes.

2. Materials and Methods

2.1. X-ray acquisition system

Radiograph acquisition is a standardized process, which is documented and monitored by clinical procedures. This process includes the patient positioning, the number of views, the dose and the time of exposition 0. The produced radiographs are consequently comparable between them and can be analyzed with an automated recognition procedure. A total of one hundred ten radiographs were selected from a large pool of thirty thousands trunk radiographs collected from 1993 to 2000. The radiographs were acquired using a FCR7501 system (Fuji Medical, Tokyo, Japan) producing a greyscale digital image with a resolution of 2140x880 pixels, 12 bits per pixel. Images are acquired with the patient facing the cassette and the source was positioned in order to include the spinal curve and the pelvis.

2.2. Global features identification

Prior to being analyzed, the large image was downscaled by a ratio of 1/100, to decrease the actual resolution and hence to reduce processing time. The downscaled image was equally divided in three sections (top, middle and bottom) in order to search for the global features described above. A multi-resolution approach has been chosen to detect the spine to model the hierarchical structures of the spinal curve. The first step of the algorithm was to identify two global anatomical landmarks that will guide the detection process. Prominent features with a high level of contrast were selected as boundary of the region of interest for the spinal curve: 1) the shape of the head which can be associated with the starting point of the spinal curve and 2) the gonadal shield, a lead apparatus designed to protect genitals organs from the effects of radiation. The latter can be associated with the area of the pelvis and is strongly associated with the end point of the curve. These reference landmarks with a high level of contrast from the overall radiographic image allowed detecting coordinates in which the curve shape lies.

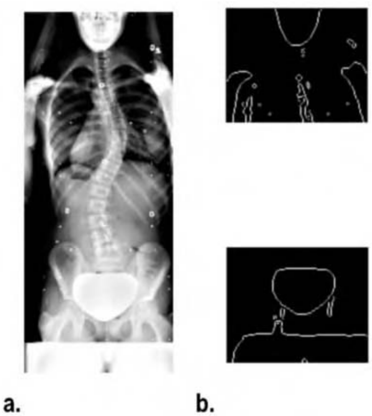

Figure 1 (a) Postero-anterior radiograph of a patient diagnosed with AIS (b) Global features detection

Edges were detected in the first and third sections using Canny operator with a different threshold value (respectively 0.5 and 0.75). Afterwards, a Hough transform 0 was used to detect the ellipsoid shape of the chin (Figure 1a) and the gonodal shield (Figure 1b). The head location was detected using the center and the orientation of a single ellipse. Three ellipsoid edges, strongly correlated to the edges of the shield, were used to approximate the pelvis location. This approach of locating region of interest was inspired by McNitt-Gray *et al* 0 in which a processing region of interest was defined for lung segmentation.

2.3. Local features identification

Scoliotic spinal curvature is a continuous, “S”- or “C”- shaped curve presenting a strong alignment property. This constraint, used in 0 to guide uniplanar 3-D reconstruction, implies that spinal deformities will always evolve continuously following the curve, with one vertebrae stacked on another. Long *et al* 0 have also used a variant of this property for segmentation and indexation of cervical vertebrae. The second level of refinement of the algorithm consisted in the detection of the spinal curve from the region identified in Section 2.2. Instead of relying on a highly variable, subjective and error-prone manual segmentation, proper identification of curve shape was performed using a combination of shock and diffusion filters. A restoration filter based on shock and diffusion equation was applied on a sub-region (a sliding window of 256x128 pixels) of the original image to provide a local noise restoration, more appropriate to detect local details. Osher and Rudin 0 first proposed the shock filter scheme for image enhancement, which is built upon non-linear time dependent differential equations. To avoid noise enhancement while restoring the image a weighted linear isotropic diffusive force is incorporated in the shock filter equation. For medical images, shock filters and anisotropic diffusion might enhance edges, but might reduce edge details as well. Thus, edge restoration might be unsuccessful while processing thin edges. Gilboa *et al* 00 proposed to overcome this limitation by integrating a complex diffusion into the process to allow a better restoration of the image.

From the higher edge of the gonadal shield, the curve shape was iteratively detected by estimating the next probable location of the vertebral body. Centroid and orientation computation of the edges were obtained using a Canny operator on the restored sub-region (Figure 2) and were used to identify the orientation and displacement of the sliding window. Local features of the curve were then iteratively identified until either the border of the image or the position of the head was reached.

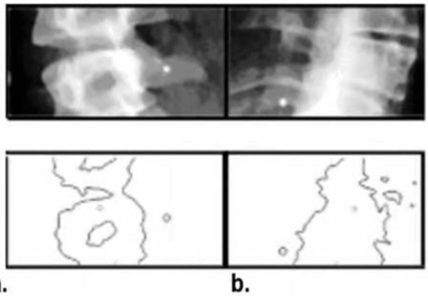

Figure 2 Local features detection in (a) the lumbar region (b) the thoracic region.

2.4. Validation

For each radiograph selected for this study, spinal curve was manually segmented on the x-rays by identifying the center of superior and inferior vertebral bodies from T1 to L5. This manual identification, performed by a trained technician, was used as a gold standard to evaluate the accuracy of automatic detection. Manual segmentation was considered as being the ground truth in order to validate the relevance of using an automatic technique. To ensure a proper comparison, a spline curve was fitted passing through the centroids of each vertebra in both automatic and manual segmentation. Errors measurements were performed by comparing the spinal curve using a discretization of the curve on regular intervals and computing the RMS error between the 2-D coordinates. The mean of the error was computed for each radiograph in order to obtain the overall error of the identification of the curve.

3. Results

Detection using the automatic detection algorithm was successful at curve identification with an RMS error of 4.25 mm +/- 1.13 mm. Error rates ranged from 1.31 mm to 7.15 mm and are presented in Table 1. Errors on manual segmentation were evaluated previously by 0 and were around 2 mm.

Table 1. RMS Error rate of automatic spinal curve identification against manual segmentation computed on 110 radiographs.

	Mean (mm)	Standard deviation (mm)	Range (mm)
Manual segmentation (as reported by 0)	2.00	-	-
Automatic segmentation	4.25	1.13	[1.31, 7.15]

4. Discussion and Conclusion

Segmentation of the spinal curve is a complex problem, mostly due to several factors namely the inherent photonic noise in radiography, the overlap of anatomical structures (ribs, organs and vertebral body itself). The proposed method has been successful at detecting an effective curve approximation of scoliotic deformities and was found to be satisfactory accurate to be used for indexing and classification purpose. Using a standardized segmentation algorithm could improve efficiency, reliability and repeatability in diagnosis of scoliosis. Information systems (PACS systems) are widely gaining acceptance in orthopedic clinics, but adequate classification and indexation tool are still to be implemented. Automated segmentation is the first step in providing clinicians a reliable and standardized knowledge base. The experiment allowed also investigating if a priori knowledge on anatomical structure (such as alignment constraints) can be used to guide computer algorithms for segmentation and identification. Thus, the design of dictionary of generic template could help refine further computer assisted diagnosis system and improve their accuracy in performing clinical predictions. The algorithm in the current study can also be extended for refining the segmentation for the identification of other features such as pedicles along the central curve of the spinal curvature. Future extension module can be connected to the system to detect further more precise landmarks, like pedicles or vertebral bodies.

Using an automated measurement technique for diagnosis of scoliosis, clinician could benefit of a wealthy knowledge base that could help to diagnose more accurately scoliotic curves. Clinicians, using standardized tools relying on the actual data, and not the visual interpretation as a basis, can increase the reliability of the diagnosis by assisting the decision making process. By identifying a rough approximation of the curve, it is possible to search similar cases and to identify the treatment and/or procedure that were then applied to correct the deformity with their associated results. A strong relation exists between the preoperative curve configuration and the surgical strategy and hence most clinical classification has been designed with this consideration in mind. However, in large-scale studies, the large number of radiograph to review, measure and analyze renders the classification task impossible for a single expert spine surgeon to perform. Hence, automation of the detection of the spinal shape could lead to a more repeatable and reliable diagnosis of the spinal curve and to a better understanding of spinal deformities.

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Prevalence of Subtle Cardiac Electrical Abnormalities in Children with Idiopathic Scoliosis

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Abstract. We aimed to assess the prevalence of ECG abnormalities in children with idiopathic scoliosis (IS).
77 girls and 13 boys, aged 7 to 18 years (15 ± 3), including 12 with thoracic scoliosis (mean Cobbe angle 33°), 4 with lumbar scoliosis (29°), 12 with thoracolumbar (27°), and 62 with double-major scoliosis (31°) entered the study. They were grouped as follows: 20 children <14 years of age (A), 35 from 14 to 16 (B), and 35 >16 years of age (C). Routine ECG was recorded and analysed automatically (GE, CASE v.4.1). Several ECG indices were further analysed. Abnormal values were considered if they exceeded upper normal limit (>95 percentile).
Results. Abnormalities were found in 66 patients (73%) independent of age. QRS duration >90ms was observed in 40 patients (44%), right axis deviation in 28 (31%), left axis deviation in 2 (2%). The Rsr'(V_{1-2}) pattern was noticed in 25 patients (28%). Ventricular gradient >60° was found in 11 patients (12%). In patients with normal ECG there was a normal leftward axis rotation with age (-10°±18° in gr.A, -5°±17° in gr.B and +2°±22° in gr.C, difference from median), whereas reversed trend (rightward deviation with age) characterized patients with ECG abnormalities (-7°±30° in gr.A, +9°±19° in gr.B and +19°±2° in gr.C, p<0.001).
Conclusion. In children with idiopathic scoliosis, subtle ECG abnormalities are frequent. Abnormal trend of rightward QRS axis deviation with age suggests cardiac involvement in natural history of scoliosis and requires more depth cardiac evaluation.

Key words. Idiopathic scoliosis, electrocardiogram, QRS frontal axis

1. Introduction

Observations regarding natural history of idiopathic scoliosis (IS) suggest that it is a benign clinical entity in terms of prognosis and longevity [1] but systematic longitudinal analyses. However, here clinical concerns focus on evidence for accompanied cardiac and respiratory abnormalities which may significantly affect overall and cardio-respiratory efficiency and quality of life [2-4]. Thus, an early detection of accompanying cardiovascular abnormalities might be of special clinical interest not only for correction purposes, but also for distinguishing patients with IS who may need special management programmes, taking into account that bracing treatment may have some adverse effects in this respect [5], while other methods may be beneficial [6]. Moreover, a relatively high prevalence of cardiac anatomical involvement, predominantly as mitral valve prolapse syndrome [7,8], manifested as a syndrome of fatigue and palpitations, may require diagnostic procedures to be extended to certain imaging techniques that are usually not available in orthopaedic or rehabilitation departments. As congenital cardiac malformation are actually infrequent in the IS population [9], the remaining patients are assumed to have normal cardiac structure and function. Limitations in exercise capacity and respiratory restrictions are common [2]. Therefore, screening tests for subtle cardiac abnormalities are required that use commonly available methods. Electrocardiography is offered as one and simplest of these methods ECG abnormalities in children and adolescents with IS are uncommon, if strict and widely accepted criteria are applied [10].

We hypothesized that there is a "grey zone" between the definite ECG abnormalities and normal ECG, which can be recognised as an abnormal deviation from mean or abnormal age-related trends in the ECG parameters. Therefore we undertook the ECG study to assess the prevalence of subtle cardiac electrical abnormalities in IS-patients.

2. Material and methods

2.1. Study population

Ninety consecutive children with IS admitted to our department were systematically examined. There were 77 girls and 13 boys, aged 7 to 18 years (15 ± 3).

Patients were grouped according to their age as follows: 20 children <14 years of age (A), 35 from 14 to 16 years of age (B), and 35 older than 16 (C).

2.2. Methods

Clinical assessment

All patients had clinical and radiological evaluation. IS was diagnosed as a thoracic scoliosis (mean Cobb angle - 33°) in 12 patients, as a lumbar scoliosis (mean Cobb angle - 29°) in 4 children, as a thoracolumbar scoliosis (mean Cobb angle - 27°) in 12 patients, and as a double-major scoliosis (mean Cobb angle - 31°) in 62 patients.

Electrocardiography

A routine ECG was recorded in each patient during in-hospital stay. Eletrocardiograms were analysed automatically (GE, CASE v.4.1) after visual inspection by one of the co-author (MS). Several ECG indices were further analysed, including QRS pattern in the V1 lead, the QRS complex duration, the QRS and the T wave axis in frontal plane, as well as the ventricular gradient, defined as the difference between the QRS and T wave axes in frontal plane.

Abnormal values were defined as those that exceeded 95 percentile, although 98 percentile values are usually used to define the upper normal limit [11]. As the ECG parameters are age-dependent, different cut-points were applied to various age-groups. They are listed in Table 1.

2.3 Statistics

Data are presented as mean ± 1 SD or as percentage. Numerical data were compared with the use of Mann-Whitney U-test, and parametric data with the use of the exact Fisher test (one-sided). Spearman R coefficients of correlation were calculated additionally.

Table 1. Limits for normal ECG parameters according to age

Parameter	Group A	Group B	Group C
QRS complex duration (UNL, ms)	80	85	90
QRS axis UNL	100	80	80
QRS axis LNL	20	10	-10
QRS-T gradient	60^o	60^o	60^o

UNL – upper normal limit (95% percentile), LNL – lower normal limit (5% percentile)

3. Results

The mean QRS duration of 91 ± 8 ms was longer than predicted, and was unrelated to the location of curvature. There were 40 patients (44%) with the QRS duration longer than 90 ms. The frequency of the prolonged QRS complex is respect to age is presented in Table 2. The mean QRS axis in the frontal plane was 69 ± 22^o and was significantly higher than predicted (63 ± 5^o, $p<0.05$). The frequency of the abnormal QRS axis in respect to age is presented in Tab.2. Abnormal right QRS axis deviation was present in 28 patients (31%) and abnormal left axis deviation was seen only in 2 children (2%) from the youngest group ($p<0.05$). The rsr' pattern of the QRS complex in the lead V1/V2 was found in 25 patients (28%) with a lower frequency in the youngest group (Table 2). Increased QRS-T gradient was observed in 11 patients (12%), with seemingly similar frequency in age-related group (Table 2). In total, there were 66 patients who presented with at least one of the above QRST abnormalities (73%). In total, any ECG abnormalities were found in 66 out of 90 IS-patients (73%) independent of age (Table 2).

Table 2. Frequency of abnormal ECG parameters according to age

Parameter	Group A	Group B	Group C	Statistical significance
QRSd > 90 ms	11 (55%)	16 (46%)	13 (37%)	NS
QRS axis >UNL *Rightward deviation*	4 (20%)	12 (34%)	12 (34%)	NS
QRS axis <LNL *Leftward deviation*	2 (10%)	0 (0%)	0 (0%)	<0.05
Rsr' pattern	2 (10%)	12 (34%)	11 (31%)	<0.1
QRS-T gradient >60^o	2 (10%)	6 (17%)	3 (9%)	NS
Any QRS abnormalities	14 (70%)	28 (80%)	24 (69%)	NS

In the IS-patients with normal ECG's there was a trend toward normal leftward QRS axis rotation with age (fig.1). When the median predicted QRS axis in the frontal plane was considered, the difference between observed and predicted values were -10° ± 18° in gr.A, 5° ± 17° in gr.B and 2° ± 22° in gr.C., respectively (NS for the trend). In IS-children with any ECG abnormalities a trend toward right QRS axis devation with age was observed (fig.1), and the difference between observed and predicted values were: -7° ± 30° in gr.A, +9° ± 19° in gr.B and +19° ± 2° in gr.C, $p<0.001$.

There were no significant correlations between QRS duration or QRS axis in frontal plane and Cobb angle or rotation in the entire study group or in age-related groups. Also, there was no relation between QRS duration or axis and type of idiopathic scoliosis or its degree.

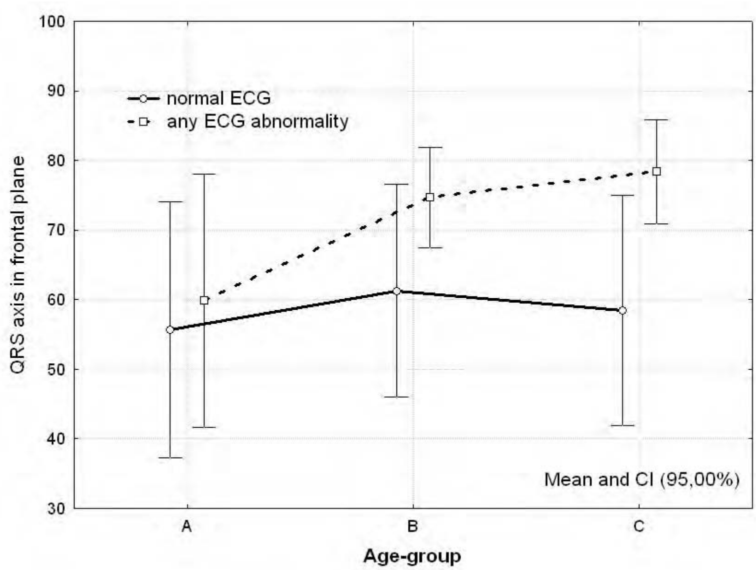

Figure 1. Mean and 95%CI for the QRS axis in respect to age.

4. Discussion

The main finding of our study was the observation of a high prevalence of subtle ECG changes in this relatively heterogeneous (in terms of scolisis location and degree) group of IS patients. These subtle changes could be recognised assuming that less strict criteria (5-95 percentiles instead of 2-98 percentile) were clinically valid. Thus, detected and described ECG abnormalities did not simply allow for cardiac pathology to be diagnosed. However, there is a discrepancy between the reported prevalence of certain structural cardiac malformations or abnormal electrical patterns (i.e. signs of right ventricular hypertrophy) [9] and the proportion of children with somewhat limited cardiopulmonary function [2,7,12,13]. We hypothesized that it can be explained by a relatively low sensitivity of ECG criteria, for which the 98% specificity is required to detect a definite pathology.

Results of our study confirmed previous observations regarding the QRS axis rightward deviations as a sing of cardiac involvement in the natural history of IS [10]. Additionally we found that as simple parameter the duration of the QRS complex provided additional clinically valid information.

Although we were unable to find either age-determined differences in most of the ECG parameters or IS-type/degree relationships with the ECG abnormalities, which is a result observed by others [14], one should be careful to reject a link between age, cardiac and pulmonary function and degree of thoracic cage deformations. Unfortunately, studies in which long-term changes in these factors are controlled for are still lacking. One should also consider the relatively high measurement error in Cobb angle assessment, thus a use of more objective method will be helpful for solving this issue [15].

5. Conclusions

In children with idiopathic scoliosis, subtle ECG abnormalities are frequent. Abnormal trend of rightward QRS axis deviation with age suggests cardiac involvement in natural history of scoliosis and requires more depth cardiac evaluation.

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A Biomechanical Study of L5-S1 Low-Grade Isthmic Spondylolisthesis Using a Personalized Finite Element Model

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Abstract. The pars interarticularis lesions in isthmic spondylolisthesis result generally from mechanical stresses in the neural arch due to repetitive overload during daily activities or to trunk imbalance resulting from spino-pelvic morphology. The L5-pelvis junction of a low-grade isthmic spondylolisthesis patient was modeled using a personalized finite element model to investigate the biomechanical behavior of the L5-S1 motion segment. Stress distribution and facet contact pressure in the altered segment were analyzed under 500 N simulating the gravitational load. High von Mises stresses were located in the pars interarticularis, in the pedicle, and in the outer region of the annulus. A high contact pressure was obtained at the facet surfaces. Influenced by the pelvic morphology, the inclination of L5-S1 junction affects the resulting shear forces and may play a crucial role in spondylolisthesis development.

Keywords. Low-grade isthmic spondylolisthesis, biomechanics, stress, shear forces, personalized model, finite element, pars interarticularis, pedicle

Introduction

Isthmic spondylolisthesis is related to a lesion in the pars interarticularis and is generally manifested by a relative sliding of two adjacent vertebrae resulting from shear forces. This type occurs in the lumbar spine at the L5-S1 level in 82.1% [1] and may be classified according to the amount of the anterior translational displacement from grade 0 to grade 5 [2]. Lesions in isthmic spondylolisthesis result generally from mechanical stresses due to repetitive overloads during daily or spurt activities [3-9]. Based on radiographic parameters measured during clinical studies, pelvic morphology and spino-pelvic balance were found abnormal [10] and pelvic incidence and sacral slope significantly greater in developmental spondylolisthesis [11]. A few finite element studies based on adult cadavers have demonstrated the weakness of the pars interarticularis region to support loads comparing to the other vertebral regions [12-13] and the increasing of the stress through the disc region with increasing percent slip [14].
The objective of this study was to investigate the biomechanics of L5-pelvis junction of a low-grade isthmic spondylolisthesis adolescent patient by analyzing the response under gravitational loading regarding to the stress distribution in the intervertebral structures and the contact pressure in facet surfaces.

Methods

A. Patient Description

Based on radiological measurement in the sagittal view X-rays of the simulated patient, the sacral slope and pelvic incidence were 35° and 63° respectively (Fig. 1).

B. Personalized Finite Element Model of the L5-pelvis Junction

Detailed, geometrically accurate 3-D finite element model of the L5-pelvis motion segment [15] was used (Fig. 1). The initial geometric shape of L5 vertebra and the pelvis was reconstructed using CT-scan of a dry specimen and their volumic structures were modeled using tetrahedral elements with a separation of cortical and cancellous bones. L5-S1 disc, composed of the nucleus pulposus and the annulus fibrosus was generated using the geometry of surrounding vertebral endplates [16-18] and modeled using a 3-D eight-nodal (brick) solid element. Corresponding ligaments, oriented along their fibers [16] and the annular fibers were modeled using bi-linear cable elements with tension resistance only. Facet joints, treated as nonlinear frictionless 3-D contact problem [12] were modeled using surface-to-surface contact elements. The nucleus was modeled as incompressible with a Poisson ratio of 0.499 [19] and all other materials were assumed to be isotropic and homogeneous and to have linear elastic properties. Once created and meshed, the volumic structures were deformed to fit the personalized geometry of the patient using a 3-D free form deformation technique (dual kriging) [20].

C. Loading and Boundary Conditions

In this study, the finite element model was fixed in all direction at the acetabula region to simulate the upright posture and to constraint any possible motion of the pelvis under loading. To simulate the body weight, 500N force was applied on L5 in the gravity direction (vertical).

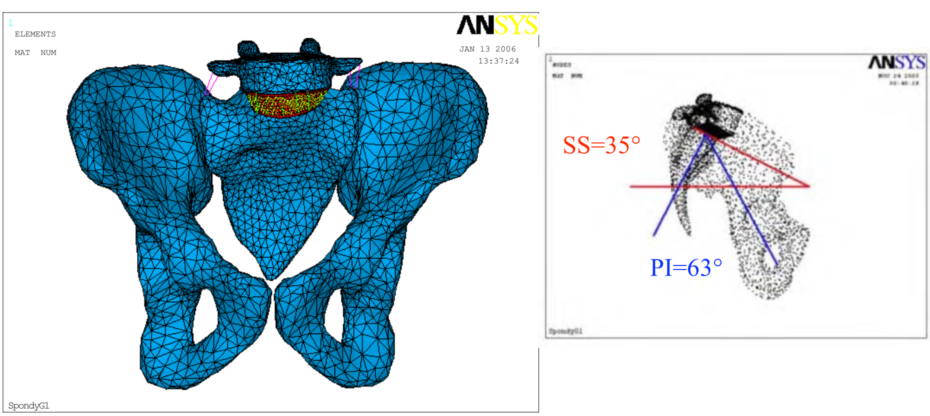

Figure 1. Personalized finite element model (left) and pelvic morphology determinants (right): sacral slope (SS) and pelvic incidence (PI)

Results

High equivalent (von Mises) stresses were located in the dorsal wall of the pars interarticularis and in the left pedicle region of L5 comparing to the other regions. In the sacrum structure, von Mises stresses were lesser than in L5 and the highest values were situated around the posterior region of S1 (Table 1). High equivalent stresses were also obtained in the postero-lateral region of the outer annular surface of the disc as well as the maximum shear stress (based on von Mises criterion). The contact pressure reached ~9MPa at the facet surfaces.

Table 1. Values and locations of the maximum equivalent von Mises and shear stresses (MPa) in L5, S1 and L5/S1 disc regions, and the contact pressure (MPa) at the facet surfaces.

L5		**S1**	**Disc**		**Facet**
Pedicle	**Pars**	**von Mises**	**von Mises**	**Shear**	**Pressure**
15.4 Left	21.7 lateral right	8.7 posterior	9.8 postero-lateral	3.0 postero-lateral	8.8

Discussion

The high stresses found in the dorsal wall of the pars interarticularis and in the pedicle of L5 for this patient are consistent with clinical observations in lumbar spondylolisthesis. It suggests that with a high pelvic incidence the pars interarticularis is subjected to high stress and thus is a vulnerable structure [12]. Under gravitational load, L5 vertebral body is in bending with respect to the posterior elements causing high stresses along to the pedicle region (Fig. 2). L5 is also rocking over the inferior disc causing a high stresses in its outer annular surface. This bending is also accompanied by anterior slipping down the sacral endplate, but the movement is restrained by the facet surfaces, as indicated by high contact pressure (Fig. 2). This mechanism also explains the stress concentration over the pars interarticularis. The vulnerability of the pars combined with repetitive overload may lead to fatigue fracture in relating spondylolysis development. Stress concentration over the annular surface may also cause lesions followed by a fatigue fracture. Resulting shear forces caused by the L5-S1 inclination are directly related to the pelvic morphology determinants such as the sacral slope (SS) and the pelvic incidence (PI) and may play a crucial role in spondylolisthesis development [10].

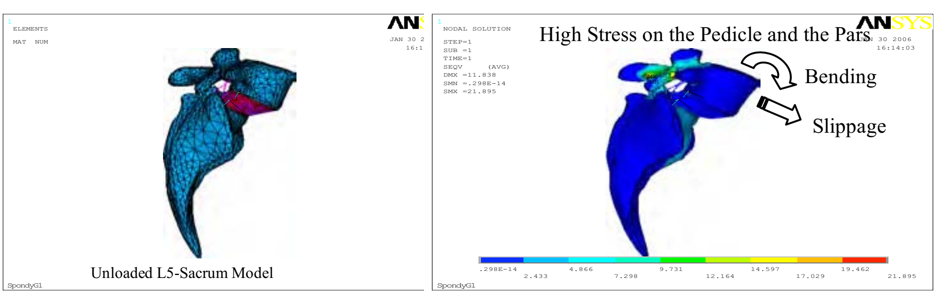

Figure 2. L5 Bending and slippage illustration

Clinical relevance

This study can ameliorate our understanding of spondylolysthesis biomechanics and help clinicians to identify the risk regions in the altered segment of the spondylolisthesis patient, thereby potentially predicting the risk of progression to a higher grade-spondylolisthesis with a more significant slip.

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Double Crush Syndrome Evaluation in the Median Nerve in Clinical, Radiological and Electrophysiological Examination

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Abstract. Double crush syndrome (DCS) was first described by Upton and McComas who proposed that focal compression of an axon often occurs at more than one level. The aim of the study was to support the hypothesis of DCS of the median nerve on the basis of available diagnostic methods. 30 patients (25 F and 5 M aged 33-73, mean 54.6±8.2 years) with coexisting carpal tunnel syndrome (CTS) and cervical radiculopathy (CR) were examined. Control group included 40 healthy volunteers (27 F and 13 M aged 17-82, mean 43.1±11 years). Medical evaluation comprised clinical examination, X-ray and MR imaging of the cervical spine, electroneurography (ENG) with F-wave and somatosensory evoked potentials (mSEPs) of median nerves. In clinical examination 96.6% of patients suffered from cervical spine pain and nocturnal paresthesies of at least one hand. Muscular atrophy was present in 43.3% in the proximal and in 70% in the distal part of the upper extremity. 30.3% of patients presented with a thoracic scoliosis. On X-ray examination, all patients showed cervical discopathy, mostly C_5-C_6 (70%) and C_6-C_7 (53.3%). Using MR investigation, the narrowing of intervertebral foramina was present in 81.25% and narrowing of vertebral canal in 37.5%. On ENG all patients presented with CTS, bilaterally in 73.3%. The F wave was abnormal in 73.3% and mSEPs in 66.7% of patients. Coincidence of MR and mSEPs in view of lateralization was observed in 71.4%. Results supported the DSC hypothesis. DCS evaluation requires both structural and functional diagnosis of peripheral neurones using MRI and electrophysiological examination.

Key words. double crush syndrome, carpal tunnel syndrome, cervical radiculopathy, electromyography, SEP

1. Introduction

Double crush syndrome is a general term referring to coexistence of dual compressive lesions of a nerve. Double crush syndrome (DCS) refers to nerve lesion at two levels – proximal and distal – where the proximal lesion facilitates a distal lesion.

In 1961 Lishman and Russel described the possibility of a nerve lesion at different levels, while in 1968 Crymble described patients with carpal tunnel syndrome and coexisting cervical radiculopathy [1].

DCS was first described in 1973 by Upton and McComas, who proposed that focal compression often occurs at more than one level along the course of an axon. They claimed that 70% of patients with carpal tunnel syndrome (CTS) had coexistent cervical radiculopathy. The authors established a diagnosis on the basis of clinical, electrophysiological and radiological examination and suggested a cause-and-effect relationship between symptoms of peripheral nerve neuropathy and lesions of cervical roots [2]. Experimental studies on animal subjects have been carried out by Japanese authors [3,4,5].

The mechanism of the DCS build-up is described as an effect of compression at two levels, resulting in axonal transport perturbation and a consequential axonal lesion. After some time, it leads to enervation of the muscle with presence of fibrillations [2,6].

Orthopedic surgeons pay attention to the presence of the double crush syndrome in the cases of carpal tunnel syndrome and cervical radiculopathy. Differences have been noted in postsurgical outcomes between patients with isolated carpal tunnel syndrome and patients with coexisting cervical radiculopathy [2,7,8].

Diagnostic problems related to multilevel lesions of peripheral nerves calls for adequate methods of evaluation, since $1/5^{th}$ of patients suffer from recurrent hand pain regardless of surgical treatment for the carpal tunnel syndrome.

2. Aim of the Study

The aim of the study was to support the hypothesis of the double crush syndrome in the median nerve on the basis of available diagnostic methods.

3. Material and Methods

30 patients (25 females and 5 males aged 33 - 73, mean 54.6 ± 8.2 years), with coexisting carpal tunnel syndrome and cervical radiculopathy, were examined. Examination included 60 median nerves. A control group comprised 40 healthy volunteers (27 females and 13 males aged 17 - 82, mean 43.1 ± 11 years).

Criteria of inclusion were the symptoms indicating the presence of CTS confirmed in electroneurographic (ENG) examination and symptoms of cervical radiculopathy, confirmed in X-ray examination in all patients and with magnetic resonance examination (MRI) when possible. Patients with cranial trauma, post-traumatic cervical syndrome and carpal tunnel syndrome without cervical discopathy were excluded from the study.

Medical evaluation comprised a medical history and a clinical examination, X-ray of the cervical spine, electroneurography with F-wave and somatosensory evoked potentials of the median nerves (mSEPs). 16 patients underwent MRI examination. mSEPs measurements were made with a Sapphire 4 ME apparatus. The median nerve was stimulated unilaterally at the wrist with a surface cup electrode. The course of the examination followed the recommendations of the International Federation of Clinical Neurophysiology (IFCN).

Following parameters of mSEPs were measured: amplitude and latencies of N9, N13, N20 segments, the N13/N9 amplitude ratio, peripheral conduction time (PCT), central conduction time (CCT), difference in latencies and amplitude of N9, N13 between the sides, and difference in PCT and CCT between the sides.

The F wave was recorded from the abductor pollicis brevis muscle after stimulation of the median nerve at the wrist.

Quantitative and qualitative analysis of SEP and F wave parameters comprised the following tests: Wilcoxon, Ancova, Anova, CHI^2, Spearman correlation test and multiple regression analysis. Results were considered significant at level $p = 0.05$. In the evaluation of mSEPs with parameters with normal distribution, values differing more than 2 SD from parameters obtained in control group were abnormal. For theremaining parameters, values outside 3^{rd} and 97^{th} percentile were considered abnormal.

4. Results

On clinical examination, 96.6% of patients suffered from cervical spine pain and nocturnal paresthesies of at least one hand. Muscular atrophy was present in 43.3% in the proximal and in 70% in the distal part of upper extremity. 30.3% of patients presented with thoracic scoliosis.

On X-ray examination, all patients showed cervical discopathy, mainly at the levels C_5-C_6 (70%) and C_6-C_7 (53.3%). On MRI examination, the narrowing of the intervertebral foramina was present in 81.25%, and narrowing of the vertebral canal was found in 37.5% of patients. On ENG examination, all patients presented with CTS, with 73.3% having bilateral lesions. F wave analysis revealed pathology in 73.3% of patients (53.3% of nerves). With mSEPs examination, abnormal mSEPs measurements were obtained in 66.7% of patients (43.6% of nerves). Serious abnormalities were observed with a decrease of N9 segment amplitude (58.6% patients, 33.3% nerves), and a decrease of N13 segment amplitude (51.8% patients, 32.1% nerves), as well as prolonged latency of N13 (37.5% patients, 24% nerves), prolonged PCT (34.6% patients, 20.4% nerves). The N13/N9 amplitude ratio was abnormal in 34.6% of patients (19.2% of nerves). Examples of pathological findings are presented in Figure 1.

Compliance of MRI and mSEPs with lateralization was observed in 71.4%. An example is presented in Figure 2. The sensitivity of F wave examination was slightly higher than mSEPs (73.3% versus 66.7%).

Applying the Spearman test, a positive correlation between terminal latency in median nerve and N9 wave amplitude ($p = 0.01$) was found; a similar finding was found between the sensory amplitude of the median nerve in the peripheral segment (SNAP) and N9 wave amplitude ($p < 0.00001$). This may suggest an influence of nerve damage on abnormal SEP measurements. However, there is no positive correlation between latency and amplitude of the nerve in the peripheral part and PCT and amplitude N20 and the N13/N9 ratio. PCT parameters and N13/N9 ratio are not dependent on the severity of nerve damage and can be useful for the evaluation of double crush syndrome. Also, there were more pathological unilateral SEP measurements in patients with pronounced bilateral symptoms, revealed with ENG examination.

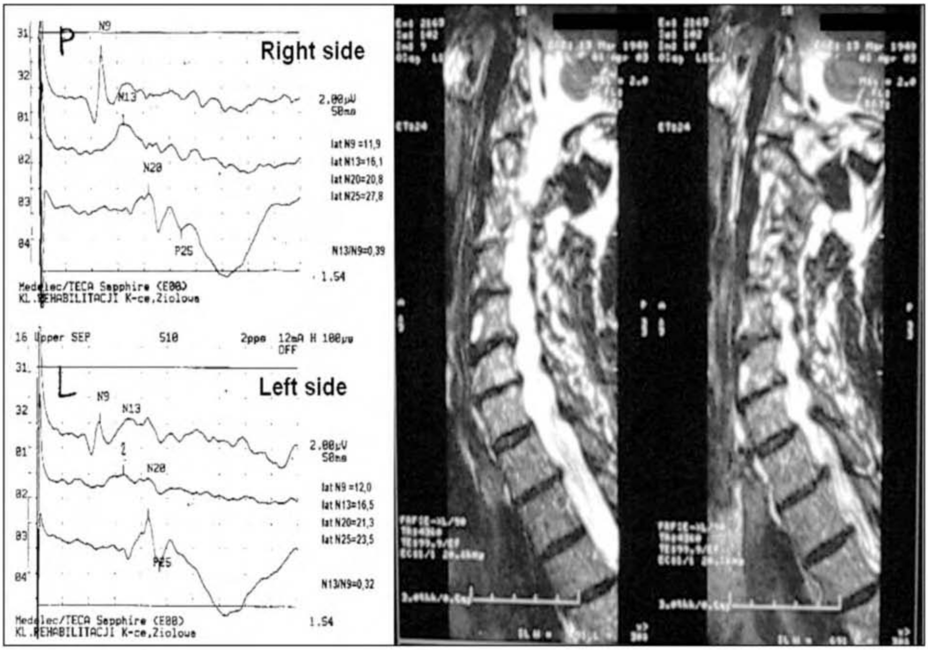

Figure 1. Median nerve SEP in cervical discopathy. Absent N13 wave on the left side

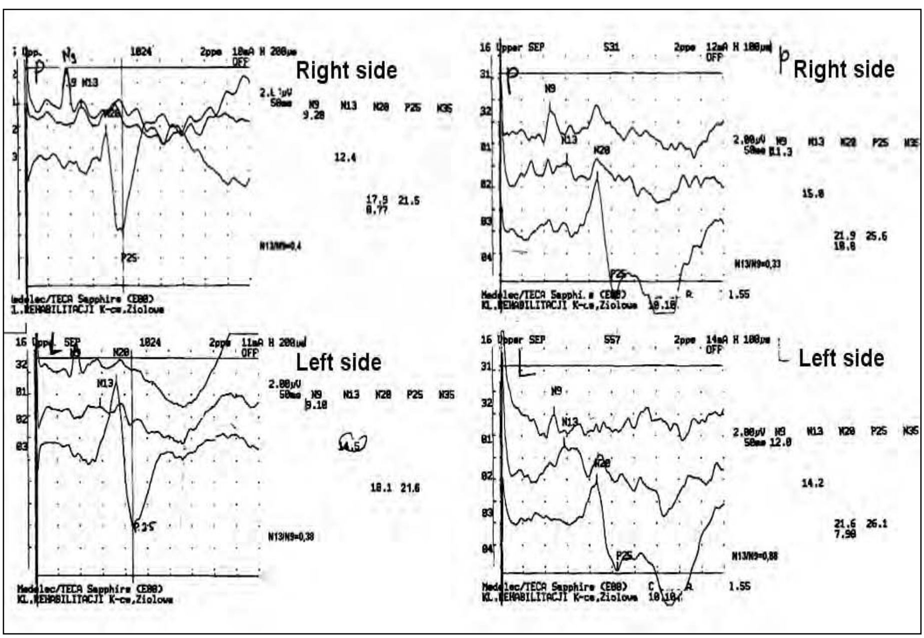

Figure 2. Coexisting carpal tunnel syndrome and cervical discopathy. Absent N13 wave and increased N20 amplitude on the left side (left). Prolonged latency of N13 wave on the right side and bilaterally decreased N9 amplitude (right).

5. Discussion

Since the first description of the double crush syndrome in 1973 by Upton and Mc Thomas, many authors have researched DCS concerning various nerves [2,6,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26]. Some animal trials support the DCS hypothesis (Nemoto, Shimpo, Suzuki), but sufficient evidence of its occurrence in human is still missing. Augustyn and Vanesse (1992) described nerve lesion in the DCS mechanism and the reverse DCS mechanism [27].

Occurrence rates for DCS reported over the last 30 years varies among authors from 5% described by Morgan and Wilbourn, 6% by Kuntzer, 11% by Hurst, 14% by Cassavan, 15% by Crymble, 18% by Ostermann, 48% by Livesone, up to 70% by Upton and Mc Thomas [1,2,6,14,20,28]. These differences are caused by different criteria for patient selection, different methods of examination and broad DCS definition of the lesion in different nerves; for example, coincidence of median and ulnar nerve neuropathy [28].

Patients suffering from idiopathic carpal tunnel syndrome after surgical release of the median nerve in the carpal region declared improvement in 84%, whereas patients with coexisting cervical radiculopathy improved in 58%, as observed by Ostermann (1988). Similar observations were described by Herczeg (1997) and Chinese authors (Choi at al., 1998) [6,7,8]. In the case of no improvement after surgery in the peripheral portion of the nerve, some patients required additional decompression in the cervical region, as reported by Japanese authors – Kaneko and Kazuo (1997) [16].

DCS hypothesis and related problems were assessed by Scandinavian authors, the radiologist and neurologists Pierre-Jerome and Bekkelung. In 2003, they described results of magnetic resonance imaging of the cervical spine and the wrists in patients with the carpal tunnel syndrome and found a correlation between carpal tunnel syndrome and cervical radiculopathy in 50%. Assessing the area of the intervertebral foramina at C_5-C_6 and C_6-C_7 levels, they found statistically significant narrowing in patients with the carpal tunnel syndrome [23].

Current work records an accordance of the ENG results with the cervical spine MRI in 71.4% of patients with cervical discopathy and carpal tunnel syndrome, as well as positive correlation between the side of narrowed intervertebral foramen and pathological result of the median nerve conduction. Also in mSEPs examination we noted a decrease in amplitudes of the N9 and N13 waves in 58.6% and 51.8% of patients (33.3% and 32.1% of nerves) and prolonged PCT in 34.6% of patients (20.4% of nerves). The predominant type of nerve lesion was axonal.

Usefulness of the SEP examination in radicular syndromes is limited by relatively low sensitivity of SEPs from mixed nerves, using cervical and lumbar radiculopathy, especially in the case of a single root lesion. SEP examinations in radiculopathy were also undertaken by Chiappa (1990), Dillingham (2002), Aminoff (2002), Fisher (2002) and others [29,30,31,32].

Low SEP sensitivity in cervical discopathy can be caused by activation of a mixed nerve, such as the median nerve, which contains components of many radices, both sensory from C_6-C_7 levels and motor from C_8-Th_1 levels. In the case of the onset of carpal tunnel syndrome, in the first order sensory fibres are first affected, followed by motor fibres. Prolonged end latency in the median nerve without prolongation of the sensory latency and decrease of the amplitude suggest a lesion of the cervical roots at the C_8-Th_1 level, and the coincidence of the pathological SEP concerning prolongation of the peripheral conduction N9-N13 indicates conduction pathology at the level of C_6-

C_7 sensory roots. In these cases, multi-root pathology from C_6 to Th_1 should be considered.

In the current work, a positive correlation was identified between the amplitude of the sensory response SNAP in the distal portion and the amplitude of N9 and N13 waves; however positive correlation was not found between end latency of the median nerve and the N9-N13 interlatency (PCT), the CCT time and the N13/N9 amplitude ratio. The parameters PCT and N13/N9 amplitude ratio are independent of the degree of peripheral nerve lesion (carpal tunnel syndrome) and can be useful for the evaluation of the double crush syndrome.

Normal mSEPs recordings were observed even in massive nerve lesions in the peripheral portion, and with an absence of excitability in the wrist region. However in other cases with a mild degree of nerve compression, considerable mSEPs pathology was observed. Such results suggests coexistence of another factor in the lesion in these patients.

On the basis of the literature [6,26,33], it can be established that, in cases of the double crush syndrome, surgical nerve release should not be delayed, or a possible worse outcome will occur.

In considering neurophysiologic, MRI and clinical examinations, it should be stated that the double crush syndrome does exists. However it is difficult to establish a cause-and-effect relation between the proximal and the distal portion of the lesion.

Conclusions

1. The results of the study support the DSC hypothesis.
2. DCS evaluation requires both structural and functional diagnosis of the peripheral neuron, using MRI and electrophysiological examination.

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Handedness and Spinal Deformity

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Abstract: Biological lateralisation is clearly manifest in scoliosis, yet its relevance is unclear. Goldberg et al. (Spine. 15(2):61-64. 1990) found an association between curve pattern and hand-preference in a screened population, but no increase in sinistrality. Milenkovic et al, (European Journal of Epidemiology, 19:969-972,2004) concluded left-handedness was a risk factor in a screened group. The database was reassessed to determine whether clinically significant scoliosis was associated with sinistrality or differed from the population norm of 10%. Patients attending the scoliosis clinic were asked their preferred writing hand. 1,636 patients were identified with complete data. Overall, left handedness occurred in 11.5%, greater than the general population (p=0.04) Left hand preference was found to be increased in boys with infantile idiopathic scoliosis and in girls with infantile, juvenile, congenital and syndromic scoliosis, but was reduced in girls with adolescent idiopathic scoliosis. Scoliosis lateralisation was random in infantile and congenital scoliosis, while left curve patterns were decreased in girls with juvenile idiopathic scoliosis and increased in boys with syndromic scoliosis. Curve pattern and handedness correlated in asymmetry in boys and girls and in girls with radiologically confirmed adolescent idiopathic scoliosis, but not in any other type. This study cannot confirm findings of left-handedness as a risk factor for spinal deformity. Its incidence is reduced in girls with adolescent idiopathic scoliosis, and the increased sinistrality in infantile scoliosis is not a new finding (Rauterberg & Tonnis Ger. Z.Orthop. 109(14):676-689. 1971). Lateralisation is undoubtedly a factor in scoliosis, but does not have a simple causal relationship, probably deriving from the underlying scoliotic process, rather than contributing to it.

Keywords: scoliosis – hand preference – asymmetry - aetiology

Introduction

The obvious predominance of right convex thoracic curve patterns in scoliosis has always suggested a parallel with hand preference and with other patterns of cerebral lateralisation. This has prompted hypotheses that associate the two, either as handedness causing scoliosis or the reverse, scoliosis determining handedness (See Miles [1] and Goldberg et al 1990 [2] for a fuller discussion). There is a tendency to interpret left-handedness as, in some sense, abnormal and pathological which must have some deleterious effect, while left convex scoliosis [3] has been perceived as a marker for an underlying pathology.

Studies at this centre on a school screening population [2,4], mostly with mild or minimal curvature, showed a normal distribution of handedness (10% left handed, [5]), a correlation between hand preference and scoliosis pattern and a tendency for patients with adolescent idiopathic scoliosis to be more uniform in there preferences (hand an foot preference for a variety of actions) than their normal peers. The possibility of an over-lateralised motor system somehow "moulding" the skeleton to give an over-lateralised spine and torso, seemed to perhaps be supported by the findings [6,7] of similar lateralisation in sensory modalities in scoliosis. However, the ever-present difficulty of separating primary from secondary effects prompted an investigation of a non-motor, supratentorial cognitive system, language organisation [8]. This showed that even at this level, AIS patients showed greater lateralisation than controls, out ruling motor lateralisation as an aetiological factor. Finally, a study of the incidence of left and right curve patterns in different classifications of scoliosis [9] showed that left thoracic patterns occurred in 50% of infantile and congenital cases, but in lower frequencies in juvenile, adolescent or syndromic cases. It did not confirm the much-repeated statement of James [10] that 80% of infantile idiopathic were in the left thoracic pattern, or that of Coonrad [3], that it was a marker for an underlying disease process. What was shown was that gender and age at onset were significant (all boys and all juvenile onset scoliosis [11]) had a high incidence of otherwise unsuspected underlying cord anomalies, but that curve convexity itself was not a major predictive sign.

A recent paper by Milenkovic et al [12] has re-opened the question, reporting an increase in left-handedness among a population who had failed the Adams forward bend test in a school screening pilot study. They argue that left-handedness is a risk-factor for spinal deformity and, more contentiously, that postural re-education and modification of school furniture and equipment would have beneficial effects by reducing the incidence of deformity and improving outcome. Since their findings are so completely at odds with this centre, the data was re-examined to include the complete spectrum of scoliosis asking whether patients with any type of scoliosis showed a pattern of handedness that differed from the population norm.

Patients and Methods

Patients were drawn from the computerised scoliosis database on the basis of having the relevant information recorded, viz. gender, diagnosis, curve pattern, preferred writing hand. Curve pattern was designated right of left on the basis of the convexity of the lower thoracic segment, irrespective of the primary curve [2]. Thus, there are two possibilities, right thoracic – left lumbar and left thoracic – right lumbar. In the case of minor asymmetry referred from the schools programme, whose "deformity" had not warranted radiograph, the pattern of rib and loin humps was the determinant.

Statistical analysis was by SPSS (Statistical Package for the Social Services Vs. 11.0) using Chi-square and the Z statistic for single or independent proportions.

Results

These are summarised in Tables 1 a & b to 6 a & b. Patients are divided into male and female and by category of scoliosis. Each table shows the incidence of handedness and curve pattern and tests for a correlation between the two.

Group 1. Asymmetry but no radiograph

This group uniquely contains patients who, on examination in the clinical setting, did not have a manifest asymmetry. Having no complaints, other than that of having been referred from a screening programme, they were not sent for radiograph and are classified as "scoliosis = 0" or none.

Table 1a. Boys. Minor asymmetry

Scoliosis	Left	None	Right	Total
Left handed	2	1	0	3
Right handed	0	17	8	25
Total	2	18	8	28
Pearson Chi-square = 18.127; p<0.001**				

The incidence of left handedness was 10%, and does not differ from that observed in the wider human population [5], p = 0.575. There is a statistically significant correlation between hand preference and pattern of asymmetry.

Table 1b. Girls. Minor asymmetry

Scoliosis	Left	None	Right	Total
Left handed	10	15	20	45
Right handed	41	157	239	437
Total	51	172	259	482
Pearson Chi-square = 7.231; p<0.05*				

The incidence of left handedness was 10%, and does not differ(p = 0.341) from that observed in the wider human population [5]. There was a statistically significant association between hand preference and lateralisation of asymmetry.

Group 2. Adolescent idiopathic scoliosis, confirmed by radiograph

Table 2a. Boys. Adolescent idiopathic scoliosis

Scoliosis	Left	Right	Total
Left handed	1	7	8
Right handed	9	30	39
Total	10	37	47
Pearson Chi-square =0.443; p=0.505. NS			

Handedness in boys with AIS does not differ from the population mean (p=0.087) and does not correlate with scoliosis pattern.

Table 2b. Girls. Adolescent idiopathic scoliosis

Scoliosis	Left	Right	Total
Left handed	9	34	43
Right handed	54	529	583
Total	63	563	626
Pearson Chi-square = 6.023; p=0.014 *			

The incidence of left handedness in girls with adolescent idiopathic scoliosis was 6.9% which is less (p=0.005) than that for the normal population. There was also a statistically significant correlation between hand preference and scoliosis pattern.

Group 3. Infantile idiopathic scoliosis, age at presentation <4 years

Table 3a. Boys. Infantile idiopathic scoliosis

Scoliosis	Left	Right	Total
Left handed	4	3	7
Right handed	11	9	20
Total	15	12	27
Pearson Chi-square = 0.010; p=0.922 NS			

The incidence of left handedness was 26% which is significantly greater (p=0.007) than that for the normal population [5]. Curve pattern is significantly different from the usual 80% right thoracic (p<0.001) and indistinguishable from a random or 50-50 distribution. There is no correlation between handedness and curve pattern.

Table 3b. Girls. Infantile idiopathic scoliosis

Scoliosis	Left	Right	Total
Left handed	5	6	11
Right handed	8	4	12
Total	15	10	23
Pearson Chi-square = 1.051; p=0.305 NS			

The incidence of left handedness was 48% which is significantly greater (p<0.001) than that for the normal population [5]. Curve pattern is significantly different from the usual 80% right thoracic (p<0.001) and, as with the boys, is indistinguishable from a random or 50-50 distribution. There is no correlation between handedness and curve pattern.

Group 4. Juvenile idiopathic scoliosis, age at presentation 4 – 10 years

Table 4a. Boys. Juvenile idiopathic scoliosis

Scoliosis	Left	Right	Total
Left handed	0	2	2
Right handed	5	17	22
Total	5	18	24
Pearson Chi-square = 0.574; p=0.449 NS			

Handedness in boys with juvenile idiopathic scoliosis is the same as the population mean and does not correlate with scoliosis pattern.

Table 4b. Girls. Juvenile idiopathic scoliosis

Scoliosis	Left	Right	Total
Left handed	1	12	13
Right handed	5	60	65
Total	6	72	78
Pearson Chi-square = 0.0; p=1.0 NS			

The incidence of left handedness was 16.7% which is significantly more (p=0.038) than that for the normal population [5]. Left thoracic patterns, at 6.7%, were statistically significantly reduced (p=0.005), taking a normal ratio of 1:4, but do not correlate with hand preference.

Group 5. Congenital vertebral anomaly

Table 5a. Boys. Congenital vertebral anomaly

Scoliosis	Left	Right	Total
Left handed	5	3	8
Right handed	28	30	56
Total	31	33	64
Pearson Chi-square = 0.724; p=0.395			

Handedness did not differ from expected (p=0.323) but curve pattern distributed randomly left and right (p<0.001 that the ratio was not 1:4, p=0.901 against an equal likelihood of left and right). There was no correlation between the two.

Table 5b. Girls. Congenital vertebral anomaly

Scoliosis	Left	Right	Total
Left handed	10	6	16
Right handed	32	40	72
Total	42	46	88
Pearson Chi-square = 1.711; p=0.191 NS			

Girls with congenital vertebral anomalies had an increased incidence of left handedness (18%, p=0.009) and a random distribution of left and right thoracic curve patterns (p=0.749 against a test value of 0.5), but no correlation between the two.

Group 6.. Syndromic scoliosis, all diagnoses

Table 6a. Boys. All syndromic scoliosis

Scoliosis	Left	Right	Total
Left handed	4	5	9
Right handed	13	30	43
Total	17	35	52
Pearson Chi-square = 0.683; p = 0.409 NS			

Left handedness did not differ statistically from the population mean (17.3%, p=0.064). Left thoracic patterns were more frequent (35%, p=0.017) than predicted but there was no correlation between that and handedness.

Table 6b. Girls. All syndromic scoliosis

Scoliosis	Left	Right	Total
Left handed	4	14	18
Right handed	17	63	79
Total	20	77	97
Pearson Chi-square = 0.035; p=0.852 NS			

The incidence of left handedness was 18.66% which is significantly more (p=0.004) than that for the normal population [5]. Curve pattern is not significantly different from the usual 80% right thoracic (p<0.490) and there is no correlation between handedness and curve pattern.

In summary, left hand preference was found to be increased in boys with infantile idiopathic scoliosis and in girls with infantile, juvenile, congenital and syndromic scoliosis, but was reduced in girls with adolescent idiopathic scoliosis. Scoliosis lateralisation was random in infantile and congenital scoliosis, while left curve patterns were decreased in girls with juvenile and adolescent idiopathic scoliosis and increased in boys with syndromic scoliosis. Curve pattern and handedness correlated only in asymmetry in boys and girls and in girls with radiologically confirmed adolescent idiopathic scoliosis.

Discussion

This revisiting of the subject was prompted by a recent report [12] where it was found that left handedness was significantly associated with scoliosis in girls, after screening 2,546 schoolchildren. This conclusion seems to have been based on physical examination only, however, as they make no reference to radiological investigations. The present authors cannot confirm the finding from their own data, collected over 25 years, from a school screening programme and from general clinical referrals. Girls with asymmetry only (i.e. who had failed the screening test) showed a normal incidence of sinistrality, but in girls with adolescent idiopathic scoliosis it was significantly decreased. The increased incidence of left handedness in the infantile-onset group has been reported before [13] as has their random distribution of left and right curve patterns [11] but the finding of increased left handedness with increased right curve patterns in juvenile-onset patients was unexpected. All these findings must be reconciled if they are to have any bearing on the development of scoliosis.

In scoliosis generally, there are several obvious biological irregularities: apart from the infantile-onset group, females predominate significantly. Excluding the asymmetry group, which comes almost exclusively from the screening programme where only girls are screened, the proportion of females with *all* types of scoliosis is 84% and 81% of patients have their scoliosis in the right thoracic-left lumbar configuration. 11.5% were left handed, which is statistically significant ($p=0.040$) but the excess is not uniformly spread across all sub-groups. It is important to remember that these are associations. There is no evidence to justify a cause-and-effect relationship or the existence of concomitant pathology. To suppose that handedness can determine a posture that is so detrimental as to cause real spinal deformity is to simply not understand how scoliosis evolves. Furthermore, the non-correlation between hand preference and scoliosis pattern, especially in infantile-onset scoliosis and in female juvenile-onset and syndromic scoliosis, refutes this concept. Left handedness itself is a normal biological variant [5] and the tendency to regard it as indicative of pathology by itself is not helpful.

The natural history of scoliosis is to commence in childhood, to progress (or not) with growth and to cease almost completely at the end of growth. A small slow deterioration has been documented throughout life [14]. While it may be associated with many pathological conditions, no specific pathology that belongs to scoliosis alone has been identified. Scoliosis has plagued clinicians for centuries because the observations seem so complex and the natural history so unpredictable. However, it has been suggested that "your observations look complicated because you don't know the simple rules that underlie them." [15]. The underlying model is of a straight spine that assumes a crooked posture which is then made structural by the remodelling of the bony elements under the mechanical effects of gravity and muscle action, external forces moulding from the outside. This is a simple idea but its mathematical rules are extremely complicated and yet cannot explain the clinical observations. When its many features are considered together, growth, gender bias, lateralisation, stress factors, the logical conclusion is that they are manifestations of the biological processes of growth and development, internal molecular forces acting from within. Scoliosis is fundamentally a failure of symmetrical growth, causing rotation and curvature of the whole trunk, not just of the spine. This comes under the remit of developmental instability which can explain the natural history better than mechanical models and has no need for occult and unidentifiable disease processes.

Conclusion

While sub-groups of scoliosis display differences in the frequency of sinistrality, there is no evidence that this could be in any sense causal. It is easier to perceive it as another of the more generalised asymmetries that occur with the condition. They all point towards a developmental, rather than a pathological, cause for all categories of scoliosis.

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Surface Topography and Vectors: A New Measure for the Three Dimensional Quantification of Scoliotic Deformity

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Abstract. The monitoring of spinal deformity uses many techniques: clinical history and physical examination for patient status, radiography for precise spinal delineation and Cobb angle, topography to quantify cosmesis and to approximate the Cobb angle. Experience with a system based on Raster photography has shown that adequate correlation with the Cobb angle is achieved, but that the relationship between spinal curvature and cosmetic effect is not simple. A measure was developed to quantify the asymmetry of the back, making it available to statistical analysis, without expressing it in terms of the Cobb angle or referring to trunk balance or rotation. The calculation expresses symmetry about the median saggittal plane (first thoracic vertebra to natal cleft), reflecting the right half onto the left and measuring the three-dimensional displacement between corresponding fixed points on the trunk. Tolerance limits were calculated and correlation with Cobb angles using routine scans was analysed. There were statistically significant correlations between the Cobb angle and all vectors except the middle antero-posterior. All vectors correlated with each other, except again for the middle Z or anteroposterior which correlated only with the middle and lowermost sets. Applied to natural history and to surgical outcome, this new parameter provides a different quantification of back shape which can be used both for patient assessment and monitoring, for the evaluation of the cosmetic (as opposed to the radiological) effect of treatment, and for aetiology and natural history studies.

Keywords. Surface topography – Scoliosis – Asymmetry - Three-dimensional measurement

Introduction

Scoliosis has been quantified by Cobb angle [1] for more than half a century. It is the gold standard and the worth of this measure in standardising and evaluating protocols is indisputable. There are, nonetheless, two problems that, while not insuperable, do give rise to disagreement: the tolerance limits of the measure (Carman *et al.* 1990 [2], Morrissey *et al*, 1990 [3]) and the incomplete correlation between the Cobb angle and other aspects of deformity (Thulbourne & Gillespie, 1976 [4]). These, coupled with the perceived need to reduce the exposure of growing children to ionising radiation, encouraged the development of additional and non-invasive systems for documentation and analysis [5 -8]. One such system (Quantec Image Processing ®. Lathom, Lancs., UK) uses Raster photography, a digital camera and customised computer software, to record and quantify deformity in scoliosis. Early reports [9 -13] have described its application and evaluation. The Quantec system currently in use records trunk balance, spinal angles, saggittal angles, rib humps and surface asymmetry, as single measures or combined scores. The authors were interested in a different parameter which would express the primary cosmetic problem, left-right asymmetry, without reference to over-all trunk balance, or predicting the Cobb angle. An analytical method was devised by one of the authors (DG) which would be applicable to all archived material as well as to new data. This study describes the new parameters and tests their validity.

1. Materials and Methods

The new parameters are based on the principle that the human body has one plane of symmetry, the median saggittal. A function was developed which would compare the left and right sides of the back surface. The investigator selects, on the patient image, the following standard reference points: natal cleft (NC), posterior superior iliac spines (PSIS), axillae (A) and first thoracic vertebra (T_1), Figure 1. The computer identifies three pairs of corresponding index points on each side of the median saggittal plane, falling on the right and left sides of the straight lines T_1-A and A-PSIS :

1. Midway between T_1 and A.
2. One third of the distance A-PSIS and one half of the orthogonal distance towards the straight line joining NC and T_1.
3. Two thirds of the distance A-PSIS.

The symmetry about the median saggittal plane is quantified by reflecting each right side reference point orthogonally about the NC - T_1 line and determining its displacement, in millimetres, from the corresponding left side reference point. The displacement is expressed in three dimensions, X (the subject's left-right horizontal, $dX=X_{left}-X_{reflected}$), Y (the subject's vertical, $dY=Y_{left}-Y_{reflected}$) and Z (the true horizontal into the image, $dZ=Z_{left}-Z_{reflected}$). To the observer, the numbers read that dX is negative if the reflected point is to the left of the left index point and positive if it is to the right (nearer the midline); dY is negative if the reflected point is caudal to the left index point and positive if it is rostral; dZ is negative if the reflected point is nearer to the observer than the left index point, and positive if it is further away. (Figure 2) The authors called these vectors, as they express both size and direction.

The displacements are expressed as absolutes and summed, signed and unsigned, to give scores; all 11 parameters are also expressed as a percentage of the NC - T_1 distance to normalise for size and growth. This gives 22 parameters in all, the first nine, the absolute values, being the more descriptive. The summed scores are more sensitive to change, as they include minor changes on many parameters. The percentage scores are particularly relevant to long-term follow-up in small children in whom growth would be a confounding factor. These measurements are self-referring: they compare the left and right sides of the trunk and are independent of the spine line, of trunk balance and of rotation.

1.

Figure 1._. Vector analysis: minor asymmetry.

T_1NC: 454.3; dX1: 1.4; dY1:0.5; dZ1:0.9; dX2: 0.9; dY2:3; dZ2: 0.7; dX3:-4.0; dY3: -1.20; dZ3: 0.2; USMS: 1.81; SMS: 0.253.
pdX1: 0.3; pdY1: 0.1; pdZ1: 0.2; pdX2: 0.2; pdY2:0.7; pdZ2:0.1; pdX3:-0.9; pdY3:-0.3; pdZ3:0. PUSMS: 0.398; PSMS: -.056.

T_1NC	= distance between natal cleft and first thoracic vertebra
dX, Y or Z 1	= cartesian co-ordinates at point 1.
dX, Y or Z2	= cartesian co-ordinates at point 2.
dX, Y or Z3	= Cartesian co-ordinates at point 3.
USMS	= Unsigned sum of all parameters
SMS	= Signed sum of all parameters

All measures in millimetres
When prefixed with "p," the absolute measure is expressed as a percentage of T_1NC.

Figure 2. Vector analysis: Right thoracic scoliosis, Cobb angle 61°, apex tenth thoracic vertebra.

T_1NC: 424.6; dX1: -4.1; dY1: 16.3; dZ1:-5.3; dX2: -3; dY2:20.2; dZ2:20.2; dX3:-11.4; dY3:7.3; dZ3:-4.7; USMS: 10.294; SMS: -4.7
pdX1: -1; pdY1: 3.8; pdZ1: -1.2; pdX2:-0.7; pdY2: 4.7; pdZ2: 4.8; pdX3: -2.7; pdY3: 1.7; pdZ3:-1.1; PUSMS: 2.432; PSMS: 0.926.

Other abbreviations as for Figure 1.

Tolerance limits were calculated as described by Remington and Schork[14], page 160. Data from the scans of 50 consecutive patients, without selection for diagnosis or age, undergoing routine topography from the spinal deformity clinic, were entered into SPSS format (Statistical package for the social services. Version 11.0.1). All scans were measured twice, in order of acquisition and then in alphabetical order. The measurements from the four repeat scans of each run were averaged automatically by the system and compared to give error margins. The tolerance limits of two measurements separated by time was calculated. The vector values from a group of 169 patients with adolescent idiopathic scoliosis were correlated with their Cobb angle, to demonstrate that an aspect of scoliosis was, in fact, being measured.

A standard technique for taking scans was used: the patient was positioned in the customised frame, standing erect with arms out from the sides until the backs of the hands were against the metal supports. Four consecutive scans (a, b, c and d) were taken, the patient stepping out of position and then resuming that position immediately. For clinical purposes, the results of these four scans are averaged, in order to reduce the tolerance limits of all parameters [9].

2. Results

2.1. Validation

There were 50 subjects, 16 males and 34 females. The diagnoses were: normal, 2; asymmetry, 7; adolescent idiopathic scoliosis, 9; infantile idiopathic scoliosis, 5; juvenile idiopathic scoliosis, 5; congenital scoliosis, 6; syndromic scoliosis, 15; juvenile kyphosis, 1. Mean age was 12.5 years, standard deviation (SD) ± 3.65, range 4.5 – 20.2. Table 1 shows the calculated tolerance limits: the upper row for each parameter gives 95% confidence that 90% of individuals will fall within the limit $\mu \pm k$ X SD, and the lower gives the same information for 95% of the population. The first column, c1 – c2, gives the tolerance for a single observer, the intra-observer error. Inter-observer error was not practicable, as there is currently only one operator of the system. The second column, b1–d1, includes the observer error but looks at the effect of positioning. The third column, 1abcd - 2abcd, using mean readings from four re-positioned scans, shows the margin reduced significantly. The final column, $abcd_1$ - $abcd_2$ gives the margin that must be allowed between scans that are taken on separate occasions with a real time interval between and is necessarily larger than the previous parameter.

Table 1. Tolerance limits for co-ordinates X, Y and Z at positions 1, 2 and 3 (Fig. 1)

Parameter	c1 - c2	b1 – d1	1abcd - 2abcd	$abcd_1$ - $abcd_2$
T_1NC 95%/90% **95%/95%**	12.38 14.76	18.23 21.73	9.76 11.64	13.81 16.46
dX1	4.16 4.96	8.45 10.07	3.06 3.65	4.33 5.16
dY1	6.06 7.22	9.14 10.90	2.98 3.55	4.2 5.02
dZ1	3.84 4.57	7.18 8.55	1.87 2.23	2.65 3.16
dX2	3.86 4.60	5.86 6.98	2.35 2.81	4.70 6.68
dY2	9.42 11.23	13.21 15.74	4.14 4.94	5.86 6.98
dZ2	2.64 3.14	5.99 7.16	1.38 1.65	1.96 2.33
dX3	4.73 5.63	6.46 7.70	2.92 3.48	4.13 4.92
dY3	3.75 4.47	6.75 8.05	2.34 2.79	3.32 3.95
dZ3	2.30 2.75	4.36 5.19	1.12 1.33	1.58 1.89
USMS	2.90 3.54	4.76 5.67	1.26 1.50	1.78 2.13
SMS	2.34 2.79	3.93 4.68	1.43 1.71	2.03 2.41

N=50, K = 1.996 for 95% confidence and 90% population (top row); K = 2.379 for 95% confidence and 95% population (lower row); Error on one reading = K X SD; Limit = $\mu \pm k$ * SD; Units: millimetres

Key:

1c – c2 = Tolerance limit: observer

b1 – d1 = Tolerance limit: positioning

1abcd – 2abcd = Tolerance limit: mean of four repositioned scans

$abcd_1$ - $abcd_2$ = Tolerance for two separate readings, $\sqrt{2}(abcd_1 - abcd_2)$ [10]

Other abbreviations as for Figure 1.

Table 2. Correlation of vectors with Cobb angle. N=169.

	Cobb	dX1	dY1	dZ1	dX2	dY2	dZ2	dX3	dY3	dZ3
Cobb:r **P**	1	-.345 ***	.351 ***	-.197 0.01	-.358 ***	.376 ***	-.043 .578	-.199 .009	.360 ***	-.253 .001
dX1:r **P**	-.345 ***	1	-.657 ***	.563 ***	.896 ***	-.696 ***	0.05 .517	.571 ***	-.545 ***	.549 ***
dY1:r **P**	.351 ***	-.657 ***	1	-.73 ***	-.661 ***	.937 ***	.133 .084	-.425 ***	.804 ***	-.589 ***
dZ1:r **P**	-.197 0.01	.563 ***	-.73 ***	1	.524 ***	-.735 ***	.135 .080	.367 ***	-.633 ***	.447 ***
dX2:r **P**	-.358 ***	.896 ***	-.661 ***	.524 ***	1	-.701 ***	.162 0.035	.550 ***	-.538 ***	.509 ***
dY2:r **P**	.376 ***	-.696 ***	-.937 ***	-.735 ***	-.701 ***	1	.197 .010	-.488 ***	.874 ***	-.637 ***
dZ2:r **P**	0.043 .578	.050 .517	.133 0.084	-.135 0.080	.162 0.035	.197 0.01	1	-.194 .012	.282 ***	-.197 .01
dX3:r **P**	-.199 .009	.571 ***	-.425 ***	.367 ***	.550 ***	-.488 ***	-.194 .012	1	-.422 ***	.573 ***
dY3:r **P**	.360 ***	-.545 ***	.804 ***	-.633 ***	-.538 ***	.874 ***	.282 ***	-.422 ***	1	-.673 ***
dZ3:r **P**	-.253 .001	.549 ***	-.589 ***	-.589 ***	.509 ***	-.637 ***	-.197 0.01	.573 ***	-.673 ***	1

Key: r = Pearson correlation coefficient. P = 2-tailed statistical significance*** signifies p<0.0001. All other p values given exactly. Other abbreviations as for Figure 1.

2.2. Correlation with Cobb angle

Correlations between Cobb angle and the new parameters are given in Table 2. There were 169 patients, 20 males and 149 females, all with a radiologically confirmed diagnosis of adolescent idiopathic scoliosis. Their mean age at diagnosis was 13.7 years ± 1.5142, range 10.4 – 19.0; mean Cobb angle was 50.3°± 21.243, range 10°-95°. All vectors correlated significantly (p = or <0.001) with the Cobb angle with the exception of the middle Z (antero-posterior dimension, lower thoracic level) although this did correlate ($p<0.05$) with all other middle and lower vectors. For the X and Y vectors, r^2 is in the region 0.12 to 0.14, and for the three Z vectors it is even lower (0.0 to 0.006) indicating that these measurements would not be suitable for Cobb angle estimation, but that was not their intention. They measure asymmetry of the back surface, permitting precise evaluation of the visible deformity and its change during evolution and treatment.

Discussion

The purpose of this new measure was not to replicate the Cobb angle but to describe back shape in quantitative terms. The original hope of surface topography, to achieve a radiation-free Cobb angle, cannot be achieved due to the nature of scoliosis: the deformity is not merely secondary to the spinal curvature and is not a simple mathematical expression of it. However, surface topography can detect change in body shape which will correlate with Cobb angle change [9] permitting adequate clinical monitoring of scoliosis, while reducing, and in minor cases eliminating, the use of radiography.

Conclusion

This new measure quantifies left-right asymmetry of the back, measuring the patient's complaint and her assessment of the effect of treatment. It augments the system's ability to monitor and document deformity, allowing a broader analysis of the problem with less exposure of growing children to ionising radiation. Its usefulness in clinical practice lies in the measurement of cosmesis and its change, and in quantifying the alterations wrought by corrective spinal surgery. Because the whole deformity of scoliosis is basically a loss of left-right symmetry, these vectors are being used to track and analyse the cosmetic deformity in different curve patterns during the evolution of their natural history, and to explore alternative hypotheses of aetiology.

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Quality of Life after Surgical Decompression of Lumbar Spinal Stenosis with and without Instrumentation

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Abstract. The aim is to evaluate the influence on quality of life of surgical decompression with and without instrumentation in lumbar spinal stenosis.
Twenty three patients, (16 women, 7 men) with a mean age of 62,8 years old (range 44-80) who underwent a surgical decompression for lumbar spinal stenosis filled the SF-36 questionnaire pre- and postoperatively, during the follow up period which was at a mean value of 42 months (range 6 to 50 months). Spinal stenosis was degenerative in 18 patients and as a consequence of spondylolisthisis in 5. In 15 patients decompression and fusion using instrumentation (group I) was performed and in 8 patients only decompression was performed (group II). Statistical analysis was carried out using the Wilcoxon Signed Rank Test.
In group I, the domains that evidenced statistical significant improvement were bodily pain ($p<0,041$), general health ($p<0,042$), vitality ($p<0,042$), social functioning ($p<0,043$), and mental health ($p<0,042$). Not any specific domain in group II showed a statistical significant improvement postoperatively. Comparing the two groups overall SF-36 score, a statistical significant improvement was noted for group I ($p<0,001$) and for group II ($p<0,017$). The statistical significance of improvement was stronger in patients of group I than group II.
Surgical decompression for lumbar spinal stenosis reduces pain and restores significantly physical and mental health. Decompression and instrumentation presents superior results in patients' quality of life when compared to patients that single decompression was performed.

Keywords. Lumbar spinal stenosis, surgical decompression, instrumentation, quality of life, SF 36

Introduction

The use of spine fusion techniques for degenerative spinal diseases has increased dramatically in the recent years. Spine surgeons now have superior diagnostic tools, better understanding of the structural causes of lumbar spinal stenosis (LSS) and realize the dangers of introducing instability after wide decompression for severe LSS and they have vastly improved surgical techniques for fusion [1-7].
The value of performing spine fusion surgery for degenerative conditions has been questioned recently [8]. Some authors have also questioned the addition of instrumentation in improving the fusion rate or the clinical outcome in patients with

degenerative spinal disorders [9, 10].
A controversy in effectiveness, the raised cost and the patients' assumption for better quality in health care resulted in the recent focusing of medical care in evidence-based practise [11]. Traditionally, evaluation was performed by retrospective analysis of anatomical, biological or physiological measures, radiographs or various non-validated functional scales, or from factors that were determined at first by the physician. In the recent years, there is a tendency to evaluate the results with more flexible methods on the basis of measured outcomes that are reported by the patient, such as the symptoms, the daily activities and the general perception about health. The term health-related quality of life (HRQoL) has been introduced, as a multidimensional construct which refers to the physical, psychological and social dimensions of health.
LSS affects mainly middle aged people and may cause severe and chronic symptoms and functional impairment of lower back the lower limbs. These neurologic deficits may greatly impair the HRQoL of patients [12]. In LSS patients, clinical, neuroradiological and neurophysiological findings were not related to validated measurements of the outcomes that are more relevant to patients such as functional status and symptoms [12].
We performed a retrospective study using the Short Form-36 Health Survey questionnaire (SF-36), in order to evaluate the influence on HRQoL of surgical decompression with and without instrumentation for LSS.

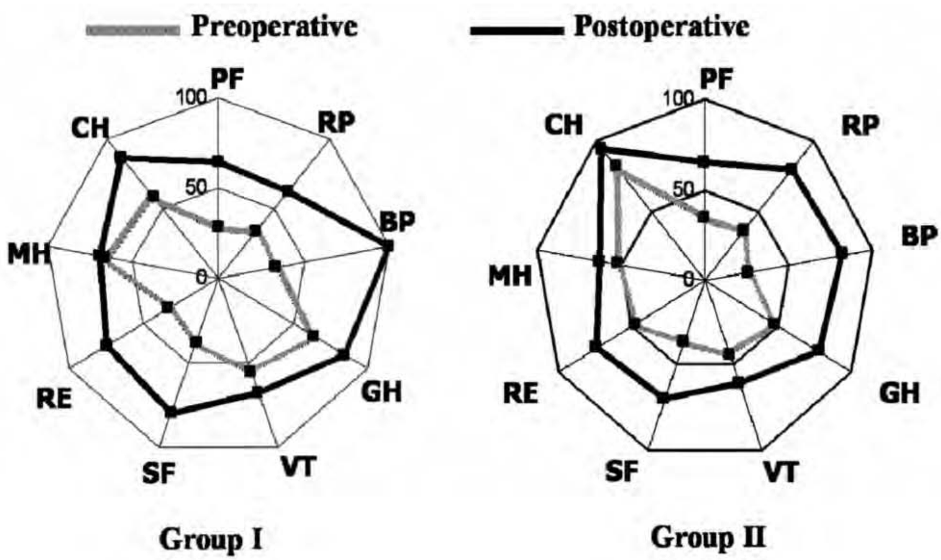
Material-Method

Twenty three patients, 16 women and 7 men with a mean age of 62.8 years old (range 44-80) were included in the study. All patients suffered low back pain and neurogenic claudication due to severe LSS. In 18 patients the LSS was degenerative and in 5 as a consequence of spondylolisthisis. All the 23 patients underwent surgical decompression and fusion through a posterior approach. The patients were divided into two groups according to the use of instrumentation or not. Fusion with the use of instrumentation was applied in 15 patients (group I) and fusion alone was applied in the remaining 8 patients (group II).
All the patients filled the SF-36 form pre- and postoperatively, during the follow up period which was at a mean value of 42 months (range 6 to 50 months).
Statistical analysis was performed by using the SPSS v.11 package. The comparison of outcome measurements pre- and postoperatively was assessed by means of Wilcoxon Signed Rank Test. Throughout the statistical analysis the significance level was set at 0.05.

Results

The pre- and postoperatively scores of the SF-36 domains in the two groups are shown in **Figure 1**.

Figure 1. The mean pre- and postoperative score of the SF-36 domains in group I and II. PF=Physical Functioning, RP=Role-Physical, BP=Bodily Pain, GH=General Health, VT=Vitality, SF=Social Functioning, RE=Role-Emotional, MH=Mental Health, CH=Change Health



In group I, the domains that evidenced statistical significant improvement were bodily pain (p<0,041), general health (p<0,042), vitality (p<0,042), social functioning (p<0,043), and mental health (p<0,042). Not any specific domain in group II showed a statistical significant improvement postoperatively **Table 1.** Comparing the two groups overall SF-36 score, a statistical significant improvement (p<0,001) was noted both for group I and for group II (p<0,017).

Table 1. Comparison between pre- and postoperatively SF 36 domain scores (p value). * statistical significant.

SF 36 domain	Group I	Group II
Physical Functioning	p<0,138	p<0,109
Role-Physical	p<0,102	p<0,180
Bodily Pain	p<0,041*	p<0,109
General Health	p<0,042*	p<0,109
Vitality	p<0,042*	p<0,414
Social Functioning	p<0,043*	p<0,180
Role-Emotional	p<0,317	p<0,180
Mental Health	p<0,042*	p<1,000
Change Health	p<0,180	p<0,317

Discussion

Spinal fusion rates have increased in the recent yeas mainly as a result from a rise in surgeries in elder people with LSS. Fusion with or without instrumentation is a rather controversial issue. With respect to fusion for LSS as well as other clinical conditions for which surgical fusion has been utilized, there is an acknowledged shortage of consistent and high quality scientific evidence. There are limits to evidence based practice in surgery that have been part of a wider discussion in the literature [13, 14, 15]. Specifically, there are an insufficient number of prospective randomized controlled trials upon which to base the decision of instrumented fusion or not. The absence of evidence based proof does not always mean the absence of "benefit" for the patients.

Fusion with instrumentation, in most studies, shows approximately equivalent results with regard to subjective clinical outcome when compared to fusion alone [5]. While instrumented fusion may not always lead to improved subjective outcomes over non-instrumented fusions, it has a significant advantage with regard to fusion rates [6].

All the 23 patients in the present study were improved in most parameters tested, regarding their HRQoL as it was measured by the SF 36 health survey overall score.

By analysing the results in group I, the most compromised SF-36 domains were role-physical and physical function which measure the difficulty in every-day activities due to physical problems. These two domains were improved, but not statistically significant. Conversely, a statistically significant improvement was noted for the domains that measure bodily pain, vitality, social functioning and mental health. In group II, a non-statistically significant improvement was evidenced in all the examined domains, even though the overall SF 36 postoperative score was statistically significant compared with the preoperative one.

With regard to the HRQoL at follow up evaluation, our data showed a mild impairment of physical aspects of HRQoL, as measured by patient oriented evaluation.

Comparing the two groups overall SF-36 score, a statistical significant improvement was noted both for group I ($p<0,001$) and for group II ($p<0,017$). The statistical significance of improvement was stronger in patients of group I than group II.

Surgical decompression for LSS reduces pain and restores significantly physical and mental health. In conclusion, decompression and instrumentation presents superior results in patients' HRQoL when compared to patients in whom single decompression was performed.

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Consequence of Paraspinal Muscle after Spinal Fusion: An Experimental Study

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Abstract. Posterior lumbar spinal fusion is a common surgery of spine. The parapsinal muscular dysfunction was postulated to be due to injured paraspinal muscle inflicted by the surgery. To better understand the muscle dysfunction after spinal fusion, this descriptive study evaluated electrophysiology and histology changes in paraspinal muscle of rabbits with and without fusion. Three New Zealand white rabbits underwent 2-level posterior spinal fusion with instrumentation. Anothor 3 rabbits underwent surgical exposure alone and served as sham control. Pre-operative and follow-up electromyography (EMG) and histological assessment were performed in a 6-month interval. All fusion achieved solid union judged by post-mortem examination. Root mean square (RMS) of EMG showed decrease in both fusion and control group immediately after surgery, but the control group recovered to pre-operative value at 6 months follow-up. At 6 months after operation, the fusion group showed lower RMS in fused region than adjacent region. In term of median frequency (MF) changes, the control group did not show obvious difference between pre- and post-operative period. However, fusion group showed obvious decrease of MF in fusion region, but increase in lower adjacent region. Histology reviewed fatty infiltration in fusion region at 6 months after spinal fusion. In addition, the muscle fiber size presented smaller in fusion region than that of pre-operative status. These results would demonstrate the lower activities and muscle disuse atrophy of paraspinal muscles in the fusion region. While, higher muscular activities were found in the lower adjacent region, which may indicate muscle hypertrophy.

Keywords. Spinal fusion, muscle atrophy, electromyography, muscle fibre size

Introduction

The surgical correction followed with instrumented and non-instrumented spinal fusion is the main treatment strategy for patients with spinal deformity[1]. However, previous studies have noted incidences of developing pseudarthrosis, low back pain, spinal stiffness and instability following spinal fusion[2-5]. Up to 34% of fused spine might have herniated nucleus pulposus [6]. Changes were also noted over the paraspinal muscle after surgery, including loss in muscle thickness on ultrasonography, [7] edematous and fatty change on magnetic resonance imaging[8] and lower muscle potential on electromyography [9]. It was hypothesised that spinal fusion leads to muscle atrophy due to denervation and disuse over fused segments. In addition, hypertrophy occurs over adjacent segments due to junctional effect.

The purpose of this study is to compare the changes in paraspinal muscle between pre- and post-operation of spinal fusion in an animal model. Presence of paraspinal muscle changes would be assessed by electromyography and histology. This study aimed to document the presence of atrophy and hypertrophy of paraspinal muscle.

1. Material and Method

1.1. Animals and Surgical Technique

Three New Zealand white rabbits were received posterior spinal fusion (fusion group) and the remaining three rabbits underwent exploration without fusion (sham control group). Both groups were cared by the same manner before and after the procedure.

For the fusion group, their spinous processes of L2 to L6 were removed. The spine was then instrumented with a 5-hole 3.5mm DC plate (Syntec Scientific Corporation, Chang Hua, Taiwan) transfixing to transverse processes of L3 to L5 by 3o ethibond. Removed bone was cut lengthwise with mayo scissor to be placed on the decorticated area. For the control group, the surgical exposure was followed by layered closure.

1.2. Electromyography (EMG) Test

Raw signal acquisition based on a self-developed high-impedence, low-noise-differential EMG-amplifier. EMG signals were amplified with gain of 2000 and a band-pass filter between 20 and 1000 Hz. The signals were digitised with a data acquisition card (DAQcard-1200, National Instruments Co. Texas, US) at 12-bit resolution and sampling rate of 2 kHz.

Ground needle electrode was inserted over the auricle. Stimuli electrodes were placed in the midline at L1. EMG was recorded through paired bipolar needle electrodes spaced transversely 2 cm apart. Three pairs of needle electrode were inserted at L2, L4 and L6 level determined by manual palpation.

EMG was recorded immediately before operation and six months after operation. Root Mean Square (RMS) and median frequency (MF) values were calculated.

1.3. Histopathology

During the index operation, a small amount (less than one gram) of para-spinal muscle specimen was collected longitudinally at over L2, L4 and L6 level under aseptic technique. Open muscle biopsies over these levels were repeated after executing euthanasia at the sixth month after the operation. With standard haematoxylin and eosin (H&E) staining, the size of myofibrils can be measured by a micrometer (Leica DMLB, Leica Microsystems, Wetzlar, Germany).

2. Results

2.1. Assessment of Fusion

After harvesting muscle specimen for analysis, motion over the fused segment was assessed before and after the removal of the implant. It was then graded as solid fusion, stiff and un-fused. Only level graded as solid was considered fused [10,11]. The L3 to L5 lumbar spine was then harvested with its ligament preserved. Pins were inserted perpendicularly to the end plates. The segment was stressed and the change of angle incurred by the pins represented the angle of motion. For the fused spines, none of them had more than 10-degree range of motion. All 3 animals in spinal fusion group were assessed as solid fusion.

2.2. Electromyography

Figure 1 showed the changes in EMG parameter between pre-operation and 6-month post-operation in control group. At the sixth month after surgery, the muscle activity returned to the original level of pre-operative status.

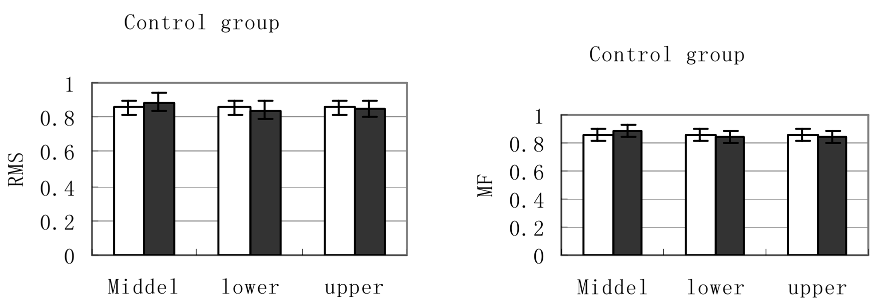

Figure 1. EMG parameters in control group at pre- (white block) and post-operative tests(black block). Bars in white represent pre-operative test, while bars in grey represent post-operative test.

In contrary to the control group, the fusion group showed different sequence pattern in EMG activities (figure 2). After spinal fusion, the paraspinal muscle showed lower RMS and MF in the fused region than that of pre-operative test. In addition, RMS and MF of EMG recorded from adjacent regions of paraspinal muscle showed increase trend in post-operative test in comparison with that of pre-operative test.

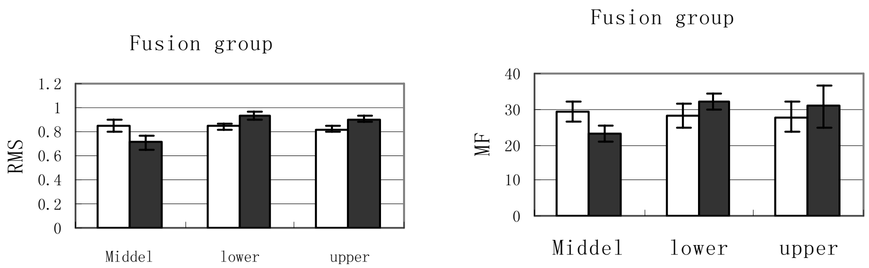

Figure 2. EMG parameters in spinal fusion group at pre- (white block) and post-operative (black block) tests. Bars in white represent pre-operative test, while bars in grey represent post-operative test.

2.3. Histology

In control group, different degrees of shrinkage were observed despite tissue processing technique remained the same. Post-operative specimens showed no significant trophic change with respect to pre-operative samples and sites of biopsy. The mean lesser diameter fibre did not change a lot between pre-operative and post-operative specimens (Figure 3).

In fusion group, the fibre size was dramatically decreased in the fused region in comparison with pre-operative examination (Figure 3). In the contrary, muscle fibre size increased in adjacent lower region after spinal fusion. However, due to the small sample size, a statistically significant difference could not be established. In addition, there was an universal finding of fatty infiltration outside and inside the muscle bundles in fused regions.

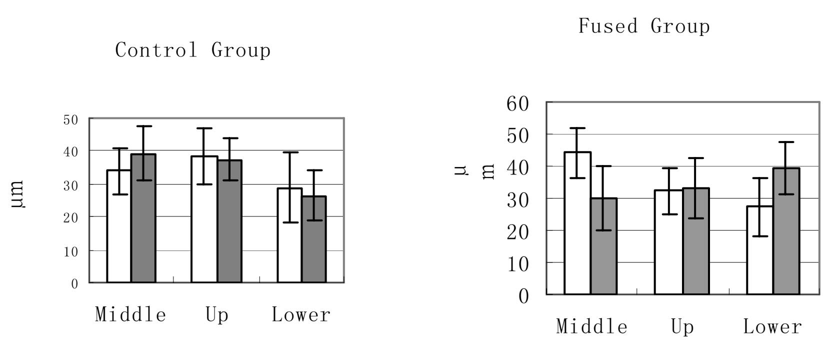

Figure 3. Mean lesser diameter of the multifidus muscle fibers with respect to different groups and sites at pre- (white block) and post-operative (black block). Error lines represent the standard error of mean.

Discussion

Spinal fusion has been widely used in surgical correction of spinal deformities. Previous long-term follow-up studies have reported adjacent disc degeneration syndrome after spine fusion [6,12,13]. The good understanding of the paraspinal muscle dysfunction after fusion will assist selection of surgical approach and post-operative rehabilitation protocol [14]. In this study, an experimental study was carried out to investigate the changes of paraspinal muscle function in order to verify the hypothesis on the above complications following spinal fusion.

In this study, an animal model of spinal fusion was developed in New Zealand white rabbit. With this animal model, we aimed to document the presence of atrophy and hypertrophy of paraspinal muscle. In muscle atrophy, a reduction in average muscle fiber cross-sectional area results in a reduction of EMG signal conduction velocity along the sarcolemma [15,16]. Presence of paraspinal muscle trophic change would be assessed by electromyography and histology. Atrophy would be reflected in EMG analysis by a decrease in RMS [17] and spectral shift to lower MF [18] in electromyography (EMG) and vice versa for hypertrophy. The results of this study, lower RMS and MF was found in fused region of spinal fusion group, which indicated the effect of muscle atrophy. In addition, the changes of RMS and MF in EMG of adjacent region might indicate the muscle hypertrophy.

In consistent with electrophysiological results, the histology study also showed atrophic features in fusion group. The muscle fibre in the fused region showed smaller average diameter than original fibre size, which indicate the decrease in muscle fiber cross-sectional area. Studies using animal models have demonstrated smaller average muscle fiber crosssectional area in atrophied muscles than in healthy muscle, which support the findings in this study. Previous studies also showed a linear relationship between MF and average muscle fiber crosssectional area [15,16]. The finding in fusion group presented the same pattern as Kupa's study, that paraspinal muscles in the spinal fusion region were measured smaller fibre diameter and lower EMG activity. These results proved the muscle atrophy in the spinal fusion region and muscle hypertrophy in adjacent regions.

Conclusion

These results would demonstrate the lower activities and muscle disuse atrophy of paraspinal muscles in the fusion region. While, higher muscular activities were found in the lower adjacent region, which may indicate muscle hypertrophy. These results would demonstrate the lower activities and muscle disuse atrophy of paraspinal muscles in the fusion region. While, higher muscular activities were found in the lower adjacent region, which may indicate muscle hypertrophy. The physiotherapist should take this possibility into consideration, and include this in forming the rehabilitation plan for patients after spinal fusion.

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The Development of Osteoblasts from Stem Cells to Supplement Fusion of the Spine During Surgery for AIS

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Abstract. Surgical correction in severe cases of AIS is often hampered by insufficient autograft bone to facilitate the fusion. The development of other sources of bone generating cells would greatly enhance the surgical. Bone marrow derived stem cells were harvested from femoral reaming during total hip arthroplasty for the purpose of differentiating into osteoblasts. Stem cells were isolated from the marrow and successfully differentiated into three cell lines (osteoblasts, chondrocytes and adipocytes) to confirm multilineage potential. Osteoblasts were developed from the stem cells and demonstrated the ability to be cultured to possibly provide a source of bone generating cells to augment surgical fusions. It is anticipated that the addition of osteoblasts created from stem cells (combined with appropriate matrix) will have significant influence on the success of AIS surgery through improvement of bone fusion.

Keywords. Adolescent idiopathic scoliosis, surgery, stem cells, osteoblasts

Introduction

Adolescent idiopathic scoliosis (AIS) is represented as an abnormal curvature of the spine with unknown aetiology. Most commonly, AIS occurs in children under the age of 16 years with an incidence of 1-2 % in the general population. Typically, the clinical course for AIS shows a progressive lateral curvature of the spine that becomes aggressive when the patient enters adolescence. Extreme cases (>45-50° Cobb angle) are usually treated by deformity correction, spinal instrumentation and bone fusion of the curved segment.

Successful surgical correction of AIS requires a stable bone fusion of the involved segmental spine to prevent progression of the deformity and improve the long-term prognosis for the patient. Iliac crest autograft has long been the "gold standard" for bone graft material. However, this graft is associated with increased morbidities and has important limitations. Morbidities include excessive blood loss, pain, scarring, and deformity at the harvest site. A major limitation is the amount of graft available. Since most patients with AIS are children and spinal deformation involves several segments of the spinal vertebrae, iliac crest autografts frequently provide insufficient bone for successful fusions. For these reasons, there is intense interest in developing alternative bone generating materials for spinal fusion to facilitate more rapid and robust bone fusion with less morbidity.

In recent years, tissue engineering approaches have been used to enhance bone healing and fusion. This has involved the use of synthetic matrices, supplementary cells and bioactive molecules or minerals [5, 6, 7,11,12,13,14,15]. Some of these biomaterials have been used successfully in the clinic for treatment of bone defects and as delivery systems for osteogenic substances.

Bone marrow-derived mesenchymal stem cells (BMSCs) appear to be an attractive source for autologous bone-forming cells in bone tissue engineering. BMSCs can be isolated from small volumes of aspirated bone marrow and expanded to a relatively large population *ex vivo* using cell culture techniques.[8] BMSCs represent a phenotypically and functionally heterogeneous population of mesenchymal stem cells which contribute to multiple lines of haemopoietic cells, bone, cartilage, adipocytes, myocytes and other cells in connective tissues.[9,10]. It is anticipated that a combination of BMSC-derived osteogenic cells with appropriate biomaterials could prove a novel alternative to bone graft by providing osteoconduction and osteoinduction capabilities. The use of autologous BMSCs combined with synthetic biomaterials would overcome the immunogenecity of allogenic bone grafts and make this approach far more attractive for a wider clinical application.

While the ultimate goal is to develop a means by which BMSCs accompanied by an appropriate matrix can be introduced to the site of surgery during a spine fusion to aid in healing (for example, during instrumentation for AIS), this project focuses on the acquiring, isolation, expansion and characterization of BMSCs from femoral reaming as a first step.

Methods

Isolation and Expansion of hMSCs

Intramedullary reamings were collected from patients undergoing total hip arthroplasty. Cells were isolated from the reamings using a 100µm cell strainer (BD Falcon) in the presence of heparin. The bone chips were washed with warm PBS (Ca^{++} and Mg^{++} free) and the liquid phase of the wash was again passed through the cell strainer and collected. The bone chips were treated with 0.05% trypsin and 0.1% EDTA solution prepared in PBS and incubated for 5 minutes at 37°C. The suspension was passed through the cell strainer, the liquid portion collected and the bone chips discarded. Density gradient centrifugation utilizing Histopaque-1077 (Sigma) was employed to separate samples. The fraction at the plasma-Histopaque interface was collected. Viability was assessed and the cells were plated to a density of 6000 cells/cm^2 in monolayer culture with DMEM plus 10% FBS and 5ng/ml FGF2 at 37°C and 5% CO_2.

Immunophenotyping by Flow Cytometry

Cell surface antigens from passage 3 cells were analyzed with flow cytometry. Cells were fixed with cold 1% formaldehyde, washed with PBS, and then stained with the primary antibodies outlined in Table 1. The cell population was analyzed on the FACS Calibur (BD Biosciences, Mississauga, Ontario) using Cell Quest Pro software and compared to the isotype control.

MSC Differentiation

For osteogenic differentiation cells were allowed to become 70% confluent and treated with osteogenic selective medium (R&D Systems) according to the manufacturer's specifications. For adipogenic differentiation cells were grown to 95% confluence and treated with adipogenic selective medium (R&D Systems). For chondrogenic differentiation cells were encapsulated in alginate beads .[16] The beads were placed in a 100mm culture dish with 15ml of Chondrocyte Differentiation Medium (CDM; Cambrex) at 37°C and 5% CO_2. The medium in all cases was changed every 3-4 days for 21days. Following differentiation the cells were plated in monolayer culture in CGM at 37°C and 5% CO_2 in preparation for subsequent analysis.

Immunofluorescence (IF) and Histology

IF for the adipogenic and osteogenic lines was carried out as per the manufacturer's protocol utilizing primary antibodies to fatty acid binding protein 4 (FABP4; R&D) and osteocalcin (R&D) respectively. For IF of the chondrogenic line, cells were fixed with 100% MeOH and blocked with 5% milk in PBS. Primary antibody consisting of either a 1:100 dilution of Anti-Collagen Type II IgG (Calbiochem) or a 1:25 dilution of Anti-hAggrecan (R&D Systems) was utilized. Secondary antibodies included a 1:100 dilution of CY-3 conjugated goat anti-rabbit IgG (Jackson Immunoresearch) and a 1:100 solution of Alexa Fluor anti-sheep IgG (Molecular Probes) for the collagen and aggrecan treatments respectively. Slides were mounted with aqueous mounting medium (R&D Systems). Negative controls consisted of cell preparations incubated without primary antibody. For histological assessment, differentiated tissues were stained directly on the tissue culture surface. For the adipogenic line Oil red O (ORO; Sigma) was employed to detect the intracellular lipid droplets .[17] The osteogenic line was stained for mineralization with Alizarin Red .[17] Osteogenic cells were then stained for alkaline phosphatase with the Sigma Alkaline Phosphatase Kit according to the manufacturers specifications.

RNA Isolation and Real Time Polymerase Chain Reaction (RT-PCR)

RNA was extracted from the chondrogenic cell line and the undifferentiated MSC control utilizing the SV Total RNA Isolation System (Promega). cDNA was generated with the Superscript III 1st-strand synthesis system (Invitrogen) according to the manufacturers specifications. The reagents for the RT-PCR were taken from the QuantiTect SYBR Green PCR kit (Qiagen). Primers utilized are recorded in Table 2. Quantification and analysis for each of the reactions was carried out utilizing the MYiQ single-color real-time PCR detection system (BioRad). The PCR conditions were as follows: 94°C for 15 seconds, annealing (GAPDH and Aggrecan 60°C; Collagen I and II 58°C) for 20 seconds, and 72°C for 10 seconds for 45 cycles.

Results

Isolation, Expansion and Characterization of Cell Isolates

Within 5 days following application of cells to the culture dishes, adherent fibroblast-like cells were observed and confluency was achieved by 14-21 days. Cells were detached with 0.25% trypsin-EDTA (Gibco) treatment, split 1:2 and in subsequent passages the cells rapidly became confluent within 7 days. Cell surface antigens on the adherent fibroblast-like cells were analyzed by flow cytometry. It was noted that these cells did not express CD45 or GlycoA making a hematopoietic origin less likely. The cells did express CD13, CD29, CD44, CD54, CD90, and CD105 cell surface antigens, consistent with a MSC immunophenotype.

In Vitro Differentiation into Adipocytes, Osteocytes and Chondrocytes

Osteogenic differentiation was successful when attempted on passage 3 cells utilizing osteogenic selective medium. After 21 days the cells demonstrated a distinct increase in monolayer density, forming a lattice like appearance. Tissue harvested at this time demonstrated evidence of both ALP and mineralization as demonstrated by Alizarin Red staining. IF for osteocalcin was also positive.

Adipogenic differentiation was also performed on passage 3 cells using adipogenic selective medium. During differentiation lipid droplets were evident after 7 days in a portion of the cells and this number increased as the cells were cultured up to 21 days. At this time the lipid inclusions stained positive with ORO and IF demonstrated the presence of FABP4 .

Chondrogenic differentiation was successful with MSCs at passage 3. Differentiated cells were removed from the three dimensional alginate environment and IF for collagen II in monolayer culture was positive while IF for aggrecan was only weakly positive. Real time PCR revealed an increase in Collagen II transcription compared to the pre-differentiated MSC population. There was negligible change in expression of GAPDH, a housekeeping gene, which was used as a standard. Both collagen I and aggrecan also demonstrated little change in expression when comparing the two cell populations. This was expected in the collagen I population but largely unexpected for aggrecan. This is likely due to the relatively short differentiation time of 3 weeks and it is hypothesized that as the differentiation time is increased increases in aggrecan upregulation will also be seen. The marked increase in collagen II production indicates expression of a chondrogenic phenotype.

Discussion

In the present study the *in vitro* isolation of MSCs from femoral intramedullary reamings collected intraoperatively is reported. Cells were separated using density gradient centrifugation and selected based on their ability to adhere in monolayer culture and rapidly expand in the presence of serum. These cells expressed the surface antigens CD13, CD29, CD44, CD54, CD90, and CD105 which are characteristic of a MSC immunophenotype. The cells did not possess the cell surface antigens CD45 and

GlycoA which are characteristic of cells from a hematopoeic lineage. However, the immunophenotype alone is not sufficient to define a MSC population. Therefore, the multilineage potential of the cell population through differentiation toward mesodermal lineages was established. Osteoblasts, adipocytes, and chondrocytes from passage 3 of the MSC population were successfully derived and their phenotypes confirmed with cell stains, fluorescent antibodies and RT-PCR.

Mesenchymal stem cells represent an easily acquired autologous cell source capable of being differentiated into a variety of different mesodermal lineages. The study demonstrates the ability to use femoral reamings to isolate, expand, and characterize successfully MSCs that can provide cells for future research. This is a necessary first step toward the final goal, which is the development of autologous osteogenic synthetic tissue to supplement spinal fusion.

Table 1. Antibodies for characterization of cell surface antigens.

Anti-Human	Dilution	Fluorochrome	Source
CD13	3/50	PE-Cy5	Caltag Laboratories
CD29	3/50	PE-CY5	Caltag Laboratories
CD44	1/10	Fluorosciene isothiocyanate (FITC)	Santa Cruz Biotechnologies
CD45	3/50	Phycoerythrin(PE)	Caltag Laboratories
CD54	1/50	FITC	Caltag Laboratories
CD90	1/50	PE	BD Biosciences
CD105	3/50	PE	Caltag Laboratories

Table 2. Primers for RT-PCR..

Gene	Size (bp)	Strand	Sequence(5´-3´)
CollagenII	257	F	GACAATCTGGCTCCCAAC
		R	ACAGTCTTGCCCCACTTAC
Collagen I	105	F	AGGTGCTGATGGCTCTCCT
		R	GGACCACTTTCACCCTTGT
Aggrecan	85	F	TCGAGGACAGCGAGGCC
		R	TCGAGGGTGTAGCGTGTAGAGA
GAPDH	189	F	TGGTATCGTGGAAGGACTCATGAC
		R	ATGCCAGTGAGCTTCCCGTTCAGC

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Recent Observations in the Biomechanical Etiology of so-called Idiopathic Scoliosis. New classification of Spinal Deformity – I-st, II-nd and III-rd Etiopathological Groups

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Abstract. The article examines the biomechanical etiology of so-called idiopathic scoliosis (AIS). It describes I-st, II-nd and III-rd etiopathological groups (epg) of spine deformity which were developed during the years 2001/2004/2005. All children with so-called idiopathic scoliosis had an abduction contracture of the right hip, often connected with a flexion and external rotation contracture. In other cases we found only limited range of adduction of the right hip in comparison to the left hip. We maintain that children with this real abduction contracture of the right hip constitute the first etiopathological group of the development of scoliosis (I-st epg). This group has an "S" double shaped scoliosis with the rib hump on the right. Other patients, with only limited adduction of right hip in comparison to the left hip, constitute the second etiopathological group of development of scoliosis (II-nd epg). This group has a "C" shaped lumbar, sacro-lumbar or lumbo-thoracic left convex scoliosis. The third etiopathological group (III-rd epg) shows either no or a minimal curve on X-ray with either no rib hump or a very minor one but have a "stiffness of spine". Such patients have problems with sporting activities and, as adults, the spinal stiffness leads to considerable "back pain". The right hip structural abduction contracture, or the differences in adduction, is connected with the "syndrome of contractures" in neonates and babies described by many authors and in depth by Mau. How does scoliosis develop? Our explanation is as follows. Asymmetry of movement of the hips during gait provokes asymmetry of loading and asymmetry of growth of both sides – left and right - and the gradual development of scoliosis. In I-st epg, the scoliosis is a secondary compensation for deformities in the pelvis and spine. The II-nd epg is linked to a permanent standing posture maintained on a free right leg during the first years of life. The III-rd epg comprises of patients from the boarder groups of I-st and II-nd epg. This classification establishes a clear therapeutic approach to every etiopathological group of scoliosis and allows for the possibility of introduction of causative prophylaxis.

Key words. so-called idiopathic scoliosis, etiology, classification, three etiopathological groups

Introduction

The biomechanical etiology of so-called idiopathic scoliosis (AIS) is based on asymmetry of movements of left and right hips and results in asymmetry of loading during gait, leading to asymmetry of growth between the left and right side of the body. In children with so-called idiopathic scoliosis, there is an abduction contracture of the right hip, often associated with co-existing flexion and external rotation contractures. In other cases there may only be asymmetry of movement, suggesting a smaller adduction of the right hip in comparison to the left hip. This asymmetry of movements is linked to the "syndrome of contractures" in neonates and babies [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15]

1. Material

The sample population comprised of 1450 patients with scoliosis, examined for spinal problems over a period of 25 years (1980 – 2005). 364 of the patients constituted a control group. In this control group, the adduction of both hips was symmetrical and the axis of spine was normal. In the studied material there were patients from I-st, II-nd and III-rd group of scoliosis (described later: see paragraph 4). The patients were followed for a period of 1 to 10 years and the age distribution was from 3 to 21 years with the largest group being made up with children from 6 to 14 years. Distribution within the three groups was: I epg group: 593 (41 %) children, II epg group: 333 (23 %) children, III epg group: 131 (9 %) patients, a mix of young adults and adults. 29 cases had congenital scoliosis (2%). About 20% of patients displayed radiological evidence of *spina bifida oculta* and occasionally *pectus infundibuliforme*. 3% displayed mild minimal brain damage symptoms (MBD). At 10% of patients had a family history of scoliosis with mothers of 2% of cases being previously treated for scoliosis.

2. "Syndrome of Contractures" of Newborns and Babies. Information about Conjunction with the so-called Idiopathic Scoliosis

The "syndrome of contractures" in neonates and babies has been previously described by Mau [1, 2] (his original description - "Siebener (Kontrakturen) Syndrom") and can be related to many early and late disorders and dysfunctions of the skeletal system. In scoliotic patients, a range of tissues are contracted and shortened in the region of the right hip. Thesed include the iliotibial tract, fascia lata, fascia of gluteus medius, fascia of gluteus minimus, sartorius, rectus and the capsule of the right hip joint. Many authors report clinical and radiological changes in the pelvic and hip regions which confirms the biomechanical theory of so-called idiopathic scoliosis [14, 27, 28, 29, 30, 31].

3. Three Etiopathological Groups of Development of Scoliosis (I-st, II-nd and III-rd)

3.1. I-st Etiopathological Group of Scoliosis

["S" deformity = double curve scoliosis]. [Fig. 1a, 1b]

1. In these children, a real abduction contracture of the right hip of 5-10 degrees is present but no adduction deformity. Left hip adduction has a large range from 35-40-45 degrees when examined in an extension position. The causative factor in development of this type of scoliosis is connected with gait.
2. Pathological influence is connected with gait but additionally with a free standing position solely on the right leg and can last for many years.
3. Onset of scoliosis in small children (3-4 years) commences as a rotational deformity, confirmed by computer gait analysis [51].
4. In the "3D deformity of the "S" shaped scoliosis", the rotational deformity of spine is accompanied by a "stiffness of the spine" and diminishing of lumbar lordosis and thoracic kyphosis and at later stages, even a "lordotic deformity of thoracic spine".
5. As result of the rotational deformity, the spine becomes stiff with a "flat back". Here, three stages of deformity follow, connected with severity of deformity and the time of its onset and age: a) disappearence of the spinous processes (*Karski*) during the forward "bending test" (*Adams, Meyer*) or side bending test to the left and right leg (*Karski*), b) flat back – hypolordosis lumbalis, hypokyphosis thoracalis during flexion examination (*Vlach, Palacios-Carvajal*), c) lordotic deformity in the thoracic spine during examination in flexion (*Adams, Meyer, Tomaschewski & Popp and others*).
6. Development of the rib hump on the right side (*gibbous costalis*).
7. Progression in the majority of children, especially in periods of accelerated growth.

Figure 1a and 1b. Examples of "S" shaped double scoliosis. I-st etiopathological group of scoliosis (view from the back on both X-ray pictures). Two girls – history numbers: 970317 (8 years old) and 980108 (7 years old). At girl (980108) larger scoliosis because the patient performed wrong.

3.2. II-nd Etiopathological Group of Scoliosis

("C" left convex scoliosis - lumbar or lumbo-sacral or lumbo-thoracic) [Fig. 2a, 2b].

1. In these children, there is only limited adduction of the right hip in comparison the left side (range of adduction of the right side 10-25 degrees, adduction of the left side 35-50 degrees when examinated in an extension position of the hip joint).
2. Firstly, a physiological side movement of spine to the left by "standing position on the right leg" is observed, followed by gradual development and fixation of a "C" shaped spinal curve, associated with clinical symptoms and changes of the spinal axis on the radiograph in older children (age 10-14 years).
3. Pathological influence is associated only with a permanent habit of standing "at free" on the right leg over many years. This commences when the child commences standing and the scoliosis becomes clearly visible when the child is over 10 years old.
4. There is lumbar or lumbo-sacral or lumbo-thoracic left convex scoliosis.
5. This is not a "paralytic scoliosis" as described by many authors [46]. It is also not "degenerative scoliosis" as thought some others authors [Weinsteina; SICOT 2005 Istanbul]. In patients with "spondyloarthrosis", the scoliosis occurs first with degenerative changes following.
6. Occasionally, and only in some cases, compensatory right convex thoracic scoliosis develops in children "on the border" of both groups.
7. These patients mainly have either no rotation deformity or a very small one and usually have either a small or no rib hump.
8. These patients are have minor or no curve progression but develop pain (*spondyloarthrosis lumbalis, lumbago, ischias*) as adults.

Figure 2a and 2b. Example of "C" shaped left sacro-lumbar scoliosis and "C" shaped left lumbar scoliosis (view from the back on both X-ray pictures). Two girls – history numbers: 940121 (11 years old) and 901112 (15 years old). II-nd etiopathological group of scoliosis. Both girls had a habit to stand "on free" only on right leg for all years.

3.3. III-rd Etiopathological Group of Scoliosis

Border between I-st and II-nd group – "scoliosis without curves".

How does this type of scoliosis develop? The main symptom in this group is the "stiffness of spine". As described in I-st epg of scoliosis, the first stage of this group is the rotation deformity, which causes stiffness of spine. In these patients progression ceases (!) because of changes in "life style activities" in adolescence ie practicing more active sports particularly special kinds of sports (karate, taekwon do, kung-fu, aikido, tai chi, judo, yoga), changes in the standing position – more on the left leg, changing the sleeping position - using a "bent position" convenient for spine.

Clinically and on radiographic examination, no or minor curves are present. There is minimal or no rib hump. This suggests there can be "scoliosis without any curves" or with "sight curves" unimportant clinically. These patients were mainly previously untreated and over the years, were unaware of their "spine problem". In adolescence, they encounter problems with sporting activities. At adulthood, they report a wide range of "back pain" [Fig. 3a, 3b]. The patients from this group need a "differential diagnosis" because some general practitioners or hospital doctors diagnose them as having rheumatism, heart pain, circulatory problems, pulmonary illnesses like bronchitis or pleuritis, neurological or gynaecological problems.


Figure 3a and 3b. Two examples of developed "stiffness of spine" in lumbar and thoracic spine. Fig. 3a - 15 years old girl examined during screening for scoliosis. Stiffness of spine, problem with practising sports, occasional pain. Fig. 3b - Monika K. (36 years old) history number 690627 – "moderate stiffness of spine" but with large back pain since 7 years. Pain with radiation to both sides and even stomach. Many visits to internists and neurologists. Adduction of the right hip 0 degree, adduction of the left hip 40 degrees. We advised her to begin "new rehabilitation exercises", thermo-therapy, hand massages.

4. Discussion of Biomechanical Etiology

In the past, nobody could confirm the hypothetic "etiological factors" of scoliosis ie genes, congenital, local anatomical disorders connected with *processi articularis*, ribs or other anatomical changes, such as hormonal causes (prostaglandin, melatonin), chemical – calcium, phosphorus, mucopolysaccarides, glycogen, actins and myosin in muscles, calmodulin, illnesses such as rickets, osteoporosis, diseases of nervous system, even disorders connected with labyrinths and plenty of other hypothetic influences [27, 44, 45, 46, 47, 52]. Observations over the period 1981 – 2005 showed that the cause of idiopathic scoliosis development is strictly biomechanical. In 1995 "the causative chain of pathological factors leading to the so-called idiopathic scoliosis" was first presented (in Hungary) and in 1996 described in medical literature (in Germany) [10]. The chain of events in the development of deformity is as follows:

a) the asymmetry in movement between right and left hip, b) asymmetry of loading of the right and left side during gait and as a result, the disturbance to spinal growth and development when a child starts walking. This observation makes it clear that the onset of scoliosis is very early, in first years of life, but at a time when the symptoms of scoliosis are very "unclear and untypical". In many orthopaedic textbooks, it is stated that "scoliosis develops from the apex of curve". Now it is clear that a scoliotic deformity develops from the "base of spine" ie from the pelvis and sacro-lumbar region upwards to all regions of the spine.

In the I-st group (I epg), the first symptoms of AIS are only clinical symptoms and these should be "observed" for many years until the deformity is clearly visible on the radiograph. Tests should include the pathological "side bending test for scoliosis" (Lublin test), examining for the disappearance of the spinous processes under the skin during "flexion of spine" (in Adams "bending test for scoliosis" or "Lublin test"), and asymmetry in adduction of both hips and a permanent "standing position" on the right leg and other.

In children with developed AIS, by careful examination, many researchers have described distant deformities such as plagiocephaly, torticollis, asymmetry of temporal bone and asymmetry of the whole body described in "syndrome of contractures" [9, 48, 8, 4, 7]. These observations confirm the connection between the "syndrome of contractures" and scoliosis. If we take into consideration "the syndrome of contractures" in the biomechanical etiology of the so-called idiopathic scoliosis, we can explain among others things a) the gender of patients - mostly girls ("syndrome of contractures" is mostly at girls), b) three etiopathological groups of scoliosis – linked with gait and "free standing position" only or mostly on the right leg, c) type of scoliosis – lumbar left convex, thoracic right convex; rib hump on the right side (connected with "left sided syndrome of contractures" coming from 85% - 90% left situated pregnancies – *Oleszczuk*), d) progression of the scoliosis during periods of accelerated growth, especially in children with differences of growth rates between the trunk and lower limbs, when the lower limbs grow faster than the trunk. Our observations confirm thoses of *Dimeglio* (EPOS Meetings) and e) a good response to the "new rehabilitation exercises" which include removal of contractures.

5. Conclusions

So-called idiopathic scoliosis is often linked with right hip abduction contracture with flexion and external rotation contracture of this hip or with a large difference in adduction movements of both hips. During walking, the contracture causes asymmetry in loading and growth of spine. With time comes the development of scoliosis. At the onset of scoliosis, there are changes in the pelvis and lower spine. The first sign is a rotational deformity of the spine with stiffness. Later a *gibbous costalis* appears and the spine curves (Ist epg). The abduction contracture of right hip makes the right leg "stronger" and leads to "free standing" only on the right leg. This is termed the "causative moment for development of scoliosis" (IInd epg).

The abduction contracture of the right hip is connected with the "syndrome of contractures" of neonates and babies described precisely by Mau (Tűbingen) and also by others - *Dega, Tylman, Gardner, Burwell, Stokes, Saji&Leong*, *Dangerfield&Coll., Willner, Wynne-Davies, Green&Griffin, McMaster, Magoun*.

There are three etiopathological groups of development of so-called idiopathic scoliosis. The first group (I-st) – a double "S" scoliosis with rib hump - is linked to asymmetry while walking, loading and growth and the habit of free standing on the right leg. The lumbar and thoracic curves appear at the same time, sometimes at the early age of 4-6 years. In small children, a curve of 5 degrees on the radiograph and "onset of a stiff spine" should be an "important sign of scoliosis problem" for clinicians.

In I-st epg, the first sign is a rotational deformity which results in a "stiffness" of spine in three stages: a) disappearance of the spinous processes T6-T12 [35, 12]; b) flat back and flattening of the lumbar spine [41, 40, 11] c) a lordotic deformity in the thoracic spine (*Adams, Meyer*). This type of scoliosis is progressive.

The second group (II-nd) – "C" scoliosis - is associated only with the habit of a "permanent standing position on the right leg" from the first year of life. In this group, the first and the only sign is the lumbar or sacro-lumbar or lumbo-thoracic left convex scoliosis. In these children, there is no rotational deformity associated with essential stiffness of the spine or thoracic curve or rib hump. If these are present, they a not important clinically. This type of scoliosis is not a "paralytic scoliosis".

There are also patients on the border between the I-st and II-nd group. In the new 2004 classification, this forms the III-rd group of so-called idiopathic scoliosis, having only spinal stiffness and in adult patients symptoms of back pain. This type of scoliosis has either a very small curves or rib hump or none. The II-nd and III-rd types of scoliosis are non-progressive.

According to "biomechanical etiology" we should introduce new stretching-flexion asymmetrical exercises and special sport programs for the children at risk of developing scoliosis or with signs of a developing scoliosis. Neo-prophylaxis is possible but it should be started early in children 4-8 years of age.

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Pre-processing Range Data for the Analysis of Torso Shape and Symmetry of Scoliosis Patients

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Abstract. This paper presents a procedure for pre-processing and reconstructing surface scans comprising an interactive technique for cropping stray points and extremities. The procedure involves three stages: cross-sectioning and clipping, hole-filling and sub-sampling, and surface re-generation. The accuracy of the reconstruction obtained was assessed by creating different patterns of holes and stray points on 30 models of the torso and pre-processing the models using the proposed procedure and existing procedures based on Bezier interpolation and Moving Least Squares (MLS) interpolation. Results obtained indicate that the proposed procedure was at least as good as the better of Bezier and MLS interpolation for all the models tested, particularly outperforming both procedures when holes account for up to 5% of the surface. Its accuracy of reconstruction ranged from 90-100% compared to 80-100% for Bezier and 50-100% for MLS. This work is a crucial step in developing techniques for understanding and assessing changes in torso shape and symmetry from torso surface scans of scoliosis patients.

Keywords. Scoliosis, Moving Least Squares, Bezier Curves, Surface Fitting, Range Scans

1. Introduction

A growing clinical use of range scanning systems is in the assessment of trunk deformities caused by scoliosis from torso surface scans. Traditionally, scoliosis is diagnosed using radiographs of the spine [1]. However, radiography does not describe the visible torso deformities caused by scoliosis. Some researchers believe that the use of torso scans can reduce the need for radiographs and advocate them for the clinical follow-up of scoliosis [2], [3], [4], [5], [6]. So far, range scans obtained using systems based on Moiré fringes, rasterstereography and optics (such as the ISIS, the Quantec system and the MINOLTA[1] VIVID digitizer based system) [7] have been used[2].

Range scans of the human torso exhibit several problems and require an elaborate pre-processing stage before they can be used in assessing torso deformities. First, stray data points from surrounding artifacts such as the positioning platform and garments

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[1] KONICA-MINOLTA Photo Imaging Inc., Mahwah, NJ, USA.

[2] Here, a system based on the MINOLTA VIVID digitizer is used to obtain the torso scans.

worn by the patient that are not of interest can be arbitrarily positioned vis-à-vis the scanned object

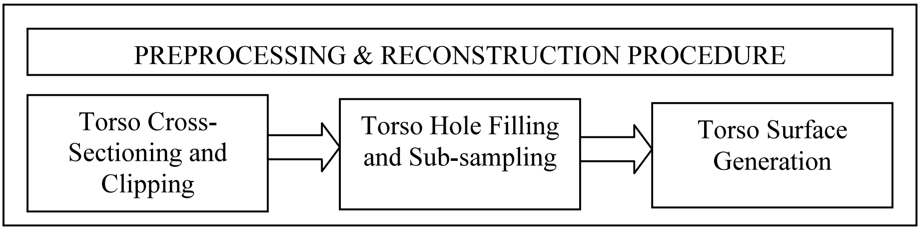

Figure 1. Flow-chart of the pre-processing and reconstruction procedure.

and have to be manually removed. Second, regions such as the head and neck and the shoulders and arms are often asymmetrically aligned and hence difficult to crop. Third, holes due to the occlusion of parts of the surface and grazing angle of incidence of the laser beam are often located at obscure regions like under arms. Fourth, additional errors can be introduced during initial processing operations (such as merging and smoothing).

This paper presents a procedure for pre-processing and reconstructing surface scans comprising an interactive technique for cropping stray points and extremities and a novel interpolation technique (spline-fitted moving least squares) for filling holes. The major contribution of this paper is putting together the pre-processing operation for range scans used in assessing the deformity associated with scoliosis into an easy to apply procedure.

2. Materials and Methods

The pre-processing and reconstruction procedure consists of three stages: torso cross-sectioning and clipping, torso hole filling and sub-sampling, and torso surface re-generation (Figure 1). The torso clipping and cross-sectioning stage is comprised of torso clipping which crops the extremities and torso cross-sectioning which sections the torso into a user-defined number of cross-sections. The sections are usually uniformly spaced[3]. The torso clipping routine uses an implementation of the Sutherland-Hodgman polygon clipping algorithm [8]. An enhancement of the algorithm detects the boundary points of extremities and *holes* in the torso using a *convexity* algorithm. A *hole* is defined as a region in the torso cross-section where the two nearest points on the plane are not connected by a line segment. At the end of the torso clipping and cross-sectioning stage, much of the surrounding artefacts that are not part of the image are removed.

In the torso hole filling stage, the points in each cross-section are evaluated to fill holes in the 3D scan. Once a hole is detected, depending on its size, a decision is made

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[3] The sections can be made to divide the object into a number of equal volume segments. It can be shown that for three or more cross-sections perpendicular to the *centroid line* of an object, the shape and positioning of the sections is unique to the shape of the object.

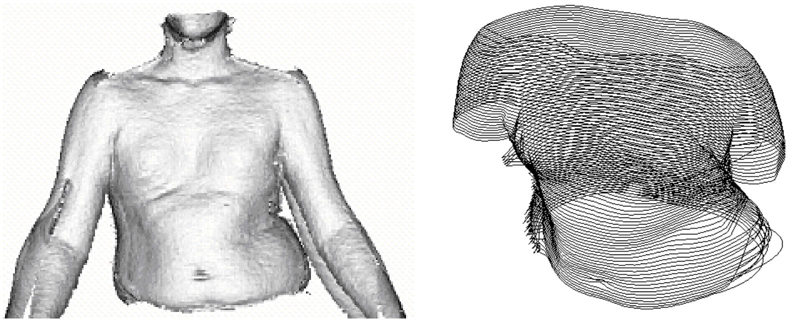
to either connect the two nearest points to it to fill it directly or to generate intermediate points to fill it by interpolation. In this paper, hole filling is achieved using the spline-fitted moving least
squares (SMLS) procedure. The procedure is based on the moving least squares (MLS) procedure and the Bezier curves (BC) approximation theory. It consists of a first pass involving spline fitting with BC approximation that yields the approximate positions of the intermediate points and a second pass during which the positions of the intermediate points are refined using MLS projection. In the second step, MLS projection theory is applied to refine the above created points by obtaining local surface polynomial approximations. This is done by creating an MLS surface polynomial approximation of three consecutive points and moving the intermediate point onto that MLS surface.

The final stage of sub sampling and surface generation obtains a user defined number of 3D points per cross section that redefines the original 3D image of the torso region. This requires two steps. The points representing each cross section at a particular height are first up-sampled using a spine interpolation algorithm. After this, a circle enclosing the cross section is constructed. Using the user-defined precision the points on this circle are determined and each point is evaluated to find its closest match to the original shape (in terms of Euclidean distance). This yields a systematic up-sampling of the torso cross-section. The up-sampled points are then joined using line segments for each cross section to create a surface that represents the best hole free approximation of the torso region. Figure 2a shows an example of hole-filled scan obtained from the MINOLTA scanner and Figure 2b shows the up-sampled cross-sections representing hole-free version of the scan. There are 180 points per cross section and 180 cross-sections in total.

The accuracy of the reconstruction obtained was assessed by creating different patterns of holes and stray points on 30 models of the torso and pre-processing the models using the proposed procedure and existing procedures based on Bezier interpolation and Moving Least Squares (MLS) interpolation.

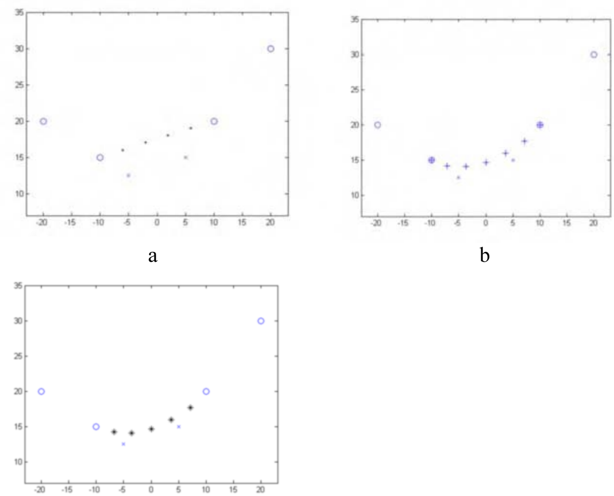
3. Results

Results obtained indicate that the proposed procedure was at least as good as the better of Bezier and MLS interpolation for all the models tested, particularly outperforming both techniques when holes account for up to 5% of the surface. Figure 3 shows an interpolation example using MLS, Bezier curves and SMLS. In the figure, the Bezier and SMLS interpolation were approximately the same but the MLS interpolation failed. In general, the accuracy of reconstruction achieved using SMLS ranged from 90-100% compared to 80-100% for Bezier and 50-100% for MLS.



a b

Figure 2. Complete 3D hole filled representation of Torso



a b

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Figure 3. Interpolation using a. MLS; b. Bezier curves; c. SMLS

4. Discussion

This paper presents a technique for pre-processing range data used in the analysis of the torso deformities caused by scoliosis. The technique uses a new interpolation scheme, spline-fitted moving least squares, for fitting holes in the scans. Experiments show that the new interpolation scheme outperforms the standard Bezier curve interpolation scheme and the more advance moving least squares approximation scheme particularly when large holes (greater than twice the average spacing of the points in the image) are present. The major contribution of this paper is that it puts together the myriad tasks involved in pre-processing range data into a single procedure. This work is a crucial step in developing techniques for understanding and assessing changes in torso shape and symmetry from torso surface scans of scoliosis patients. Future work will focus on developing an easy-to-use graphical user interface that implements the technique.

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Adjacent Segment Disc Pressures Following Two-Level Cervical Disc Replacement Versus Simulated Anterior Cervical Fusion

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Abstract. Anterior cervical fusion (ACF) has been shown to alter the biomechanics of adjacent segments of the cervical spine. The goal of total disc replacement is to address pathology at a given disc with minimal disruption of the operated or adjacent segments. This study compares the pressure within discs adjacent to either a two-level simulated ACDF or a two-level total disc replacement with the *ProDisc-C* ™. A special automated motion testing apparatus was constructed. Four fresh cadaveric cervical spine specimens were affixed to the test stand and tested in flexion and extension under specific loads. Intradiscal, miniature strain-gauge-based transducers were placed in the discs above and below the "treated" levels. The specimens were then tested in flexion and extension. Pressure and overall angular displacement were measured. In the most extreme and highest quality specimen the difference at C3/C4 registered 800 kPa and the difference at C6/C7 registered 50 kPa. This same quality specimen treated with the ProDisc reached a flexion angle at much lower moments, 24.3º at 5 N-m, when compared to the the SACF 12.2º at 8.6 N-m. Therefore, the moment needed to achieve 15 degrees of flexion with the SACF treatment was 5.5 N-m and the ProDisc treatment was only 2.9 N-m. This initial data would indicate that adjacent level discs experience substantially lower pressure after two-level disc replacement when compared to two-level SACF. Additional testing to further support these observations is ongoing.

Introduction

Anterior cervical fusion (ACF) has been shown to alter the biomechanics of adjacent segments of the cervical spine. This may contribute to accelerated degenerative disc disease. [1,2]. The goal of total disc replacement is to address pathology at a given disc with minimal disruption of the operated or adjacent segments. The purpose of this study was to compare the pressure within the disc at adjacent segments following two-level disc replacement with the *ProDisc-C* ™ versus simulated two-level anterior cervical fusion with plating (SACF) using established testing methods. [3,4].

Methods

A test apparatus was constructed to automate the physiologic motions of spinal segments with the three treatment types. The apparatus shown in Figure 1 incorporates automated load generation and measurement controlled by a computer and programmable logic controller (PLC).

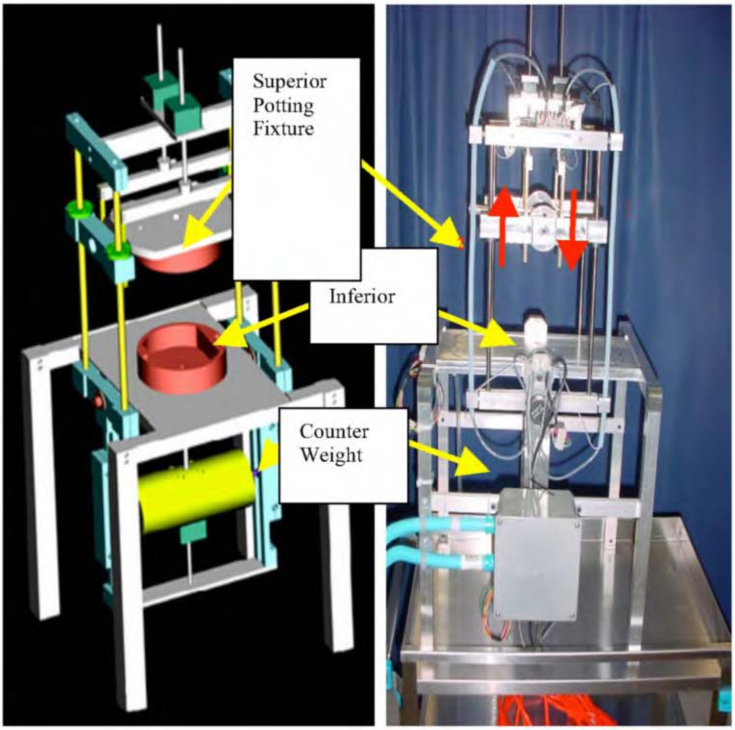

Figure 1: Automated motion testing device: (a) computer design and (b) actual device.

It is also capable of continuously monitoring the pressures in the discs using miniature strain gage transducers in the disc spaces. The unique design functions as follows to produce a simulated anatomical movement. The lower potting fixture is fixed to the device frame. The upper potting fixture slides up and down freely on four linear bearings. Force and/or torques can be applied to the upper fixture by two stepper motors that drive forked rack gears that drive the circular spur gears. Load cells are mounted in line with the racks to monitor the applied loads. Thus, forces F_1 and F_2 can be generated on the upper potting fixture. To provide a pure moment loading F_1 is held equal to, but in the opposite direction of F_2. To provide an axial load the forces may be controlled to act in the same direction, and finally force control can be implemented to provide a combination of moment and force loading a combination of the two types of pure loading can be generated in combination. When a specimen is mounted then, pure moment flexion can then be generated by a downward (F_2) and upward force (F_1) of equal magnitude and pure moment extension can be generated by an upward (F_2) and downward force (F_1) of equal magnitude. A typical loading cycle for pure moment control is shown in Figure 2. The forces change with equal and opposite signs, the force difference first becomes negative causing a flexion moment and then becomes positive causing an extension moment. The sum of the forces remains near zero indicating no axial loading on the specimen. Four fresh cervical cadaveric specimens (ages 46 to 69) were dissected and fixed at C1 and T2 with PMMA bone cement and mounted into a customized testing platform. Miniature strain-gauge-based transducers [5] were inserted to measure intradiscal pressures at C3/C4, C4/C5 (untreated specimens only), C5/C6 (untreated specimens only) and C6/C7.

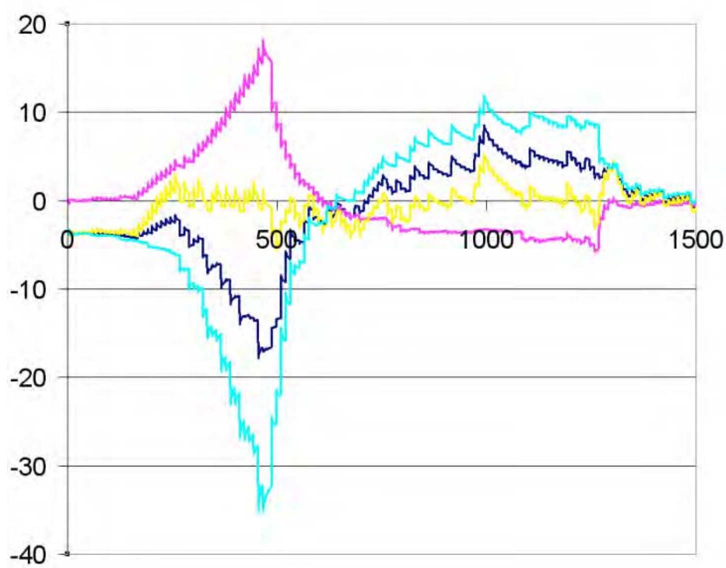

Figure 2. A typical loading cycle for pure moment loading. F_1 and F_2 are equal and opposite, the axial load remains near zero and the moment first becomes negative (flexion) and then becomes positive (extension).

Each specimen was studied under three conditions: (1) untreated, (2) two level disc replacement with Synthes *ProDisc-C* ™ and (3) simulated two-level fusion using two polyethylene spacers and a two-level anterior titanium plate. *ProDisc-C* ™ prostheses were placed at the C4/C5 and the C5/C6 levels using the accepted surgical technique.
Each specimen was then loaded incremental load changes were completed in one-half second and allowed to relax for 10 seconds while pressures were continuously monitored. This allowed for quantitative evaluation of relaxation time. Pressure and

overall angular displacement were measured in the following manner: (a) incremental loading to 4 N-m in extension, (b) incremental unloading to zero N-m in extension, (c) incremental loading to 2 N-m in flexion, and (d) incremental unloading to zero in flexion.

Results

The difference between maximum pressure deviations measured in the C3/C4 disc level were substantially greater than those measured in the C6/C7 disc level, as seen in Figure 3. In the most extreme and highest quality specimen the difference at C3/C4 registered 800 kPa and the difference at C6/C7 registered 50 kPa. Greater overall flexion angle displacements could be achieved at lower applied loads with the ProDisc versus the SACF. This same quality specimen treated with the ProDisc reached a flexion angle at much lower moments, 24.3º at 5 N-m, when compared to the the SACF 12.2º at 8.6 N-m. Therefore, the moment needed to achieve 15 degrees of flexion with the SACF treatment was 5.5 N-m and the ProDisc treatment was only 2.9 N-m.

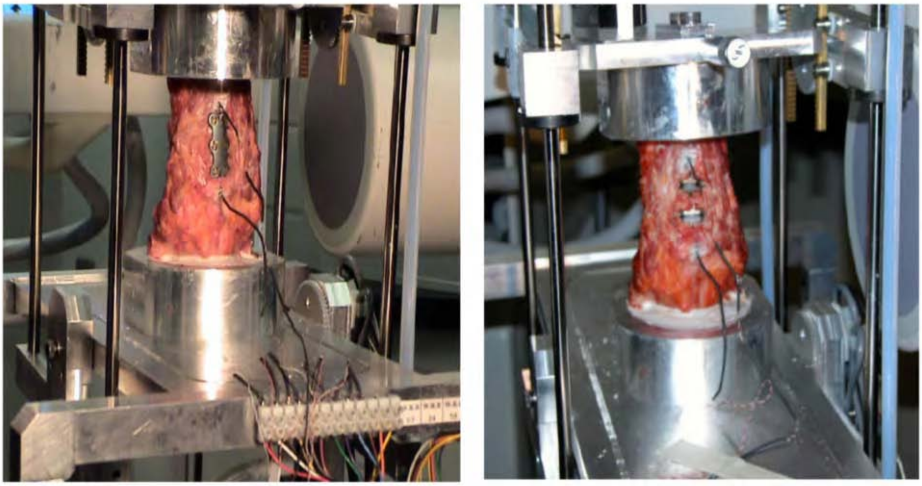

Figure 3. Testing of two-level fusion and two-level Prodisc-C®.

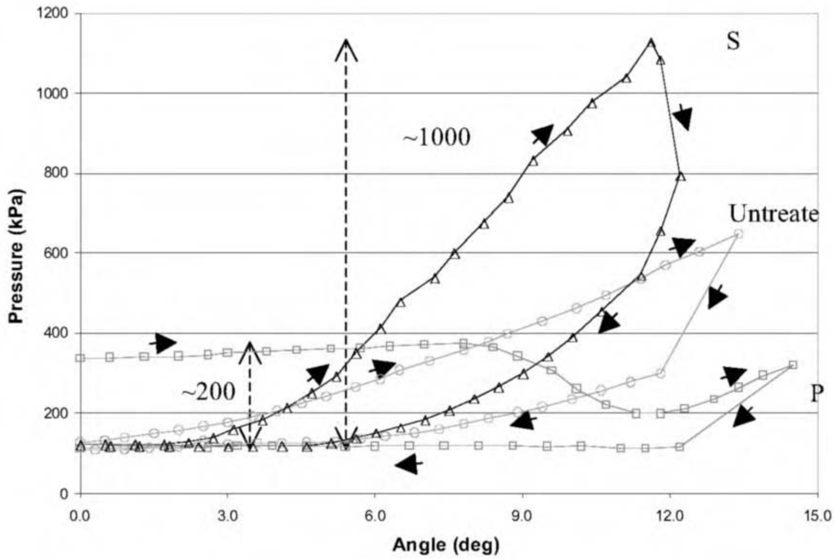

Figure 4. C3/C4 disc pressure for each treatment during the flexion loading cycle. The differences in max pressure deviation between ProDisc and ACP at during the loading cycle was approximately 800 kPa.

Conclusion

This initial data would indicate that adjacent level discs experience substantially lower pressure after two-level disc replacement when compared to two-level SACF. This pressure difference was significantly higher at the C3/C4 level versus the C6/C7 level. The disc replacements allowed for significantly more flexion than did the SACF specimens at lower applied moment. Additional testing to further support these observations is ongoing. Also, enhanced control of the test stand and new alignment procedures are being developed.

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The Effect of Instrumentation with different Mechanical Properties on the Pig Spine during Growth

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Abstract. The effect off mechanically altered bone on spinal growth using instrumentations with different mechanical properties is quantified through the use of experimental tests. Eight spine segments from three female pigs weighing 60~90 lb were subjected to a continuous tensile force. The load (0 – 400 N) was applied using a MTS™ Alliance RT/50 machine and the resulting extension recorded using an extensometer. Displacements between the screws were measured in control without implant, metal plate system, and spring system, respectively. It is shown that the addition of an implant will increase the stiffness of the spine, which will affect the extension of the spine and hence hinder growth in the spine.

Keywords. Spine growth, Mechanically altered bone, Mechanical testing, Pig spine

1. Introduction

Recently, spinal Fusionless instrumentation in the treatment of scoliosis has been introduced clinically. Such instrumentations include multiple level staples, vertical expanding prosthesis, and changeable rod system. Although the study of using cow tails similar to the vertical body structure demonstrated there are changes of the bone growth under tensile or compressive loading provided by the external fixation [1], the effect of mechanically altered bone on spinal growth using instrumentations with different mechanical properties is not well quantified. The goal of the present study was to examine the behavior of the pig spine with different implants during distraction of the spine.

2. Materials and Methods

Eight spine segments from three different pig spines were subjected to continuous tensile stress. The thoracic segment of each pig spine was divided into three segments – T1~T4, T5~T8, and T9~T12. The three pigs were female weighing 60~90 lb. Each cadaver pig spine segment was thawed to room temperature before testing. In the spine segment, two titanium screws were inserted into the center of two adjacent vertebral bodies. Both ends of the specimen were set in a PMMA block. The specimen was attached to specially designed fixtures that were screwed into place through the PMMA blocks. These fixtures were designed to fit over the PMMA blocks and into an MTS load frame for testing. One end of the specimen was fixed in all directions, acting as the base.

The MTS Alliance RT/50 machine constantly applied tensile forces and recorded the resulting extension of the spinal segment. The MTS Extensometer model# 63213E-50 measured the extension between the two screws on the specimen. Two L-shaped rods protruding from the two screws held the extensometer in place.

Three tests were performed on each pig spine segment under sustained tensile stress. The extensometer measured the extension of the spine segment between the two screws for every applied force. The applied force ranged from 0 N – 400 N depending on when a test was stopped due to spine pullout from the PMMA block. Spine pullout equated to failure during testing. The three tests were called the control test, plate test, and the spring test.

The control test measured displacement between the screws without any material linking the two screws. The spring test involved linking the two screws with a metal spring. A spring length of 0.3790 in was used throughout testing until this spring became damaged. A longer metal spring of 0.4830 in was used in place of the shorter spring for two segments and one segment was tested with both spring lengths.

The plate test consisted of connecting the screws with a metal plate link where each screw was inserted through the oval-shaped holes at each plate end. The plate was positioned so that each screw rested at the center of each hole in the plate to allow for spine extension during loading. Programs were written in MATLAB™ version 6 to filter the load and extension data and to obtain the stiffness of each spine segment and the corresponding load range for each test.

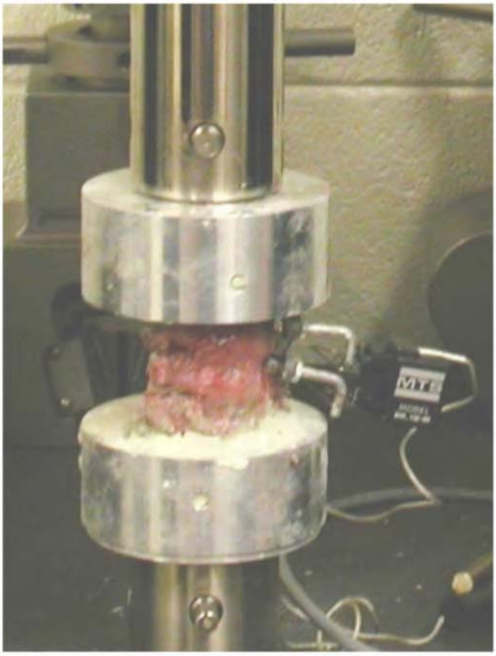

Figure 1. A spine segment loaded with a tensile load

3. Results

The spine stiffness was determined from the slope of the load versus extension curve using a linear least squares fit. Using all our tests, including data not presented here for sake of space, minimum, maximum and average values for the tests may be obtained (Table 1). This data comprises the load range 0 to 110 N.

Shown in Figure 2 are typical curves obtained for a spine with and without implants. For the sake of brevity, we plot one example here, but results were obtained for much higher load ranges. In Table 2, we give the spine stiffness for various segments and load ranges.

Table 1. Minimum, maximum and average stiffness values for all tests (0-110 N)

Test Type	Spine Stiffness (N/m)		
	Minimum	Maximum	Average
Control	390	215,960	44,157
Plate	1,913	316,460	60,848
Spring	1,783	911,770	169,174

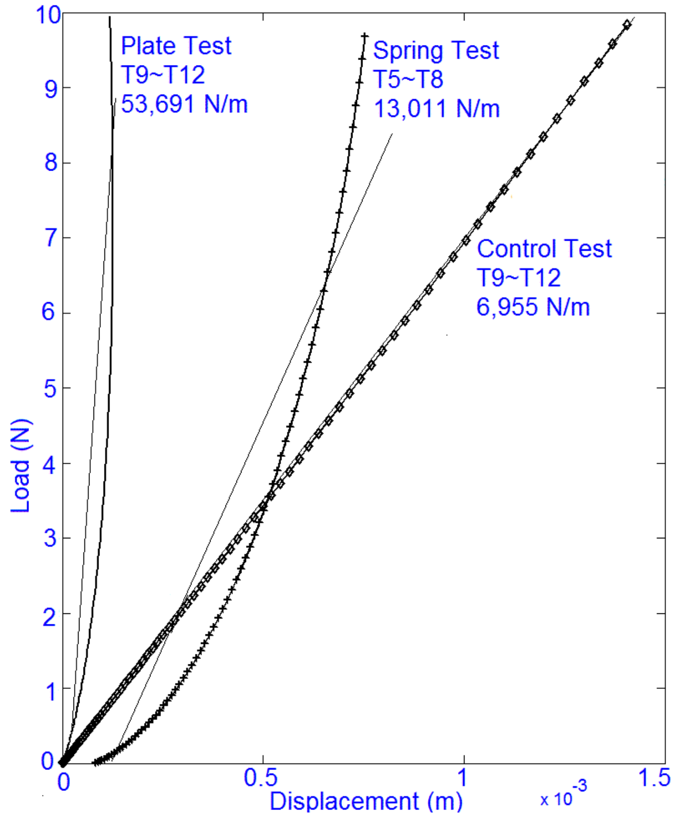

Figure 2. A typical load extension curve for a spine segments with and without implants

Table 2. Spine stiffness and load range for various spine segments

Spine Segment	Test Type	Spine Stiffness, (N/m)	Long Range (N)
T1T4 PIG A	Control	11,761	14 – 18
	Plate	10,151	14.5 – 19
	Spring (long)	10,965	3 – 10
T5T8 PIG C	Control	75,571	75 – 90
	Plate	114,920	20 – 35
	Spring (short)	80,076	25 – 40
T9T12 PIG B	Control	6,955	0 – 10
	Plate	53,691	0 – 10
	Spring (short)	13,011	0 – 10

4. Discussion

The results from this study indicate that the addition of an implant will increase the stiffness of the spine, which will affect the extension of the spine and hence hinder growth in the spine.

The plate had oval holes that allowed for some motion. At small loads, there is less effect on the spine then there would be higher loads where there is considerable extension of the spine. This can be seen by examining in Table 2 the plate tests for T1T4 Pig A and T5T8 Pig C. Thus, the more rigid is the link, the more is the spine stiffness.

Comparison of the spring and plate tests, indicates, that in general, the spine is stiffer with the addition of the plate than the spring. This is because the plate is a rigid link and allows very little displacement compared to a spring. It is interesting to note that the stiffness of the spring affects the stiffness of the spine, as one would expect. In our tests, we examined both short and long springs. The springs had the same spring stiffness. However, the length of the springs allowed us to vary the initial stretch of the springs. Thus a short spring that was stretched more than a long spring, over the same distance, would apply a larger resistive force (see tests T9T12 Pig B, and T1T4 Pig A). Even though the load ranges are practically the same, the spine stiffness for the short spring is 13,011 N/m and for the long spring 10,965 N/m. This implies that the more rigid the implant is, the stiffer the spine and hence the greater the resistance to growth.

The results from this study may be used to support a future finite element analysis of the title problem. In this study, we have quantified the effect of implant properties on spine stiffness and hence the effect on the growth plate. Future extrapolation of the work may lead to better fixations that will not impair or hinder spinal growth.

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Improving Brace Wear with Active Brace System

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Abstract. There is considerable controversy regarding the effectiveness of brace treatment for patients with adolescent idiopathic scoliosis (AIS). Researchers believe that to be effective, patients must wear their braces as prescribed including both compliance and tightness. Compliance is how much time the brace is worn relative to the prescribed time. Brace tightness is usually prescribed by orthotists during brace fitting session. Asking the patient or examining the brace for wear are the most common methods to evaluate the brace usage. A low powered microcomputer system was developed to monitor and maintain loads exerted by braces used to treat children with spinal deformities during daily living. This system records brace usage information and helps patients to wear their brace at the prescribed tightness. Laboratory tests have been performed and six patients have used the system for four weeks. The patients reported that the system helped them to wear the brace properly. The time that the patients wore the braces at the prescribed tightness level increased from 48±16% during the monitor period (first 2 weeks) to 63±18% during the automatic adjustment period (last 2 weeks).

Keywords. Brace management, scoliosis, instrumentation

1. Introduction

Scoliosis is a three-dimensional deformity caused by lateral curvature of the spine with vertebral rotation within the curve. This lateral curvature affects the rib cage and presents as deformities of the trunk. It is usually detected at about age ten to skeletal maturity, with females comprising around seven of every ten cases in curves of over 30 degrees. Brace is the most commonly used non-surgical treatment for scoliosis. The purpose of brace treatment is to halt curve progression during the high-risk growth period of early adolescence and to reduce the number of surgeries. To be effective, patients must wear their braces daily and for long periods of time as well as at the appropriate tightness. Simply prescribing a brace does not mean that the patient will wear it appropriately. Daily activity alters the tightness of the brace. Since most brace wearers seldom adjust the brace tightness after it is donned, the brace effectiveness may vary during daily activities.

In 1976, the Milwaukee brace was the most frequently used brace in the United States for non-operative treatment of AIS. Since that time, different types of braces have been developed[1-3] through removal of the cervical component, use of lighter materials, and customization to improve comfort, cosmesis and hopefully compliance. Some braces have been developed for nighttime use only[4], but most are intended to be worn 18 or more hours per day. Currently, the Boston brace is the most common type of brace used in North America and orthopaedic surgeons recommend up to 23 hours of daily use. If brace treatment fails, surgery may be required. Scoliosis surgery is a complicated operation undertaken with significant potential risks, including death, paraplegia and a 6-9 month recovery period. Scoliosis surgery has a life altering impact that occurs typically in otherwise healthy adolescents.

Symptoms that occur in association with scoliosis may include pain[5] and psychological stress[6]. If severe scoliosis is left untreated with a large curve, it can injure both the lungs and heart and cause significant cosmetic deformity. Therefore, a more effective brace that can reduce or maintain the curvature will have a significant impact on adolescents with IS.

Although bracing for scoliosis has been used for more than thirty years, its effectiveness is still debatable[7-10]. Some researchers believe that brace treatment is ineffective and some believe that braces can help stop curve progression. Clinical studies have been conducted to investigate the effectiveness of brace treatment with compliance[11-16]. However, these studies did not measure how tightly the brace was worn. It may be misleading to make conclusions about the effectiveness of bracing without recording both quantity and quality of brace usage. Some work has been done to measure the loads while patients wore their brace[17-21]. However, all of the above studies were done in a laboratory environment; the required equipment and set up were not portable. The above studies may not be true indicators of the pressure exerted by braces over a treatment period lasting several months or years.

Furthermore, traditional braces are passive devices; they are fitted once with occasional adjustments and it is left to the patient or care givers to monitor and make further daily changes as they see fit. The combination of powerful microprocessors and the Internet technology enabled the active brace to be developed that responds to the needs of the patients. The active brace system was able to sense the wear tightness and adjust to the prescribed level automatically during daily activities, allow data to be downloaded remotely, change their parameters based on feedback from clinicians, and log information as an aid to determining treatment effectiveness.

2. Objective

The study goal was to determine the capability of the active brace and to investigate whether the active brace could increase the portion of time that patients used the brace to the prescribed tightness level.

3. Methods

The active brace system has been fully described[22] which consisted of a force transducer, a microcomputer unit and a pressure control unit which are installed in an standard brace to monitor and control the brace wear characteristic during the treatment period. Pressure at the pad site is monitorized and the amount of air in a bladder under the pad is adjusted under computer control to maintain the prescribed load applied by the brace. The system can be controlled and configured from a remote site to download data and change clinical protocols. Figure 1 shows the overview of the system.

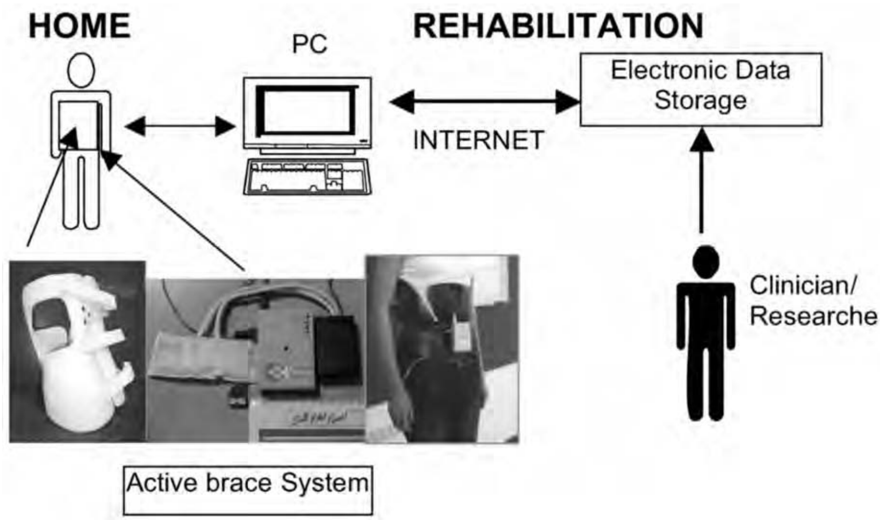

Figure 1. The overview of the active brace system.

3.1 Clinical Trials

Six brace subjects, 1 male and 5 females, age between 9 and 14, average 12.7 ± 2.0 years, who were new brace wearer were recruited for this study. All subjects signed the consent forms before participating in this study. The Cobb angle of the major scoliosis curve of the patients prior to brace treatment was 33 ± 6 degrees. After the system was installed, each subject performed in-laboratory measurements. Loads were measured when each subject performed the following postures: normal standing, bending forward and backward, bending to the left and to the right, sitting normally, sitting with support and holding breath (sample rate: 5 samples/second and an average of 25 samples taken for each static posture). These measurements verified the device was functioning properly, served as a training session for the subjects, and showed them how various postures and activities affected the amount of pressure applied by their braces. The sample rate for the clinical trial was set to be one sample per minute. Each patient used the system for 4 weeks. During the first two weeks (the passive session), the system only monitored the load. During the last 2 weeks (the active session) the feedback module was automatically activated and the interfaced pressure was adjusted automatically. The pressure pad level was defined below, in-range and above when the level was below 80%, between 80 to 120%, and above 120% of the prescribed level, respectively. The prescribed level was set by the orthotist while the subject was standing.

4. Results

Six subjects used the device to measure the daily force patterns exerted by the brace upon the trunk. The average prescribed force was 1.8 ± 0.6 N, and the sensing area of the transducer is 1.17cm^2; the corresponding pressure is 15.4±5.1 kPa. The real time clock inside the system logged how much time the subjects actually used their braces and provided the wear pattern during school and out of school time. The average time that the braces were used was 66 ± 15% (12.1 hours/day) of the prescribed time (18.3 ± 3.2 hours/day) over the study period. Individual compliance is shown in Figure 2. There was no difference of the brace wear time between the passive and active mode periods. Since this study was to investigate whether the active brace increased the proportion of time that the brace was worn was at the prescribed tightness level, the time that the brace was not used was not included in the analysis process. During the passive mode (the first two weeks), the time that the forces level was below 80%, between 80 to 120%, and above 120% of the prescribed level was 38 ± 21%, 48 ± 16% and 14 ± 7%, respectively. During the active mode (the last two weeks), the time that the forces level was below 80%, between 80 to 120%, and above 120% of the prescribed level was 24 ± 12%, 63 ± 18% and 13 ± 7%, respectively. Individual brace quality usage is shown in Figure 3. Figure 4 summaries the result of the percentage of time versus force distribution over the passive and active periods. Of the 6 subjects, 2 used the Internet to send the data to our sites. The data received was 100% accurate and reviewed by researchers and clinicians. Appropriate feedback on brace wear was given to the subjects. The Cobb angles of all six subjects have been reviewed at their next clinic appointment, approximately 3 months after they used the active brace system. Their Cobb angles are the same or within the measurement error between the first (33 ± 6^o) and second visits (34 ± 6^o).

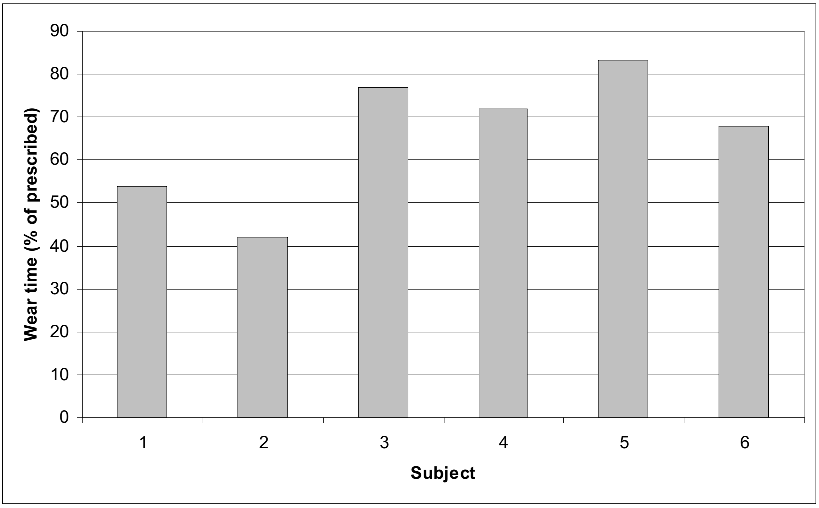

Figure 2. Compliance of each subject.

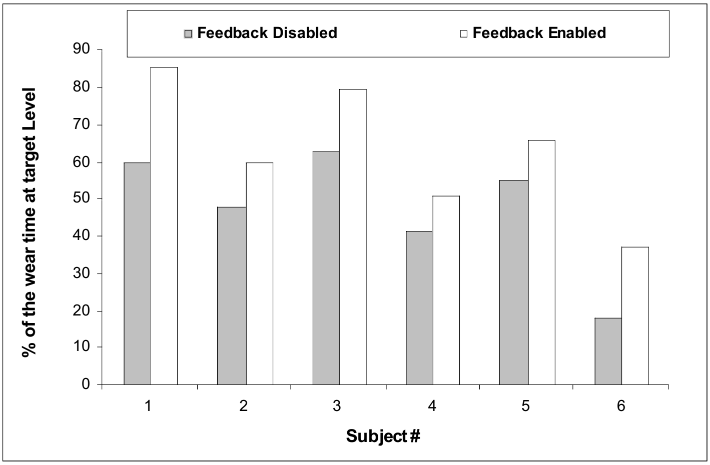

Figure 3. Quality brace usage of each subject.

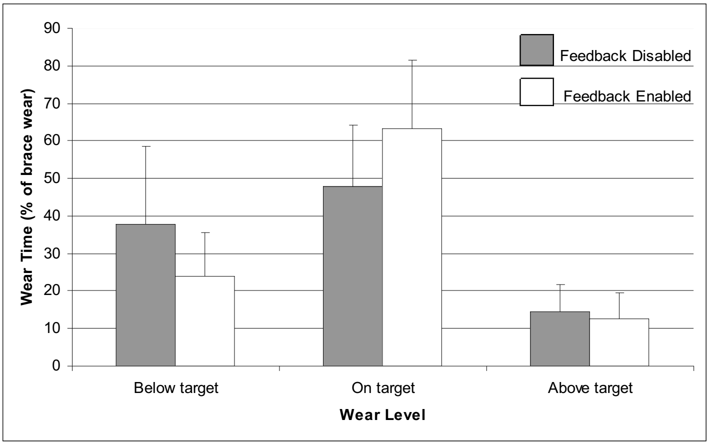

Figure 4. The percentage of time plus the standard deviation versus force distribution over the passive and active periods.

5. Conclusion

Although brace treatment is currently favoured as a means to treat children with moderate scoliosis, it remains controversial. To investigate the effectiveness of bracing, how the subject wears the brace in term of both the quality and quantity needs to be considered. In this study the treatment is considered effective if the Cobb angles can be reduced or maintained within 5 degrees of the pre-brace level. All subjects realize their compliance was monitored; no deception took place. We suspected by knowing of the monitoring, the patients may wear their brace more (a good side effect). From this pilot study, patients reported that the time they wore their braces (compliance) was not affected by wearing the monitor. However, the active brace system is able to increase the quality wearing, which means the time that the pressure pad level maintains to the prescribed level is increased. Although the active brace system seems to be able to maintain the patients' Cobb angles, a conclusive statement cannot be made because the number of patients is still small and all patients have not reached skeletal maturity yet.

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3D Back Shape in Healthy Young Adults: An Inter-rater and Intra-rater Reliability Study

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Abstract: Whilst postural evaluation of spinal dysfunction is routine in physiotherapy practice, objective measurements are rarely undertaken due to the scarcity of reliable low cost assessment tools. Warren et al [12] found high intra-rater reliability but inter-rater reliability has not as yet been evaluated. The purpose of this study was to assess both the intra-rater and inter-rater reliability of the Middlesbrough Integrated Digital Assessment system (MIDAS).
Methods: A convenience sample of twenty-five healthy University of Teesside students was recruited for the study. One rater palpated fifteen key landmarks on each subjects back. Each of three raters took two measurements on each subject in a standardized upright posture. Rater order was randomized to minimize data recording bias. X (medio-lateral), Y (antero-posterior) and Z (height) landmark positions were recorded via a computer interface.
Data Analysis: Intraclass Correlation Coefficients (ICC 2,1) were used to analyse data using SPSS v13.
Results: Both intra-rater agreement (mean ICCs - rater 1 r= 0.970, rater 2 r= 0.965 and rater 3 r= 0.965, p<0.001) and inter-rater agreement (mean ICCs r = 0.967, p<0.001 was very high between repeated measures and between markers. Error values for the z-axis (height) were lowest.
Conclusions: The system demonstrated both high inter-rater and intra-rater reliability. Before the system is used on a clinical population, data output needs to be converted from raw format to a clinically applicable format. Work is currently being undertaken to develop an interactive visual display and control for postural sway.

Keywords: Posture assessment, evidence-based practice, low-cost system

Introduction

Low back pain (LBP) is a common musculoskeletal health problem treated by health professionals [1] and is one of the largest causes of compensation claims in the workplace [2]. Retraining of posture is a traditionally integral physiotherapeutic intervention in the treatment of back pain [3] and the benefit of postural correction exercises for the relief of back pain has previously been studied [4, 5, 6, 7]. Despite much research being devoted to postural retraining and the general acknowledgement that poor posture is a major factor in musculoskeletal disorders, there is a paucity of objective measures to determine postural factors before and after treatment [8, 9]. This lack of objective measures for assessing posture does not agree with standards set out by governing bodies, which stipulate that treatments should be based on objective markers [10]. To ascertain any possible benefits from posture retraining it is important to implement a reliable and cost effective method that meets guidelines for clinical governance.

Previous work using the MIDAS has found very high intra-rater reliability (ICC >0.999, $p < 0.0001$) on an anatomical mannequin [11] and on 50 subjects ($r=0.92$ to 0.99, $p<0.001$) [12]. The purpose of this study is to report intra-rater and inter-rater reliability of the MIDAS on healthy young adults.

Instrumentation

The MIDAS (Fig 1) is a low-cost portable Microscribe 3DX digitiser [13] with bespoke software used to measure x, y and z coordinates of landmarks on a subjects' back.

Subjects

A convenience sample of twenty-five "healthy" University of Teesside students was recruited for this study. Subjects were excluded if they had any injury that prevented standing for the duration of data collection or a known allergy to self-adhesive stickers when in contact with the skin

Data analysis

The Statistical Package for Social Sciences (SPSS) version 13 was used for data analysis. Intraclass correlation coefficients (ICC 2,1) were calculated based on methods described by Batavia [14].

Figure 1. – The MIDAS in resting position

Procedure

A pilot study using one subject and the three testers was carried out to ensure the procedure was correct and the results were suitable for analysis. Subjects were attired so that their back was visible for landmark identification (females with a bra top). To limit the intra-rater and inter-rater sources of error, palpation and marking of anatomical landmarks with 8mm self-adhesive stickers was carried out by the principal researcher with the subject standing and left in place for the other testers to use. The landmarks used were identical to those used in previous MIDAS studies [11, 12]. Subjects stood in a standardized foot position and fixed their vision to a point on a wall chart and the order of testers was randomized using a random sampling numbers table [15]. Data collection involved one tester touching the MIDAS stylus tip to each of the marked points in a standardized order dictated by the software and pressing the foot pedal of the MIDAS to store the position on the computer. The same tester repeated the process once more, totaling two sets of data per subject, per tester (six per subject in total).

Results

The intra-rater mean scores (CI's) were very high $r = .970$ (.934 – .987, $p < 0.001$ rater 1), $r = .965$ (.915 - .985, $p < 0.001$ rater 2) and $r = .965$ (.924 - .984, $p < 0.001$ rater 3). Mean inter-rater ICC values (CI's) were 0.967 (0.903 – 0.978, $p<0.05$). Consistently across all raters and all fifteen points measured, the values for the z-axis were higher than the x or y-axis scores (0.997 vs. 0.885 and 0.918), indicating greater reliability in this aspect of the MIDAS.

Discussion

The results of this study demonstrate excellent agreement between repeated measures made by individual raters and repeated measures between raters with the MIDAS on healthy young adults, supporting previous research [11, 12]. However, some variability existed between the results of the three axes measured. The z-axis corresponds to height measurements and therefore is unaffected by factors such as postural sway, whereas the x and y axes are susceptible to medio-lateral (ML) and antero-postior (AP) sway. The order of testers was randomized in this study in an attempt to minimize changes in posture over time, despite this step, postural sway was unlikely to be controlled.

Currently the MIDAS' software allows calculation of landmark heights relative to points on the spine [12] however, data output is in raw format and is not currently displayed visually. Future development could provide such an output, allowing clinical monitoring of posture and long-term studies on both asymptomatic/symptomatic back pain populations may provide information on factors predisposing people to developing back pain and dysfunction.

Conclusions

The aims of the study were to assess the intra-rater and inter-rater reliability of the MIDAS 3D posture assessment tool when repeated measures were made on a convenience sample of healthy young adults with three raters. The results confirm that agreement between repeated measures for intra-rater values and inter-rater values were very high, as analyzed by ICC (2,1). It is concluded that subject postural sway may have caused slightly lower values for the x and y values. A study that controls for postural sway, develops a visual representation of the MIDAS' output and uses a patient population may lead to clinical uptake of this low-cost posture assessment tool.

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Comparison of Isometric Trunk Rotational Strength of Adolescents with Idiopathic Scoliosis to Healthy Adolescents

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Abstract Trunk rotational strength asymmetry has been suggested in adolescents with idiopathic scoliosis (IS), but is unconfirmed. The sitting isometric trunk rotational strength, at neutral and 18° or 36° of right or left pre-rotation, of a group of healthy adolescent females (CG), n=12, is compared with a group of female adolescents with IS (ISG), n= 14. Torque values were normalized to lean body weight. There is a significant weakness when rotating towards the concavity found in patients with AIS at the 36 lo (p 0.07 marginal), 18 lo ($p < 0.03$) and neutral positions ($p < 0.02$), with no side strength asymmetry found in a cohort of healthy adolescents without AIS.

Keywords Trunk rotational strength, scoliosis, healthy adolescent females

Introduction

It has been reported that trunk rotational strength training may be an option for the conservative management of adolescent idiopathic scoliosis (AIS) [1, 2]. In their report Mooney et al. (2000) suggested that there was a rotational strength asymmetry in patients with idiopathic scoliosis with a weakness on the concave side. The strength asymmetry reduced and spinal curve progression stopped in their subjects after trunk rotational strength training. Their result suggested that a trunk rotational strength asymmetry may be related to the progression of spinal curve in AIS patients. However, their report provided no statistical analysis of their data. Further more, there has been no studies comparing the trunk rotational strength asymmetry between healthy female adolescents and female adolescents with idiopathic scoliosis.

The purposes of this study were to compare trunk rotational strength of a group of female adolescents with idiopathic scoliosis, to a group of healthy female adolescents without scoliosis. The result of this study will be helpful for continuing the study of a trunk rotational strengthening protocol for the conservative management of AIS.

Methods

A group of female adolescents with idiopathic scoliosis (ISG) and a control group of healthy adolescent females (CG) participated in this study. The patient group (n=14) had a mean age of 13.3 (± 1.5) years with a mean Cobb 28° (±8°, range 19°-41°). The control group (n=12) has a mean age 14.6 years (± 2.3). Subjects' isometric trunk rotational strength at neutral, 18º and 36º of right or left pre-rotation were measured using a dynamometer. Briefly, the subject's legs and hips are secured using pads and Velcro straps on the testing machine. Subject's shoulders were secured using a Velcro strap onto a rotational attachment. The subject was then randomly positioned in five different trunk positions, as mentioned above. At each position the subject exerted an isometric rotational contraction in the right direction for five seconds, and then in the left direction for five seconds. The contraction sequence was repeated two more times for a total of six alternating contractions (three to the right and three to the left). This procedure was repeated at each of the five trunk positions.

A one second moving window was used to identify the highest mean torque value with the lowest variation for each isometric contraction. The final torque value was an average of all three torque contractions at each position. If there was a 20% difference between any of the torque values, the lower value was discarded as an inconsistent effort. Torque values were normalized to lean body weight. CG individuals torque values were examined between the right and left contraction directions. ISG individuals' torque values were assessed in relationship to their primary curve direction so that reported torque values were in relation to the direction (i.e. convexity or concavity) of the primary curve. A paired t-test was used to compare contraction directions for CG and ISG. Alpha was set at $p<0.05$.

Results

In the 36° pre-rotated position, rotating away from the midline (36 Lo) the CG had an average torque of 0.60 Nm/Kg (±0.15, range 0.39-0.92) to the right and 0.65 Nm/Kg (±.2, range 0.41-0.95) to the left, not significant ($p<0.2$). The ISG had an average torque of 0.58 Nm/Kg (±.16, range 0.31-0.85) towards the convexity of the curve and 0.52 Nm/Kg (±.17, range 0.22-0.78) towards the concavity ($p<0.07$). This data is shown in Figure 1 labeled "36 Lo".

In the 18° pre-rotated position, rotating away from the midline (18 Lo) the CG had an average torque of 0.73 Nm/Kg (±0.22, range 0.38-1.08) to the right and 0.8 Nm/Kg (±.19, range 0.56-1.19) to the left, [ns ($p<0.07$)]. The ISG had an average torque of 0.72 Nm/Kg (±.17, range 0.43-0.98) towards the convexity of the curve and 0.6 Nm/Kg (±.2, range 0.23-0.95) towards the concavity ($p<0.03$).

At the neutral position the CG had an average torque of 0.87 Nm/Kg (±0.27, range 0.41-1.41) to the right and 0.9 Nm/Kg (±.22, range 0.56-1.27) to the left, [ns ($p<0.25$)]. The ISG had an average torque of 0.9 Nm/Kg (±.23, range 0.4-1.3) towards the convexity of the curve and 0.76 Nm/Kg (±.16, range 0.46-1.03) towards the concavity ($p<0.02$).

In the 18° pre-rotated position, rotating toward the midline (18 Hi) the CG had an average torque of 1.02 Nm/Kg (±0.23, range 0.67-1.40) to the right and 1.08 Nm/Kg (±.25, range 0.72-1.44) to the left, [ns ($p<0.170$]. The ISG had an average torque of

0.99 Nm/Kg (±.23, range 0.58-1.4) towards the convexity of the curve and 0.96 Nm/Kg (±.1, range 0.81-1.16) towards the concavity [ns (p<0.3)].

In the 36° pre-rotated position, rotating toward the midline (36 Hi) the CG had an average torque of 1.19 Nm/Kg (±0.23, range 0.89-1.6) to the right and 1.1 Nm/Kg (±.3, range 0.7-1.8) to the left, [ns (p<0.1)]. The ISG had an average torque of 1.1 Nm/Kg (±.29, range 0.54-1.54) towards the convexity of the curve and 1.06 Nm/Kg (±.17, range 0.74-1.32) towards the concavity [ns (p<0.3)].

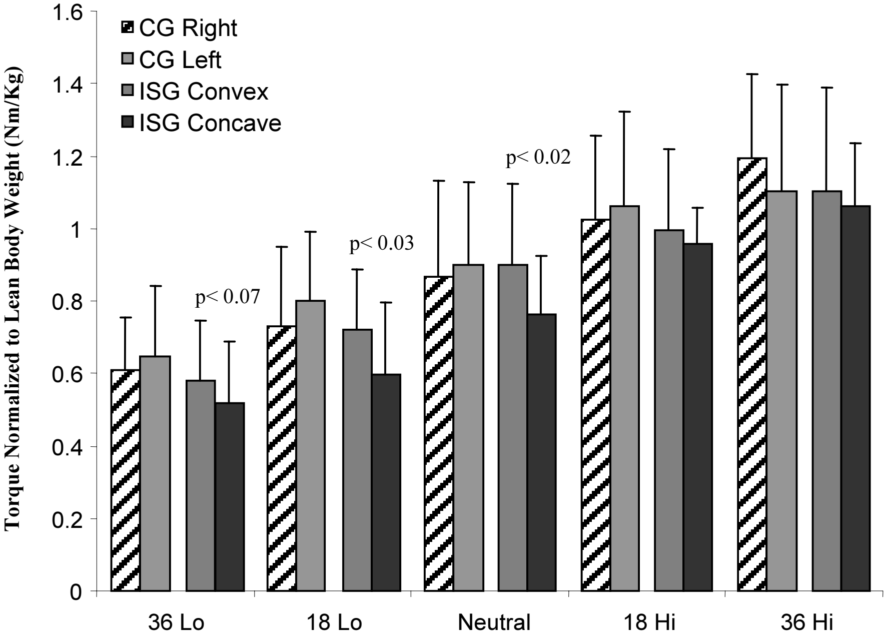

Figure 1 Torque normalized to lean body weight for the control group (CG) and the idiopathic scoliosis group (ISG). Concave values at 36 Lo, 18 Lo, and neutral positions were significantly lower than the convex values. There were no other differences.

Conclusions

No previous studies have examined trunk rotational strength asymmetry in a healthy adolescent group with a comparison to a patient group with idiopathic scoliosis. There are a number of studies that have reported no trunk rotational strength asymmetry in the adult population,[3-10]. Two pilot studies reported individual trunk rotational strength asymmetry in patients with idiopathic scoliosis, but no group statistics [1, 2].

This preliminary study has measured trunk rotational strength in a scoliotic patient population as well as a non-scoliotic adolescent population. It appears that individuals with scoliosis have a statistically significant weakness when rotating towards the concavity of the curve in what we have termed the “low force arc”. Simply, the “low force arc” is any torque contraction while rotating away from the neutral position. A trunk rotational strength asymmetry does not exist in a healthy adolescent population.

We are interpreting these results with caution because our numbers are so low. While we agree that there is most likely a trunk rotational strength asymmetry in the scoliotic population, we are not convinced that the weakness is only in the low force arc and neutral position. The two groups (CG and ISG) were not compared to each other because they were not matched for age, pubertal status, and activity, all of which has been found to be influential in strength measurements. More subjects are being recruited and will be studied in this project.

Acknowledgements

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Intra-Operative Spinal Load and Displacement Monitoring: Towards a Better Understanding of Scoliosis Correction Mechanics

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Abstract. Surgical correction of scoliosis reduces deformation and improves overall function and esthetics. Understanding and monitoring of mechanics during scoliosis surgery is an invaluable tool to optimize correction without compromising patient safety. Our objective was to use intra-operative monitoring tools to study how spinal load and displacement relates to obtained correction and chosen instrumentation. Instrumented pedicle screws, a "gripper" and active markers were developed. Instrumented pedicle screws provided three-dimensional forces at the screw-vertebra interface while the instrumented "gripper" measured the force and the rotation applied by the surgeon to the rod rotator. Vertebral displacement was monitored with light-emitting diodes and motion capture technology. These instruments were used successfully with 16 scoliosis subjects. Analysis of applied force, displacement, and curve flexibility influence on correction percentage is the long term goal. Raw results for instrumented screws and gripper showed that recorded force decreased with respect to percentage of correction obtained. Measured force increased with respect to the pre-surgical Cobb angle while percentage of correction obtained decreased as pre-surgical Cobb angle increased. Active marker results showed three-dimensional vertebral rotation and translation during correction, with axial rotation and caudal-cranial translation having the greatest magnitudes. Using greater correction forces does not necessarily result in an increased correction; flexibility and Cobb angle also play a role in the mechanics of correction. Further data collection will provide better understanding of the interconnected role between these factors helping complete the description of surgery mechanics.

Keywords. scoliosis, biomechanics, intra-operative measurements

1. Introduction

Scoliosis is a three-dimensional deformation of the spine. Magnitude of deformation is often quantified through the Cobb angle [1] measurement. When the magnitude of the Cobb angle exceeds 40 degrees in a growing child, surgery may be recommended to prevent further deformation, which could result in decreased lung function and other permanent consequences. Different techniques are used to correct the deformation. The Cotrel-Dubousset (C-D) [2] derotation procedure is widely used. Its main advantage is the three-dimensional correction it provides. As with other techniques, possible concerns such as over and under-correction can hinder patient safety or prevent them from obtaining an optimal correction which reduces esthetic and functional correction. The success of the C-D procedure is well documented [3] but the mechanics involved in the surgery have yet to be completely quantified. A better understanding of the mechanics of surgery will provide valuable quantifiable information to be used for example in the surgical simulations [4-6] and the surgical simulators being developed [7,8]. The measurement of quantifiable values intra-operatively has always been important in the advancement of surgical techniques and improvement of patient safety during surgery [9-11].

2. Objective

The objective of this work was to use intra-operative measurements to further the understanding of scoliosis correction surgery. The relationship between quantitative intra-operative measurements and patient-specific factors such as percent correction, pre-operative Cobb angle and number of instrumented vertebrae were studied.

3. Materials and Methods

Three intra-operative tools were designed to monitor the different forces and displacement involved in scoliosis surgery. The “gripper” [12] was developed as an attachment for the rod rotator to determine the force and moment applied by the surgeon and the rotation during the derotation maneuver. The instrumented hooks and screws [13] were developed to measure the three-dimensional force and moment acting at the implant-vertebra interface. The active markers [14] were used to determine the three-dimensional vertebral motion during the correction procedure.

The first step was to incorporate these tools in scoliosis surgery to ensure that the surgeons were comfortable with them and that patient safety was not compromised due to the increase in time. Subsequently, observation and study of intra-operative measurements were performed. Quantitative results from 16 healthy scoliosis patients with an average Cobb angle of 59.2° ± 16.5° were obtained with the intra-operative instruments. The analysis focused on determining the relationship between the quantitative results and the overall improvement of subject. The percentage of correction was used as the quantifiable value for subject improvement. The relationship between the intra-operative measurements and additional patient specific factors was studied. These factors were: percent correction, pre-operative Cobb angle, as well as the number of vertebrae instrumented. By studying how the intra-operative measurements vary as a function of these factors, a better understanding of the mechanics involved in scoliosis correction was obtained.

4. Results

Graphical representation of the intra-operative measurements is found in Figures 1 to 3. The instrumented screws measurements (n=6) are represented in Figure 1. The forces for the instrumented screws are plotted as a function of the percent correction, the initial Cobb angle and the number of vertebrae instrumented (Figure 1).

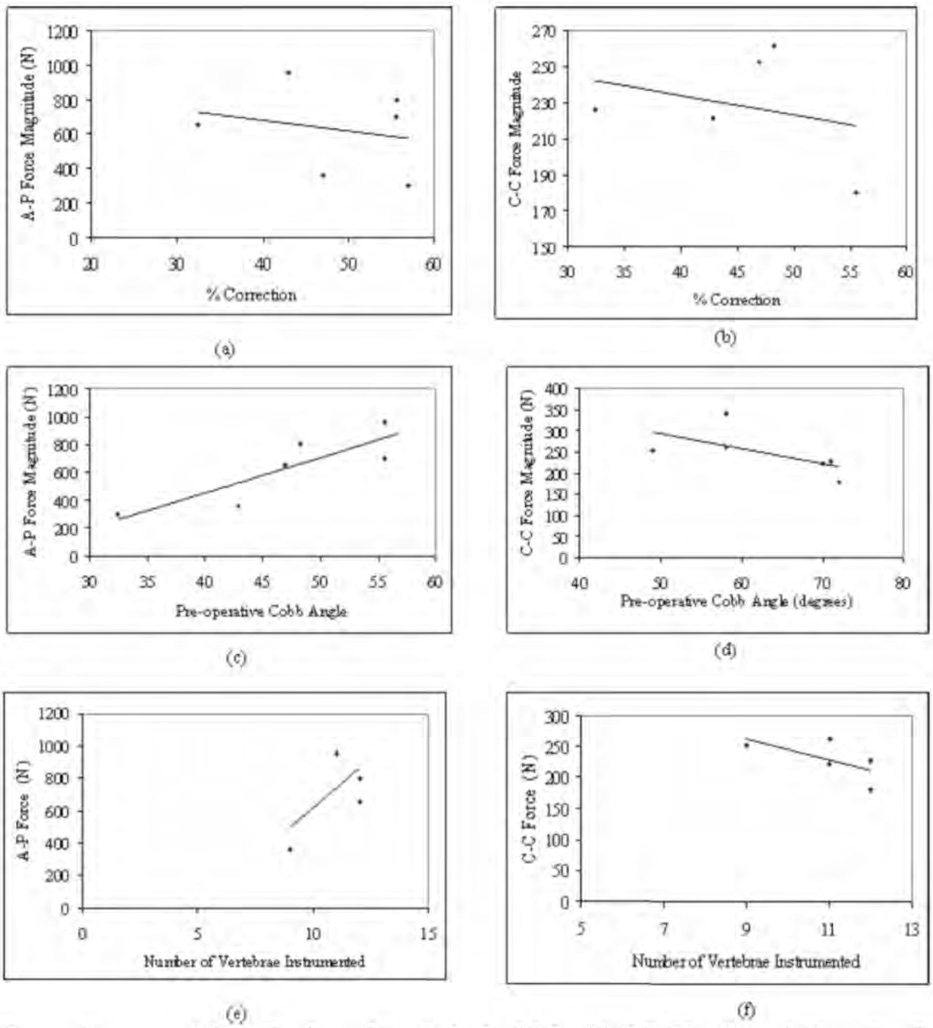
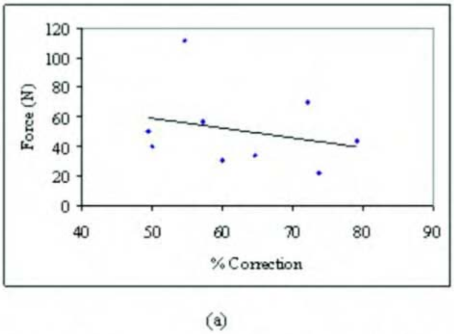


Figure 1: Instrumented Screw Results: (a) Force in the Caudal-Cranial (C-C) Direction vs % Correction; (b) Force in Anterior-Posterior (A-P) Direction vs % Correction; (c) Force in the A-P Direction vs pre-surgical Cobb Angle; (d) Force in the C-C Direction vs pre-surgical Cobb Angle; (e) Force in A-P Direction vs number of instrumented vertebrae and; (f) Force in C-C Direction vs number of instrumented vertebrae.

The developing trend shows that the force decreases in both the caudal-cranial and anterior-posterior direction as the percentage of correction increases. Figure 1c shows, as expected, that greater pre-surgical Cobb angle does require a greater anterior-posterior force during the correction. The force in the caudal-cranial direction does not follow then same trend (Figure 1d) which could be due to the larger Cobb angles producing a greater distance, hence lever arm, between the initial (pre-surgical) position and the desired position. A smaller lever arm will require a greater force to produce the same displacement. The behaviour of forces as a function of instrumented vertebrae is also different between the anterior-posterior and the caudal-cranial direction. The force in the anterior-posterior direction increases as the number of implant increases while the force in the caudal-cranial has an opposite behaviour The relationship between the number of implants and the intra-operative force measurements show that the implants restrict the motion in the anterior-posterior direction.

Similarly, the gripper measurements (n=9) were plotted as a function of % correction and pre-operative Cobb angle, shown in Figure 2. The force measured by the gripper shows a similar trend for the applied surgeon force on the rod rotator. The force used by the surgeon on the rod rotator increases as the pre-operative Cobb angle increases. The rotation measured by the inclinometer always reaches the maximum value of 90 degrees. The force measured by the gripper changes direction over time, from anterior-posterior to medial-lateral due to this rotation. The force applied directly by the surgeon is lower than the force measured at the screw-vertebra interface, as the maximum force measured by the instrumented screws in the anterior-posterior direction is significantly higher than the maximum force recorded by the gripper, by an approximate factor of 10.



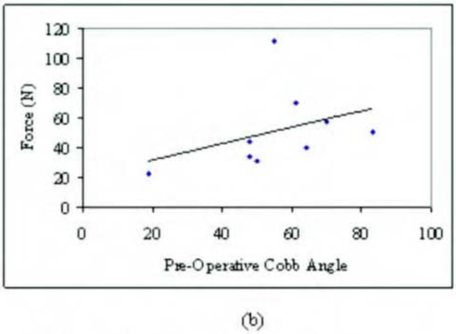


Figure 2: Gripper Results: (a) Surgeon Force as a function of % Correction and; (b) Surgeon Force as a function of pre-surgical Cobb Angle

A sample active marker rotation and translation results are summarized in Figure 3 (n= 1). The results are presented as the difference between the minimum and maximum position values measured by the markers.

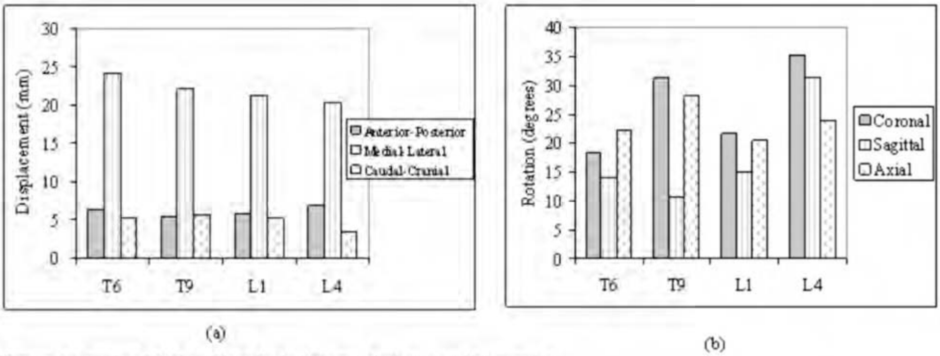


Figure 3: Active Marker Results in (a) translation and (b) rotation

In addition to illustrating the three-dimensional correction in translation and in rotation, active marker results complement the force measurements in the three anatomical planes. They illustrate if the larger vertebral displacements occur in the same planes as the larger force at the implant-vertebra interface as well as if there is truly a three-dimensional correction occurring through a three-dimensional rotation of each vertebrae. As shown by Figure 3, the greatest vertebral rotation occurs in the coronal plane, which corresponds to forces in the caudal-cranial and medial-lateral directions. The greater translation occurs in the medial-lateral direction, which corresponds to coronal translation correction. Other direction translations are significantly lower. It is interesting to note that the displacement in the caudal-cranial direction is close in value to the anterior-posterior direction whereas the force is significantly larger in the latter direction, as per the instrumented screws results. This provides insight on the spinal stiffness in the different anatomical planes and on the required force in each direction to provide optimal correction.

5. Conclusions

The information and subsequent analysis is one step in the overall project of mathematically defining the mechanics of scoliosis correction using intra-operative measurements. The incorporation of the instruments in surgery and the resulting analysis is outlined in this work. By combining the information from all three instruments, mechanical behaviour of the spine during scoliosis correction can be quantified. Preliminary analysis shows that anterior-posterior direction is much stiffer, as largest implant-vertebrae forces are measured in that direction and translation recorded with the active markers is similar to translation in caudal-cranial direction. Trends developing by combining results from several surgeries show that a larger pre-surgical Cobb angle increases the required force in the anterior-posterior direction while it decreases the required force in the caudal-cranial direction. As expected, results show the spine anisotropic behaviour. Additional intra-operative data is required to strengthen the relationships between the different factors. In parallel to data collection, the existing data can be used to validate a surgical simulator being developed by this team which can subsequently be used in pre-surgical planning. Finally, once the surgical simulator can provide the surgeons with approximate forces and displacement required to obtain maximum correction, the intra-operative monitoring tools can be used as a feedback tool ensuring the surgeons that they are using force which results in the optimal correction.

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A Controlled Prospective Study on the Efficacy of SEAS.02 Exercises in Preparation to Bracing for Idiopathic Scoliosis

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Abstract. The Lyon school has proposed a preparation to brace wearing through an intensive mobilization in order to obtain a better reduction of the braced scoliotic curve. Our aim was to verify this hypothesis. Design: a prospective controlled study on consecutive patients having idiopathic scoliosis with brace management. Outcome: results after 5 months of brace wearing were reviewed by radiographic examination without the brace. Treatment: SEAS Group exercises according to the protocol SEAS.02 (Scientific Exercises Approach to Scoliosis, version 2002); CONT Group various type of exercises. Population. 110 patients (34 females), 13.5±2.4 years, 31.1°±11.1° Cobb (°C), 14.4°±6.0° Bunnell (°B). All parameters improved at follow-up in both groups. SEAS had better results than CONT for °C. Clinical results (variations of at least 5°C and 2°B) were better in SEAS than CONT. This study proves the efficacy of SEAS.02 exercises preparatory for bracing. Bracing demonstrated its short term efficacy.

Keywords. Idiopathic scoliosis, Physical exercises, Bracing Controlled study

1. Introduction

It has been hypothesized that exercises can reduce brace side-effects such as paravertebral hyposthenia, breathing difficulties or reduced co-ordination[1] [2].
Even though many centres (Milwaukee, Boston, Lyon) have claimed a synergy between exercise and braces, there is no published research supporting this hypothesis.
In particular, the Lyon centre has proposed that preparation for brace wearing through intensive mobilization obtains a better reduction of the braced scoliotic curve [2]. Our aim was to verify this hypothesis.

2. Materials and Methods

This is a prospective controlled study on idiopathic scoliosis patients with a brace prescription: all patients corresponding to the inclusion criteria were enrolled consecutively.

The results before treatment and after 5 months of wearing were obtained using radiographs without the brace and a medical evaluation; each patient was examined by the same physician and braces were made by the same orthopaedic workshops.

2.1. Treatment

The groups compared were identified through self-selection by the patients.
The SEAS Group performed exercises according to the protocol SEAS.02 (Scientific Exercises Approach to Scoliosis, version 2002), learning individually adapted exercises at a centre specializing in scoliosis treatment (1.5 hours single sessions every 2-3 months) with further exercises in a facility nearer home twice a week (40 min) plus 1 exercise daily (5 min).
The CONT Group performed exercises at a local facility according to the protocol developed by the single treating therapist, usually 2-3 times a week for 45 to 90 minutes.

2.2. Population

SEAS: 40 patients (33 females), 13.3 ±2.1 years, 30.6° ±10.8° Cobb (°C), 14.4° ±6.3° Bunnell (°B). CONT 70 patients (61 females), 13.6 ±2.6 years, 31.3° ±11.3°C, 14.3° ±5.9°B.

2.3. Statistical analysis

T-test for uncoupled data, Mann-Whitney, Fisher's Exact and chi-square with $\alpha = 0.05$.

3. Results

At the baseline there were no differences between SEAS and CONT, and all parameters improved at follow-up in both groups.
SEAS had better results than CONT for °C: all curves (-5.7 ±5.6° vs. -3.4 ±6.0° - $P<0.05$), more severe curve (-6.7 ±4.7° vs. -3.5 ±6.0°- $P<0.05$) and lumbar localization (-6.9 ±5.8° vs. -3.9 ±6.8°- $P<0.05$), with a tendency for thoracic (-4.6 ±5.2° vs. -2.6 ±5.1° - P=0.06) and thoraco-lumbar (-7.44 ±5.2° vs. -4.7 ±6.0° - P=0.09).
SEAS had better results for Aesthetics (Figure 1).
Clinical results (variations of at least 5°C and 2°B) were better in SEAS than CONT (Figure 2): radiographically (°C) 58.0% improved, 1.5% worsened vs. 45.8% and 10.3% respectively ($P<0.05$), while clinically (°B) 81.5% improved, 2.0% worsened vs.81.9 % and 8.3% respectively ($P<0.05$).

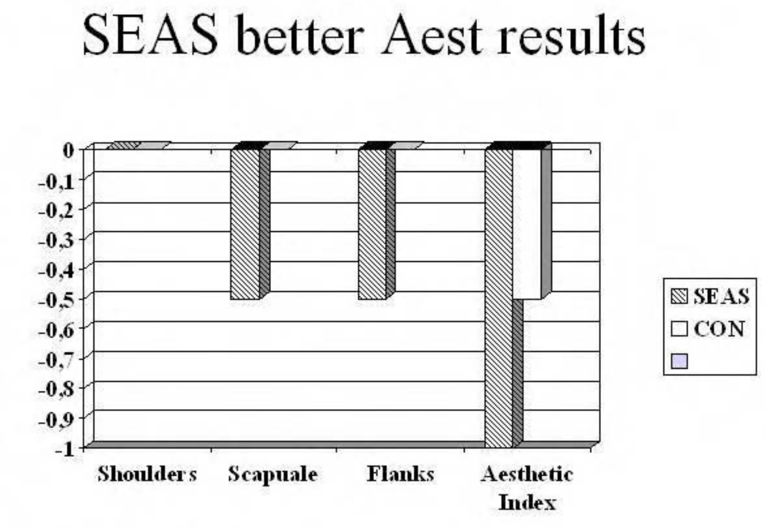

Figure 1

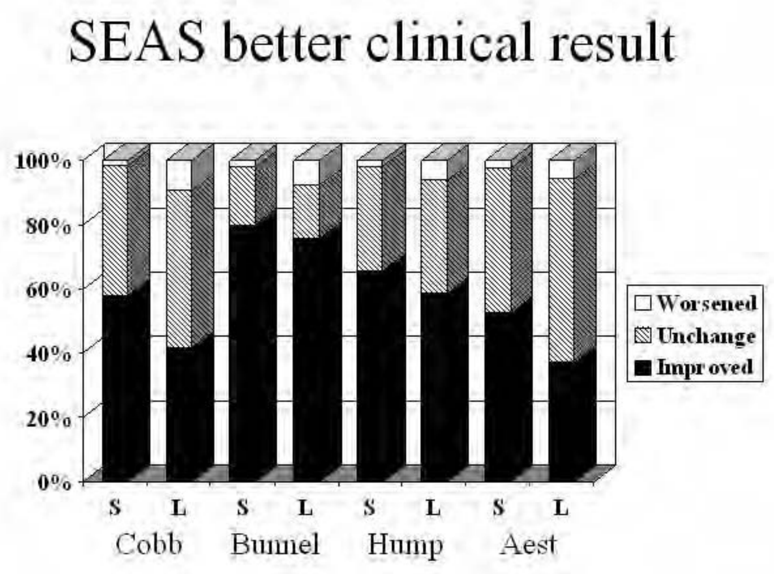

Figure 2

4. Discussion

This study demonstrates the efficacy of SEAS.02 exercises preparatory for bracing.

Bracing established its short term efficacy in a highly progressive population; even if completing the treatment is was obviously necessary to have some final results.

The study design was considered adequate in order to verify the effectiveness of the preparatory exercises, because radiographs taken without the brace documented the actual results, as well as any short term benefits most likely to have been influenced by exercises preparatory to bracing.

We could discuss the clinical significance of 3°C reduction when compared to controls, but it should be understood that it correspond to 10% of the total curve, and that is twice as much as what could be obtained with inadequate exercises (6°C reduction vs. 3°C).

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A Controlled Prospective Study on the Efficacy of SEAS.02 Exercises in Preventing Progression and Bracing in Mild Idiopathic Scoliosis

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Abstract. There is low evidence on the possible efficacy of exercises to treat idiopathic scoliosis, graded as C by the existing Italian Guidelines. Our aim was to verify if exercises quality has an effect on results.Design: prospective controlled study on idiopathic scoliosis patients that performed only exercises to avoid progression. Treatment: SEAS Group make exercises according to the protocol SEAS.02 (Scientific Exercises Approach to Scoliosis, version 2002). The CONT Group performed exercises at a local structure according to different protocols preferred by the treating therapists. Population. SEAS: 48 patients (37 females), 12.5±2.2 years, 15.1°±5.7° Cobb (°C), 9.0°±3.3° Bunnell (°B). The difference in the number of braced patients within the first year has been almost statistically significant (P=0.07): 1 in SEAS vs. 5 in CONT. Cobb degrees improved with treatment (P<0.05) only in the SEAS group. Clinical results (variation of at least 5°C or 2°B) were better in SEAS than CONT. Not all exercises for scoliosis have the same efficacy: this study proves the short term efficacy of SEAS.02 when compared to usual care.

Keywords. Idiopathic scoliosis, Physical exercises, Rehabilitation, Controlled study

1. Introduction

There is evidence supporting the efficacy of exercises alone in treating idiopathic scoliosis [1-6] graded as C (multiple controlled non-randomised studies, whose results are consistent with each other) by Italian Guidelines [5].
In the daily clinical practice, results are sometimes poor, but this could depend on the quality of the exercises used. Our aim was to verify if exercise quality has an effect on results.

2. Materials and Methods

This is a prospective controlled study on idiopathic scoliosis patients that performed only exercises to avoid progression; all patients meeting the inclusion criteria were enrolled consecutively.

The results consider findings from the first year of radiological follow-up. Each patient was always evaluated by the same physician. The groups compared have been identified through self-selection by the patients.

2.1. Treatment

The SEAS Group performed exercises according to the protocol SEAS.02 (Scientific Exercises Approach to Scoliosis, version 2002) based on active self-correction learning (Figure 1) with individually adapted exercises at a specialist scoliosis centre for treatment (1.5 hours single sessions every 2-3 months) with further exercises at a facility near home twice a week (40 min) plus 1 exercise daily (5 min).
The CONT Group performed exercises at a local centre according to the preferred protocol of the single treating therapist, usually 2-3 times a week per 45 to 90 minutes.

2.2. Population

SEAS: 23 patients (18 females), 12.7 ±2.2 years, 15.3° ±5.4° Cobb (°C), 8.9° ±2.8° Bunnell (°B). CONT: 25 patients (19 females), 12.1° ±1.1 years, 14.9° ±6.0°C, 9.1° ±3.7°B.

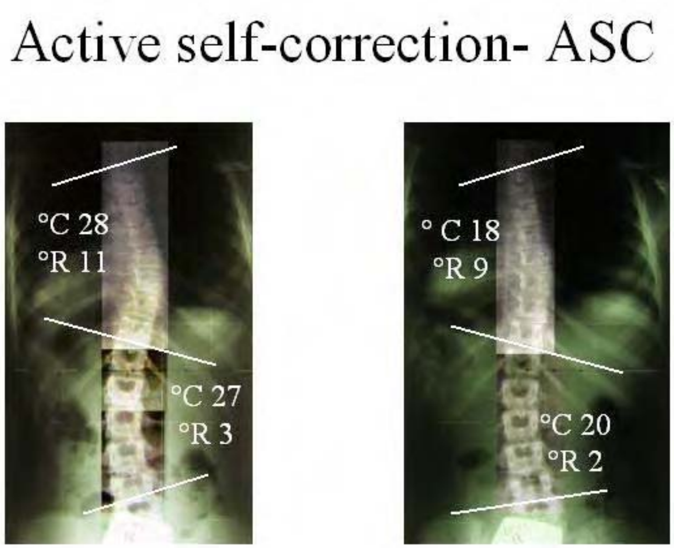

Figure 1

2.3. Statistical analysis

Analysis employed the T-test for uncoupled data, Mann-Whitney, Fisher's Exact and chi-square with $\alpha = 0.05$

3. Results

No statistically significant difference was been found between the two groups at the baseline.
The difference in the number of braced patients within the first year approached statistical significance (P=0.07): 1 (4.3%) in SEAS vs. 5 (20%) in CONT (Figure 3).
The Cobb angle improved with treatment (P<0.05) only in the SEAS group (Figure 2) in the total of curves (-3.2±6.2°), worst curve (-2.6±5.2°) and thoracic localization (-3.1±5.1°) with a trend (P<0.1) for thoracic (-3.1±5.1°) and thoraco-lumbar (-1.7±2.7°) being found.
Clinical results (variation of at least 5°C or 2°B) were better in SEAS than CONT: radiographically (°C) 28.9% improved and 2.7% worsened vs. 5.0% and 12.9%; clinically (°B) 30.4% improved and 13.1% worsened vs. 36.4 % and 27.3%.

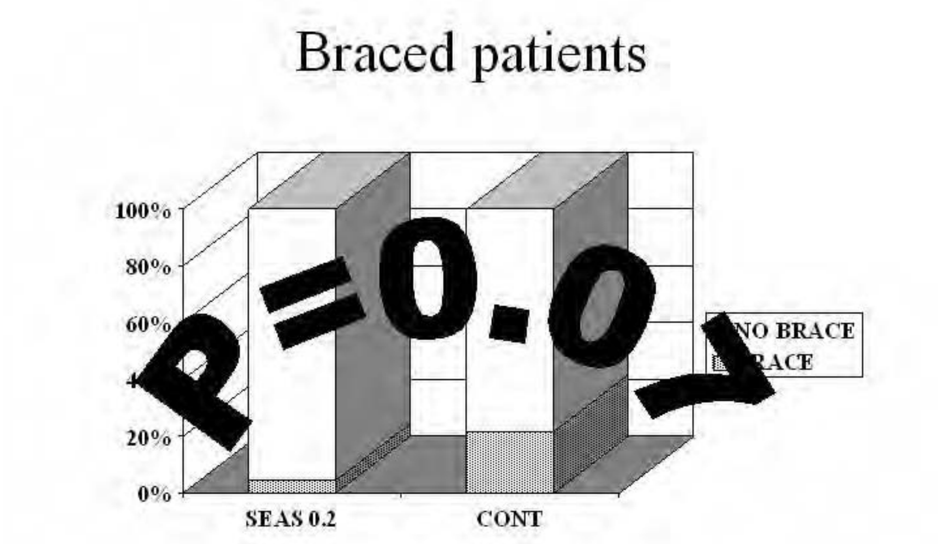

Figure 2

4. Discussion

Not all exercises for scoliosis have the same effectiveness [2]. This study indicates a short term effectiveness of SEAS.02 when compared to normal treatment methiods.

In the age at risk, the group with the qualitatively better treatment (SEAS) demonstrated an improvement of their median values; furthermore, the less effective treatment allowed a higher stabilization if compared to the natural history. The difference in terms of bracing has been impressive, with 83% of prescribed braces (5 out of 6) in CONT: this datum documents the clinical value of SEAS.

The quality of work is crucial in this field: if the therapeutic team is not trained adequately in all its components, results cannot be guaranteed. Limitations of the study is the relatively short control time, but it was focused on the most critical period.

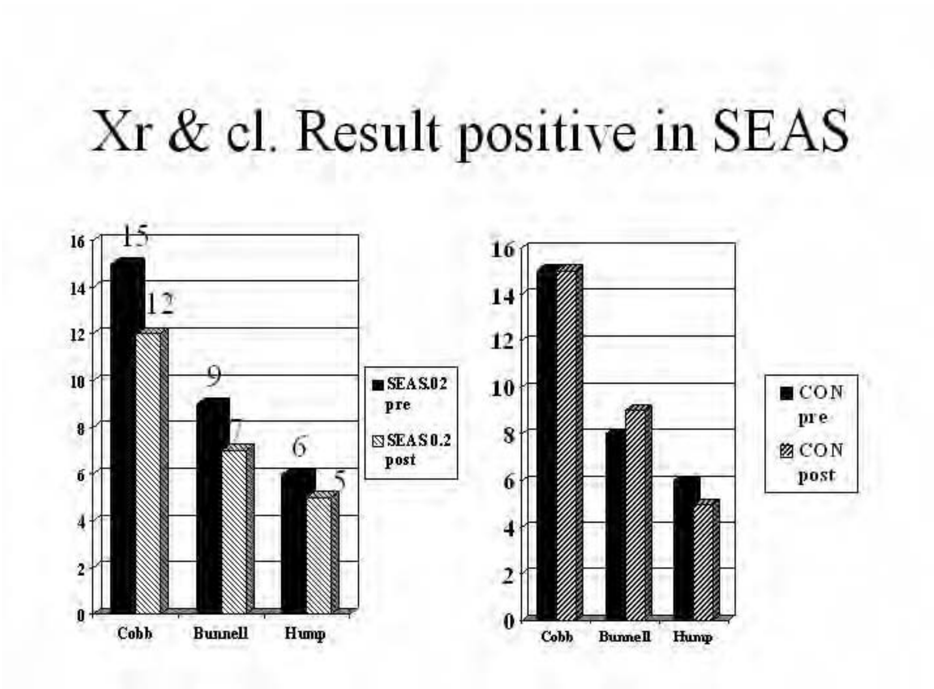

Figure 3

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Research into Spinal Deformities 5
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An Innovative Diagnostic Procedure of Vertebral Deformities without Exposure to X-Rays

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Abstract. The objective of the study was to compare standard manual X-ray measurements of vertebral deformities and values obtained from the Ortelius 800. 52 patients (41 females and 11 males: mean age 20.35 years) with adolescent vertebral deformities, was studied. The patients were evaluated with standard radiographic views and the Ortelius 800. The parameters considered for the comparison were the angles of scoliosis and kyphosis and the values of global axial deformity, shoulder asymmetry and pelvic tilt. We also evaluated the modification of pelvic/shoulder angle after surgery (this parameter allows to evaluate vertebral rotation and can be derived only from the Ortelius 800). This study allowed us to conclude that there is a perfect agreement between measurements with the Ortelius 800 and those resulting from standard x-rays. The system has also proved to have the capability of quantifying changes in vertebral rotation.

Keywords. Vertebral deformities, Diagnosis, Ortelius 800, X-Rays, Non-invasive

Introduction

The radiographic examination has always constituted and still constitutes the standard procedure for diagnosis and follow-up of the progression of vertebral deformities. However, this means that the patients affected by vertebral deformities are exposed to relatively high doses of ionizing radiation (average of 10.8 cGy) in the course of their life. Moreover, exposure to radiation occurs during a period of life when growth is rapid, potentially amplifying any deleterious biological effects. The organs most vulnerable to radiation injury due to spinal radiographs are the breast, thyroid, ovaries and bone marrow. Thus, scoliosis patients have a significant risk consequential to radiation exposure. A retrospective cohort study conducted in 5573 female patients with scoliosis found that women with scoliosis or abnormal curvature of the spine, who were exposed to multiple diagnostic x-rays during childhood and adolescence, were found to have a 70% higher risk of breast cancer as compared to women of the general population [1,2,3,4,5]. Furthermore, as the deformity of a vertebral column affected by scoliosis evolves in three planes, the corrected interpretation of its progression should be three-dimensional. This is impossible with the traditional x-rays. Consequently, it is very important to find new methods capable of studying the spine in the three planes, avoiding at same time an excessive exposure of the patient to ionizing radiations.
The Ortelius 800 (Fig. 1) is the system that we have developed. It is a non-invasive radiation-free system that allows both a graphical reconstruction of the spine (Spine

Scan examination), and a complete postural study of the patient (Body Balance examination), allowing the possibility of real time diagnosis of vertebral deformities and their consequential effect on body balance. It consists of a main console, a magnetic field generator and a fingertip sensor. Firstly, the examiner measures the vertebral rotation with the aid of a Scoliometer [6] and palpates the spinous processes of the vertebrae (C7 to L5) using the fingertip sensor (Spine Scan). Upon completion of this examination, the system instantaneously creates a graphical reconstruction of the spine, displaying the calculated Cobb angle [7] of deformity (Fig. 2,3). Then, the examiner proceeds with the Body Balance examination, recording specific body landmarks (mastoid process, C7, acromion-clavicular joints, anterior superior iliac spines, posterior superior iliac spines, sacrum, greater trochanters). Using the recorded landmark data, body balance can be analyzed by the system.

Figure 1

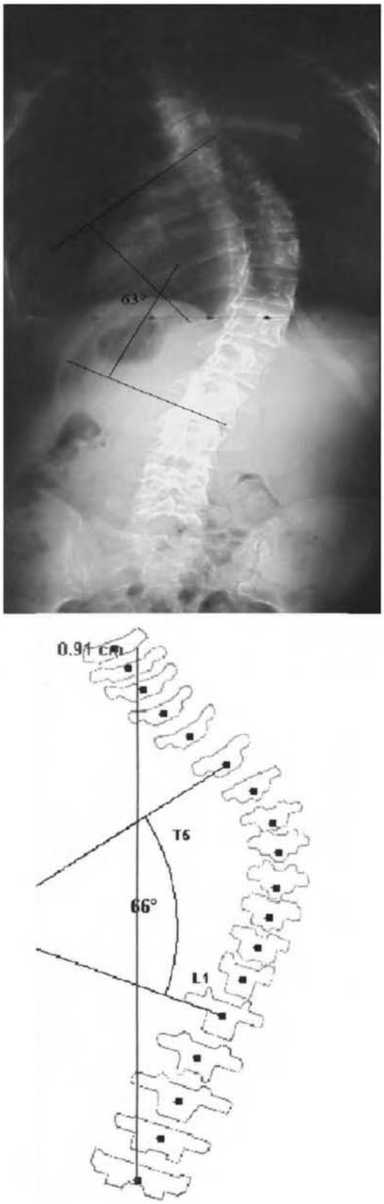

Figure 2

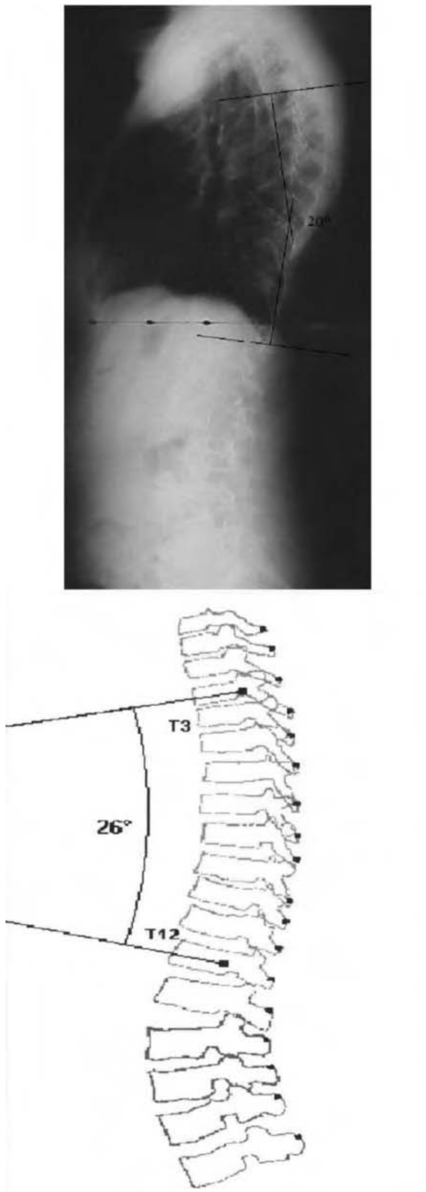

Figure 3

Aims of study

The aims of the study were to check: 1) whether there is agreement between standard manual X-ray measurements of vertebral deformity, expressed in degrees (Cobb method), and the values resulting from the Ortelius 800 (statistical comparison);

2) whether numerical values, calculated on standard radiograms, as an expression of global axial deformity (in the frontal plane) of the spine also match those obtained with the Ortelius; and 3) the capability of the Ortelius 800 test to integrate information supplied by standard postoperative X-rays, and in particular data concerning transverse de-rotation of the spinal axis.

Materials and Method

The study involved a group of 52 patients (41 females and 11 males: mean age: 20.35 years), with adolescent vertebral deformity, in all cases prevalent in the frontal plane. 26 subjects were assessed in outpatient clinics and had a deformity which did not require surgical treatment at the time; 26 had a deformity requiring surgical treatment, which was performed at Istituto Ortopedico Rizzoli, Department of Vertebral Surgery and Traumatology, Bologna, between October 2003 and September 2004. Radiographic assessment was based on two standard views, namely antero-posterior (AP) and latero-lateral (LL), of the entire spine on one long film, with load bearing. Controls with the Ortelius 800, consisted of two tests, Spine Scan and Body Balance. These were undertaken on the conservatively treated patients at the outpatient unit during routine follow-up and on patients undergoing surgical treatment on the day before the procedure and postoperatively as soon as they could stand erect and had already had load-bearing radiograms (in this case only the Body Balance test could be performed).

Results

The 52 patients were assessed globally and then broken down into four groups, two of which were based on the site of the main scoliotic curve (thoracic or lumbar) and two based on the angle value of the scoliotic curve (< 50° or ≥ 50°). Further assessment was then undertaken in the surgically treated patients. The parameters considered for the X-ray/Ortelius 800 comparison were: the angle value of the main scoliotic curve and of kyphosis, the value of global axial deformity, shoulder asymmetry and pelvic tilt. In pre- and post-operative assessments, the modification, resulting from surgical procedure, of the following parameters was evaluated: global axial deformity, shoulder asymmetry, pelvic tilt and rotation angle (this value can only be obtained with the Ortelius 800). The Pearson test was used for the X-ray/Ortelius 800 comparison and the Student t test for pre- and post-operative value comparison. Among the 52 patients being studied, a mean difference of 6.61° was detected for the main scoliotic curve, with a Pearson r coefficient of 0.95; whereas in the case of kyphosis a mean difference of 5.71° was observed, with a Pearson r of 0.88 (Table 1). A high statistical correlation has also been found when patients were broken down into 4 groups based on the site and angle value of the scoliotic curve. Obviously, the main difference was found in the group of patients with main scoliotic curve ≥ 50°. However, such a difference always fell within statistically acceptable values, with a mean difference of 7.16° and a Pearson r coefficient of 0.87. A high statistical correlation between X-rays and the Ortelius has also been found for the values of global axial deformity, shoulder asymmetry and pelvic tilt, in both the conservatively and surgically treated patients. In the latter, the Ortelius 800 allowed for assessment of pelvic shoulder angle change following surgery. The pelvic shoulder angle (PSA) is a parameter used to evaluate vertebral rotation and cannot be derived from standard radiographs. In the 26 surgically treated patients, a statistically significant (p = 0,0001) 4.20° reduction of pelvic shoulder angles was observed, which demonstrated the degree of the derotation produced by the procedure (Table 2).

Table 1

	52 CASES			
	SCOLIOSIS		KYPHOSIS	
	MEAN ± SD	RANGE	MEAN ± SD	RANGE
X-RAYS	51,67 ± 24,86	10 – 105	33,67 ± 14,33	5 – 72
ORTELIUS	49,36 ± 24,16	8 - 97	33,38 ± 14,46	0 - 62
DIFFERENCE	6,61		5,71	
PEARSON "r"	0,95		0,88	

Table 2

	PRE OPERATIVE		POST OPERATIVE		CORRECTION	"*t*" TEST
	MEAN ± SD	RANGE	MEAN ± SD	RANGE		
PSA	6,44 ± 5,15	0 - 27	4,00 ± 2,94	1 - 12	4,20	0,0001

Conclusions

This study allowed us to conclude that there is perfect agreement between measurements with the Ortelius 800 and those resulting from standard radiographs. The system has also proved to have the capability of quantifying changes in vertebral rotation. The Ortelius 800 or similar systems should therefore be included in the diagnostic equipment in scoliotic clinics to assess the pathology and their use will be crucial in the screening of large school populations.

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Research into Spinal Deformities 5
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Semi-Automatic Detection of Scoliotic Rib Borders Using Chest Radiographs

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Abstract. Stereoradiography is a well known technique to obtain 3D reconstructions of the rib cage. However, clinical applications are limited by the associated 2D rib detection method. Either this detection is widely supervised and time-consuming for the user, or it is fully automatic and not accurate enough for proper 3D reconstruction or clinical indices extraction. To address these issues, we propose a novel, semi-automated technique for detecting scoliotic rib borders in PA-0º and PA-20º chest X-ray images, using a modified edge-following approach. The novelty consists in following multiple promising edges simultaneously. Detections are initiated from starting points (input by the user) along the upper and lower rib edges and the final rib border is obtained by finding the most parallel pair among the detected edges. Promising results show the superiority of this approach over classical rib detection in terms of accuracy. Moreover, the proposed method is of great relevancy in the scoliotic context since scoliotic ribs present very few shape priors, due to their irregularities, and hence, standard rib detection techniques become unsuitable.

1. Introduction

Rib detection from chest radiographs has been widely investigated in the past two decades. Many different solutions have been proposed for detecting ribs in standard chest radiographs of normal patients [1,2,3,4,5,6,7], but very few concerned scoliotic patients [7,8]. In fact, many intrinsic characteristics of the scoliotic rib cage would make the classical rib detection methods fail. First, because of their great variability in shape and curvature, scoliotic ribs are not properly detected using parametric curve fitting techniques [1,2,3,4,6]. Also, techniques using global filtering approaches [1,4] often miss the edges at rib crossings because of their very faint contrast. In the scoliotic context, crossings and overlapping between ribs are frequent and cumbersome, making the use of global edge detection techniques totally obsolete. Model-based approaches [5,6,7,8] use a mean shape and a limited number of modes to explain the variance observed among rib cages in the training set. Although very good results have been reported using this method [8], only the midline of each rib is considered and full information about the actual rib border is lost. Finally, another drawback with the abovementioned automatic methods is that most of them only apply to dorsal parts of the ribs.

To overcome these issues, we propose herein a novel, semi-automated technique for detecting actual rib borders, for both dorsal and ventral parts of the ribs, using a modified edge-following approach with multiple-path branching.

2. Materials and Methods

Currently, at Sainte-Justine's research center, we are using a fully supervised technique which requires a technician to manually identify eleven points on the midline of each rib on two postero-anterior (PA-0° and PA-20°) X-ray images taken at different angles [9]. Rib midlines are reconstructed and generic rib models are fitted onto the reconstructed rib midlines to obtain the final 3D rib cage. The present results are accurate enough for clinical applications, but the technique is really time-consuming for the user. Typically, it takes about two hours to manually identify all the points on all the ribs in both PA-0° and PA-20°. Yet another major limitation with this technique is that only rib midlines are considered for reconstruction. Thus, any specific shape information about the actual rib border is lost. Our goal is to develop a rib detection technique that would output the true rib borders, while being fast and accurate. In the scoliosis context, where very few shape priors are available, slight semi-automation, with human intervention for the missed ribs, was considered a better approach than full automation. In the proposed solution, the technician needs only identify four points by rib, located on the upper and lower borders near both rib ends. As shown in Figure 1, these points, referred to as *OS*, *OE*, *IS* and *IE*, are very easy to identify.

Figure 1. An illustration of the required four user input points per rib. OS = "outer-start", IS = "inner-start", OE = "outer-end" and IE = "inner-end". For a specific rib, the inner border is defined as the one staying closer to the spine.

2.1. Edge-following

Given a starting point and initial direction on a rib's edge, the proposed edge-following algorithm applies a step-by-step directional filtering and scanning approach to choose the directions to take at each encountered pixel. The chosen step is 5 pixels and, at each step, many promising directions can be taken simultaneously, based on a gradient strength model developed for this application.

Once the four starting points have been clicked by the user, the edge-following algorithm is successively run from each of these four points. The novelty here, as mentioned above, contrary to classical edge-following, is that many borders are followed simultaneously, allowing many branching edges to be detected from each of the four starting user points. Intersections between outer borders from OS and OE are then expected, as well as intersections between inner borders from IS and IE. Two sets of all intersecting borders (outer and inner) are then created for each rib.

2.2. Most parallel paths retaining

Once both outer and inner intersecting border sets have been created, the problem of finding the actual rib border resumes itself to finding the most parallel pair of borders. This is justified by the fact that even in the scoliotic context, each single rib outer and inner borders are approximately parallel to each other, no matter how bent the rib is. However, the problem of computing the amount of perceptual parallelism between two curves is a hard one. Recent techniques [10] are not suitable in the present case because short computing times are needed. To solve this problem we propose thereafter a very simple parallelism criterion, while retaining not only the most parallel border solution, but a group of most parallel border solutions. Eq. (1) shows a simple thickness function $\psi(k)$ between two borders IP_i et IP_j.

$$\psi(k) = \min\left\lfloor \sqrt{(x_{ik} - x_{jl})^2 + (y_{ik} - y_{jl})^2} \right\rfloor, \forall l \in \overrightarrow{IP}_j \tag{1}$$

where x_{ik} is the x coordinate of the k^{th} point in IP_i. The same reasoning applies for x_{jl}, y_{ik} and y_{jl}. A simple parallelism criterion ρ_{ij} is then obtained in Eq. (2) by summing square differences between thicknesses $\psi(k)$ and the mode thickness $\eta(\psi(k))$.

$$\rho_{ij} = \frac{1}{\sum_{k=1}^{N} \left(\psi(k) - \eta(\psi(k))\right)^2} \tag{2}$$

For every pair in the intersecting sets, the proposed parallelism criterion is computed. Pairs are grouped in clusters using the K-means algorithm. Then, the cluster with the highest mean parallelism criterion is retained.

2.3. Smoothest path Retaining

Among all the borders in the retained cluster, only the smoothest one, in terms of internal energy [11], is retained. Finally, a cubic spline is passed through all the detected points forming the smoothest retained border. Figure 2 shows the block diagram of the proposed method.

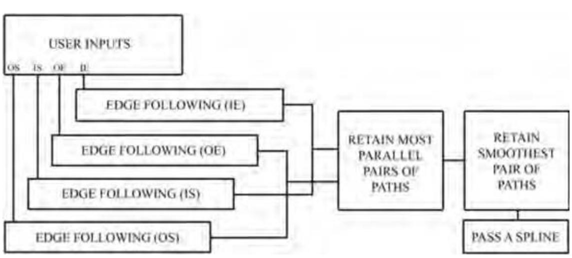


Figure 2. The proposed method. Boxes represent logical units and lines indicate program flow.

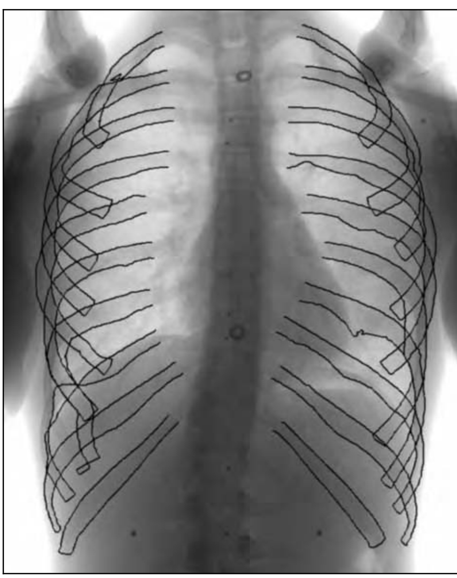
3. Results

Detections have been run on seven chest radiographs (five PA-0º and two PA-20º). All of them were from scoliotic patients. Quantitative validation has yet to come. Table 1 shows the qualitative results obtained in terms of rib detection validity. A “valid” detected rib is defined as a followed rib border whose thickness function stays between lower and higher predefined thickness limits. To define those limits, actual rib border pixels were sampled from 30 X-ray images and thickness functions were computed for all the ribs. A mean thickness was obtained for each rib level (rib T1 to T12) and limits were set separately for each rib level at ± 3 standard deviations about the mean.

Table 1. Rib detection results. Number of ribs per radiograph on which the algorithm was run, number of valid detected ribs per radiograph and percentage of valid detections.

Radiograph #	1	2	3	4	5	6	7
Radiograph view	PA0	PA0	PA20	PA20	PA0	PA0	PA0
Nb of ribs considered	20	21	22	20	22	22	20
Nb of valid ribs detected	18	17	17	16	17	18	18
Percentage of valid ribs	90.0	80.5	77.3	80.0	77.3	81.8	90.0

Figure 3 and Figure 4 show the first two detections in Table 1. The detected borders are delineated in black. In the first X-ray, the algorithm was run for 20 ribs (T2 to T11) whereas in the second, it was run for 21 ribs (T2 to T12, with rib T11 left omitted because it was not visible).



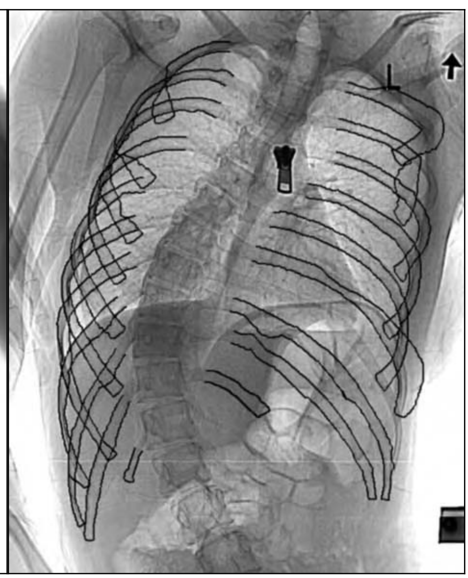


Figure 3. Detection results. Radiograph #1.

Figure 4. Detection results. Radiograph #2.

4. Discussion and Conclusion

By looking at Figure 3 and Figure 4, we can appreciate the quality of these results as most of the detected ribs seem to be precisely delineated and neither rib crossings nor overlapping structures seem to have interfered with the detection behavior. However, low-contrast parts of some ribs made the edge-following algorithm temporarily loose track of the true rib edge, resulting in some very strange detected rib borders. Also notice that rib T8-left in Figure 4 has been completely left undetected. This is explained by the fact that none of the borders from any of the four starting points intersected each other. This behavior is undesirable in the context of this work. We would expect the algorithm to propose a solution for every rib, even if it's not optimal. It would then be the user's task to choose whether to accept the detected rib or to manually correct it. Future work will address this issue. On the other hand, by looking at Table 1, the mean percentage of valid ribs is 82.5 %. This means that human intervention would only be required in less than 20% of the detected ribs. We believe that falsely-detected rib borders could be easily and rapidly corrected by human intervention in a post-processing stage with a simple interface that is yet to develop.

In conclusion, these results are very promising and indicate that reconstructions of actual rib borders are feasible in the scoliosis context. In fact, the proposed method calls for a new 3D reconstruction technique that would provide us with more personalized 3D models, considering that full information from rib borders would be used instead of only fitting generic rib models onto reconstructed midlines. Moreover, with such a new reconstruction technique, clinical indices could then be extracted with confidence directly from the reconstructed rib cage, which should improve the associated orthopedic and surgical treatments.

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Research into Spinal Deformities 5
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Brachial Plexus Palsy Associated with Halo Traction before Posterior Correction in Severe Scoliosis

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Abstract Objective: To retrospectively analyse clinical features and related factors of brachial plexus palsy associated with halo traction before posterior correction in severe scoliosis. **Method**: 300 cases of severe scoliosis performed with halo traction before posterior correction wereconsidered with 7 cases suffering from brachial plexus palsy (2 males and 5 females). The average age was 14 years (range,9-19 years).The average Cobb angle was 110° (range, 90° - 135°); Diagnoses were idiopathic scoliosis (1), congenital scoliosis (3), and neuromuscular scoliosis (3). Halo-gravity traction was used in 3 cases preoperatively; and Halo-femoral traction used in 4 cases postoperatively (anterior release 2 cases, anterior epiphyseal arrest 1 case, combined anterior and posterior release 1 case). **Results**: Traction was used for an average of 3.5 weeks before spinal fusion (range, 2-6 weeks) for these 7 patients. The average traction weight was 8kg; the average traction weight was 19 % (range 13-26%) of the average body weight (40.2kg). The mean stature was 175cm; all the 7 patients had a long and thin body configuration. Duration between brachial plexus paralysis and detection was 1 to 3 hours. All the 7 patients suffered different degree from numbness of ulnaris of the hand and antebrachium. Median nerve palsy was found in 3 cases, ulnar nerve paralysis was found in 4 cases. Complete nerve functional restoration had been achieved by the end of three months after rehabilitation training, drug treatment were adopted. **Conclusion**: Brachial plexus palsy associated with halo traction in severe scoliosis is related to the weight of traction, body type and patient-pathology status. If the symptoms are promptly detected with rehabilitation training and appropriate drug treatment adopted, complete nerve functional restoration can be achieved.

Key words Scoliosis; Halo traction; Brachial plexus palsy

1. Introduction

Halo-traction has been used as one of the adjunctive therapy measures prior to reconstructive surgery in the treatment of severe scoliosis, especially for cases of respiratory dysfunction. It can gradually improve coronal and sagittal deformity and trunk balance, it can also allow the spine to elongate and improves respiratory function [1]. The time necessary to achieve the desired result may be several weeks and can risk neurological complications; its use must, therefore, be carried out with extreme caution and monitored very thoroughly for any changed neurological signs. Significant complications have also been documented with these techniques such as cranial nerve complications, neurological deficits of the lower extremity, and sphincter dysfunction [2-4], however there are few reports of brachial plexus palsy associated with halo traction. The purpose of this study is to retrospectively analyze clinical feature and related factors of brachial plexus palsy associated with halo traction before posterior correction in severe scoliosis

2. Materials and methods

The study included 300 patients of severe scoliosis who were treated with halo traction before posterior correction in our hospital between 1997 and 2004. There were 134 male and 146 female cases. The age at surgery ranged from 9 years to 44 years, with mean age of 19 years. Preoperative diagnosis was idiopathic scoliosis in 140 patients, congenital scoliosis in 80, and neuromuscular scoliosis in 36, arthrogryposis in 3, neuro-fibromatosis in 24 and Marfan's syndrome in 17. The average Cobb angle was 120° (range, 90° -170°). Seven cases developed a brachial plexus palsy (2 males and 5 female). The average age was 14 years (range, 9-19 years). Diagnoses were idiopathic scoliosis (1), congenital scoliosis (3), and neuromuscular scoliosis (3). The average Cobb angle was 110° (range, 90° -135°); Six of these seven patients had severe restrictive ventilation function disturbance.

Traction is usually started immediately with a weight of 2 kg and is gradually increased at a rate of 2 to 3 pounds per day as tolerated. The goal is to reach a maximum traction of 33% to 50% of body weight depending on how well it is tolerated. Traction is applied for a minimum of 12 hours per day, with the weight lessened by 50% when the patient is sleeping in bed at nighttime. During the procedure, the patient's neurological status is frequently checked. If hyper reflexia of the extremities, Babinski sign, paresthesia, or dysfunction of cranial nerves develps, the weight is immediately reduced. The length of the traction period is determined by radiographic evidence of curve improvement on weekly radiographs, in addition to clinical evaluation of the patient's pulmonary and neurological status. Halo-gravity traction was used in 74 patients and Halo-femoral traction used in 226 patients. In the seven cases suffering a brachial plexus palsy, Halo-gravity traction used in 3 cases preoperatively and Halo-femoral traction used in 4 cases postoperatively (anterior release 2 cases, anterior epiphyseal arrest 1 case, combined anterior and posterior release 1 case).

3. Results

All patients had improvement in their deformity from the halo-femoral traction and spinal release. Initial scoliosis averaged 120°. The best bending film curve measurement averaged 73 degrees. The correction obtained with bending averaged 25%. The Cobb angle averaged 80°at the end of the traction treatment, and improved to 51° after posterior correction. The average correction rate was 30% after halo traction. For the seven patients with brachial plexus palsy, before treatment, the average Cobb angle was 110°. This decreased to 85° after traction, 49° after surgery. Mean correction rate achieved by traction was 23%.

Traction was used for an average of 3.8 weeks before spinal fusion (range 2–12). The average traction weight was 12kg and was 34 % (range 13-50%) of the average body weight. Traction was used for an average of 3.5 weeks before spinal fusion (range, 2-6 weeks) for the seven patients with brachial plexus palsy. Their average traction weight was 8kg and was 19 % (range 13-26%) of their average body weight (40.2kg). Their mean stature was 175cm; all the 7 patients has a long and thin body configuration. Duration between brachial plexus paralysis and detection was 1 to 3 hours. The characteristics of these seven patients are listed in Table 1.

Table 1 Details of scoliosis in 7 patients with brachial plexus palsy associated with halo traction

Case No.	sex/age	Diagnosis	Body Wt (kg)	Traction % of Body Weight	Duration of recovery（Days）
1	M/11	Congenital scoliosis,	35	8（23%）	7
2	M/13	Idiopathic scoliosis	42	10（24%）	14
3	F/15	Neuromuscular scoliosis	44	9（21%）	14
4	F/9	Congenital scoliosis,	30	4（13%）	26
5	F/16	Neuromuscular scoliosis	45	8（18%）	21
6	F/19	Neuromuscular scoliosis	47	12（26%）	90
7	F/14	Congenital scoliosis	39	7（18%）	60

All 7 patients had normal function of the wrist, elbow and shoulder articulation, but suffered to different degrees from numbness of ulnaris of hand with a median nerve palsy detected in 3 cases, with disturbed flexion and opposition of the thumb. Ulnar nerve paralysis occurred in 4 cases, affecting the intrinsic muscles and disturbance of abduction and adduction of the fingers. . The traction weight was immediately reduced if the patient developed any abnormal neurological symptoms or signs. Complete nerves functional restoration was achieved by the end of three months after rehabilitation training; drug treatment was also used.

4. Discussion

Halo traction is an effective treatment for severe scoliosis, but complications should not be ignored, such as the cranial nerve problems which have been described frequently in the orthopedic and neurosurgical literature

A total of 42 consecutive patients with severe operative scoliosis, kyphoscoliosis, or kyphosis treated with halo-gravity traction were treated by Rinella [5]. Triceps palsy (2.38%), and brachial plexus palsy (2.38%) occurred during halo traction. In the present study, 7 cases (2.33%) suffered with a brachial plexus palsy (2 males and 5 females). Direct trauma, excessive stretching, external pressure, or some combination of these effects, was reported to have caused the acute onset of brachial plexus injury in such cases [6,7]. Since our patients had no prior history of trauma or mechanical compression, it suggests that stretching is the most likely cause of the brachial plexus injury.

Brachial plexus palsy associated with halo traction in severe scoliosis was related to the weight of traction, body type and patient-pathology status. No neurological deficit occurred if the traction weight was less than 50 percent of body weight [1]. In our study, no neurological deficit was recorded if the traction weight was less than 13 percent of body weight. When the traction weight reached 26 percent of body weight, brachial plexus palsy occurred possibly because these patients had a very severe scoliosis. The most likely cause of the injury is thought to be a combination of downward tilting of the head and hyperabduction of the arm, which probably stretched the brachial plexus, especially at the cord compnent where it passes beneath the coracoid process of the scapula.

Treatment of brachial plexus injury varies depending on the mechanism and the time the injury is discovered in relation to the inciting trauma [7], Current treatment include protection of the hypesthesic skin from further injuries, physical therapy to avoid muscle wasting and joint change, daily intermittent galvanic stimulation to the affected muscle, or surgery if recovery does not occur.

Weight is immediately reduced if the patient develops any abnormal neurological symptoms or signs. The recovery times may vary anywhere from hours to months. Sensation always returned first, followed by motor function. In Rinella's report, complications included triceps palsy (one, resolved within 2 weeks) and brachial plexus palsy (one, resolved within 2 months) [5]

From this study, we conclude that if the symptoms are promptly detected and rehabilitation training, combined with appropriate drug treatment, adopted, complete nerve functional restoration can be achieved.

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Radiologic Presentations in Relation to Curve Severity in Scoliosis Associated with Syringomyelia

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Abstract The purpose of the study was to further explore the radiological presentations of scoliosis associated with syringomyelia in relation to curve severity. 87 children and adolescents were divided into three groups: Group I (10°≤Cobb angle≤30°), Group II (30°＜Cobb angle≤60°), and Group III (Cobb angle＞60°). Curves were classified into typical and atypical patterns in the coronal plane and the sagittal profile measured. Cerebellar tonsillar descent or syrinx patterns in relation to curve severity and the frequency of atypical curves were also investigated. The frequency of atypical curve patterns from Group 1 to 2 was 46.2%, 45.2%, and 40.7% respectively. 65.3% patients with typical curve patterns had atypical features in all of the three groups. There was a significant difference of kyphotic angle among the three groups. Both the degree of cerebellar tonsillar descent and syrinx patterns had no correlation with the curve severity or the frequency of atypical curves. These results show that radiographic presentations including atypical curve patterns, atypical features in typical curve patterns, and a normal to hyperkyphotic thoracic spine may suggest the need for preoperative MRI. There is no evidence to suggest that the degree of cerebellar tonsillar descent and syrinx patterns have an effect on the progress of scoliosis and the frequency of atypical curves.

Key words scoliosis, syringomyelia, Chiari malformation, pattern, severity

1. Introduction

There is an established clinical association between Chiari I malformation, syringomyelia and scoliosis. The diagnosis of Chiari I malformation and syringomyelia is usually relatively easy in advanced stages of the diseases because of classic features. However, clinicians may also be confronted with patients with spinal deformity with only very subtle or entirely absent signs or symptoms suggesting Chiari I malformation and syringomyelia. Few radiographic guidelines are available to assist clinicians in deciding whether to or when to order an MRI in patients with a normal history and physical examination. The radiographic characteristics of scoliosis secondary to Chiari I malformation and syringomyelia have recently received increased attention. A heightened index of suspicion has been warranted with certain curve patterns, especially in males and patients with a normal to hyperkyphotic thoracic spine.[1~5] However, most of the published reports are limited by a small number of patients, and because of the risk of rapid curve progression and neurological compromise, early surgical procedures is often addressed before the curvature becomes large. To our knowledge, little study has elaborated on the characteristics of scoliosis with a large curve, and the association between radiological features and the severity of scoliosis. The purpose of this study is to further explore the radiological presentations in relation to curve severity in scoliosis associated with Chiari I malformation and syringomyelia.

2. Materials and Methods

A retrospective radiographic review was performed on 87 children and adolescents who had scoliosis associated with syringomyelia and Chiari Ⅰ malformation, operated between 1997 and 2004 in the authors' hospital. On standing postero-anterior radiographs, the coronal data collected were the curve location (end vertebrae, segments and apex), curve direction and magnitude for both primary and secondary curves. Based upon Spiegel's classification scheme[4], curves were classified into typical and atypical patterns. Atypical curve patterns included left thoracic, left thoracic/right lumbar, left thoracic/right thoraco-lumbar, right and left double thoracic, right thoracic (King Ⅳ), triple and quadruple curve patterns. Typical patterns therefore consisted of right thoracic, right thoracic/left lumbar, right thoracic/left thoraco-lumbar, thoraco-lumbar, and lumbar curve patterns. Typical end vertebrae and apexes for these typical patterns were as follows[4,6,7]: right thoracic (T5–T6→T11–12, apex T7-T8), right thoracic/left lumbar (King Ⅰ [T4–T6→T11, T11→L3–L4, apexes T8 and L2], King Ⅱ [T5→T11, T11→L4, apexes T9 and L2]), right thoracic/left thoraco-lumbar (T3–T5→T10, T10→L3, apexes T4-5 and L1), thoraco-lumbar (T9–T10→L3, apex T12 –L1), and lumbar (T12→L4, apex L2).

On standing lateral radiographs, thoracic kyphosis and lumbar lordosis were measured using the Cobb angle. Values were interpreted with respect to normative data for sagittal alignment in children and adolescents. Thoracic alignment was defined as normal (20°–50°), hyperkyphotic (>50°), and hypokyphotic (<20°). Normal lumbar lordosis was 64° ±10°; accordingly, lumbar alignment was defined as normal (54°–74°), hyperlordotic (>74°), and hypolordotic (<54°) .

Chiari I malformation and syringomyelia were diagnosed by whole-spine MRI. The following were noted from the T1-weighted mid-sagittal scan: degree of cerebellar tonsillar descent, configuration, location and length of syrinx, the maximal ratio of syrinx to cord (S/C ratio). The degree of cerebellar tonsillar descent was classified into three grades[1]: Grade 1 in which the tonsil descended over the foramen magnum but did not reach the C1 arch, Grade 2 in which the tonsil reached the C1 arch, and Grade 3 in which the tonsil descended over the C1 arch. The configuration of syrinx was categorized into distended, moniliform, slender, and circumscribed type[1]. The length of a syrinx was defined as vertebral segments spanned by the syrinx. The maximal antero-posterior diameter of the syrinx was determined as S, the diameter of the cord (C) was measured at the same level, and S divided by C gave the maximal S/C ratio.[8]

In order to investigate the correlation between radiological presentations and curve severity, all the 87 patients were divided into three groups: Group Ⅰ composed of those with scoliosis of 10° or more but less than or of 30°, Group Ⅱ including those with scoliosis more than 30° but less than or of 60°, and Group III consisting of those with scoliosis more than 60°. SPSS version 10.0 was used for all statistical analysis. Statistical significance was considered with $p<0.05$.

3. Results

The mean Cobb angle of Group I was 22.8°±7.6° (range, 10°–30°), that of Group II was 44.4°±7.1° (range, 32°–60°), and that of Group III was 89°±23.4° (range, 62°–146°). The Cobb angle had a significant difference between Group I and II, Group I and III, and Group II and III (One-way ANOVA, $p<0.05$).

3.1. Atypical Curve Patterns in Coronal Plane

The overall frequency of atypical curve patterns was 43.7% (38/87) in our series. Left-sided thoracic curve patterns including single and double curves occurred in 42.5% patients (37/87). The total frequency of atypical curve patterns from Group I to II was 46.2%, 45.2%, and 40.7% respectively. No significant difference was demonstrated between any two groups (Crosstabs analysis, $p>0.05$).

3.2. Atypical Features in Typical Curve Pattern

In typical curve patterns, a superior or inferior shift of the upper or lower end vertebrae, and/or the apex was defined as atypical features. In Group I, the frequency of atypical features in typical curve patterns was 85.7% (6/7). In Group II, atypical features occurred in 52.2% (12/23) patients. The frequency of atypical features in Group III was noted as 73.7% (14/19). 63.1°±17.3° (range, 37°–100°) in Group II. An obvious correlation was found between the kyphotic angle and the lordotic angle (Bivariate correlation, $p<0.05$).

3.3. Cerebellar Tonsillar Descent or Syrinx Patterns in Relation to Curve Severity

No association was demonstrated between the degree of cerebellar tonsillar descent and the curve severity (Crosstabs analysis, $p>0.05$). No correlation was obtained between the location of syrinx and the curve severity (Crosstabs analysis, $p>0.05$). The mean length of syrinx was 12±5.9 vertebral bodies (range, 4 to 19) in Group I, 7.1±5.5 vertebral bodies (range, 2 to 20) in Group II, and 7.3±4.7 vertebral bodies (range, 1 to 20) in Group III. There was no evidence that the greater the length of syrinx related to more severe curves. The configuration of syrinx was classified into four types to elaborate the association with the curve severity; there was also no apparent correlation between them (Crosstabs analysis,

$p>0.05$). The maximal S/C ratio was categorized into less than or of 50% and more than 50%, and its association with curve severity was also analyzed. No obvious correlation between them was noted (Crosstabs analysis, $p>0.05$).

3.4. Cerebellar Tonsillar Descent or Syrinx Patterns in Relation to Curve Patterns

The frequency of atypical curve patterns in patients with different degrees of cerebellar tonsillar descent was as follows: 26.3% (10/38) in Grade I, 48.6% (17/35) in Grade II, and 42.9% (6/14) in Grade III. Statistical significance of $p<0.05$ was not found between them (Crosstabs analysis). The mean length of syrinx was 8.5±5.3 vertebral bodies in typical and 7.4±5.4 vertebral bodies in atypical curve patterns, and there was no statistical significance (T test, $p>0.05$). With an eye to the configuration of syrinx, atypical curve patterns occurred in 34.8% (8/23) patients with a distended syrinx, in 45.4% (10/22) patients with a moniliform syrinx, in 22.2% (2/9) patients with a slender syrinx, and in 54.5% (18/33) patients with a circumscribed syrinx. Atypical curve patterns had no significant correlation with the configuration of syrinx (Crosstabs analysis, $p>0.05$). The frequency of atypical curve patterns was 51.4% (19/37) in patients with the maximal S/C ratio less than or of 50%, in contrast to 47.5% (19/40) in those with the maximal S/C ratio more than 50%. Statistical significance of $p<0.05$ was also not noted between them (Crosstabs analysis).

4. Discussion

In order to investigate the correlation between radiological presentations and curve severity in scoliosis secondary to Chiari I malformation and syringomyelia, the 87 patients were divided into three groups. It was noted that the Cobb angle had a significant difference between any two groups, and 36.8% (32/87) patients had a large curve of more than 60°. Hence, a well scheme has been established in the present study. In this series, the proportion of males was overwhelmingly higher (65.5%, 57/87), which was similar to the results of previous studies.It was found that the total frequency of atypical features in three groups was 65.3% (32/49). Statistical significance of $p<0.05$ was not demonstrated between any two groups (Crosstabs analysis).

4.1. Sagittal Patterns of Scoliosis

Radiographic quality was adequate to measure the sagittal profile in 81 patients, all the other 6 patients unable to be measured fell into Group I. The mean kyphotic angle of thoracic spine was 32° ±8.4° (range, 15–43°) in Group I, 42.1°±10.7° (range, 30–85°) in Group II, and 60.2°±18.6° (range, 35–110°) in Group III. There was a significant difference among the three Groups (One-way ANOVA, $p<0.05$). The mean lordotic angle was 44.6° ±13.1° (range, 30°–68°) in Group , 49.5°±11.1° (range, 18°–78°) in Group I, and

On the basis of the existing literature, atypical coronal curve patterns were defined in the present study by referring to patterns seen with a low frequency in idiopathic patients, which had a total frequency of 11.6% of 2000 cases in the Coonrad et al series.[6] Spiegel et al reported 51% atypical curves in a series of 41 patients. The overall frequency of atypical curve patterns was 43.7% in our study. There was no significant difference of the frequency of atypical curve patterns between any two groups, which shows there is no evidence to suggest that atypical curves will progress to more severe scoliosis. As scoliosis of atypical left thoracic curve occurs in approximately 50% of patients with Chiari I malformation accompanied by syringomyelia, it has become routine in many centers to order an MRI in all patients with left thoracic curves. Our study showed that left-sided thoracic curve patterns (both single and double curves) occurred in 42.5% patients. Therefore, we advocate routine MRI scanning for patients with atypical coronal curve patterns, especially with left thoracic curves.

We further explored the atypical features in typical curve patterns in each group. A superior or inferior shift of the upper or lower end vertebrae, and/or the apex was defined as atypical features, in contrast to the typical end vertebrae and apexes for typical patterns reported by published studies. 32 of 49 (65.3%) patients with typical curve patterns had atypical features in all of the three groups, we also recommend preoperative MRI for these patients. Furthermore, no statistical significance of the frequency of atypical features was demonstrated between any two groups, which suggests that typical curves accompanied with atypical features may not be more progressive.

Loder et al[2] confirmed that thoracic kyphosis was increased in children with scoliosis associated with Chiari I malformation and syringomyelia. Charry et al reviewed 25 patients with syringomyelia and scoliosis, and found that none of the patients had the lordotic thoracic component characteristic of AIS. Similar to the above findings, the current study showed that the incidence of normal kyphosis and hyperkyphosis was 84.6% in Group I, 100% in Group II, and 100% in Group III. We propose MRI scanning for scoliotic curves accompanied with a normal to hyperkyphotic thoracic spine. In addition, a significant difference of thoracic kyphotic angle was obtained among the three Groups ($p<0.05$), which suggests that as scoliosis advances, the thoracic kyphosis may also increase, and that kyphosis may be indicative of progressive scoliosis in this patient population. Similar findings were reported by Flynn et al[9], who found that half of the cases of progression of scoliosis secondary to syringomyelia had a kyphosis greater than 50°, whereas only 1 out of 7 non-progressors presented with significant kyphosis.

The association between the degree of cerebellar tonsillar descent and the curve severity has been investigated in this study. No obvious association was found between these markers; ie the degree of cerebellar tonsillar descent has no strong impact on the progress of scoliosis, which was similar to the results in adult scoliosis secondary to syringomyelia. Although Ono et al demonstrated a tendency that the greater the length of the syrinx, the more severe the curve in adult patients, this observation was not confirmed in our 87 patients aged from 6 to 20 years. Kontio and co-workers[10] reported on nine cases and noted there was no apparent consistent association between the magnitude of S/C ratio and the curve severity. Similarly, a recent report by Ozerdemoglu et al reported that the size of the syrinx had no relation to the size of the scoliosis at presentation. Likewise, the present study has showed no evidence that the larger the maximal S/C ratio, the more progressive the scoliotic curve. Also, the configuration of the syrinx did not appear to influence the progress of the curve in our series. This is in accordance with the findings in adult scoliosis reported by Ono et al.[1] Furthermore, we investigated the association between atypical curve patterns and the degree of cerebellar tonsillar descent or syrinx patterns. Our results revealed that the frequency of atypical curve patterns had no significant difference in patients with different degrees of cerebellar tonsillar descent, atypical curve patterns had no correlation with the length and the configuration of syrinx, and the prevalence of atypical curves in patients with the maximal S/C ratio ＞50% was similar to that in those with the maximal S/C ratio ≤50%, which suggest that the degree of cerebellar tonsillar descent and syrinx patterns may not play an important role in the presence of atypical curves.

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Evaluating Similarity Metrics in an Image Matching Tool for Image Guided Spine Surgery

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Abstract. This paper presents a comparison study of the effect of three similarity measures (mutual information, normalized mutual information, and mean squared error on the edges of the input image) in an image matching tool that can be used in image guided spine surgery. Using 3D rotational x-rays and magnetic resonance images of a spine phantom, it was found that the similarity measures had similar effect. Therefore, experiments with other datasets are needed before making conclusions about the suitability of these similarity metrics for image guided surgery.

1. Introduction

In image-guided spine surgery, correspondence between before surgery acquired images and the patient is required. This correspondence can be found using image matching methods of which the similarity measure is a key component. Similarity measures quantify the quality of the match. The objective of this work was to compare the effect of three similarity measures in an image matching tool for image guided spine surgery. The results of this study can be used in the selection of similarity measures for image guided surgery for the correction of spinal deformities associated with scoliosis.

Medical image matching [1]-[3] is the process of finding a transformation that aligns anatomical structures of interest in one image with corresponding anatomical structures in another image. Given two input images, the image matching process is illustrated in Fig. 1. The moving image is transformed (moved in space and/or deformed) according to a transformation. The transformed moving image is compared to the fixed image by means of a similarity measure. If the images are aligned, the system outputs the transformation parameters. Otherwise, the transformation parameters are updated and the process continues.

The goal of this work is to compare the effect of three similarity measures in the performance of an image matching tool for image guided spine surgery. The similarity measures selected for this study were mutual information, normalized mutual information, and the mean squared errors. These similarity measures are explained in detail in [1]. Mutual information and normalized mutual information are similarity measures computed using information theory concepts. These measures are suitable to cases in which the fixed and moving images are of different modalities (as is the case in this study) because they only assume a statistical relation between images. The mean squared errors similarity measure is computed based on the difference in image values for corresponding locations in the two images. This similarity measure works best in cases in which the fixed and moving images are of the same modality.

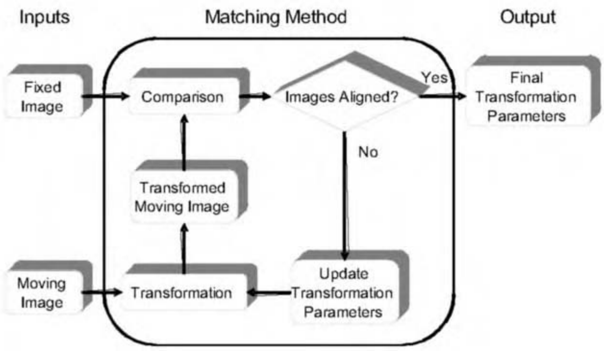

Fig. 1 Image matching process.

2. Methods

Magnetic Resonance images (MRI) and 3D Rotational X-ray images (3DRX) from a spine phantom [4] were used in the experiments (see Fig. 2). The ground-truth consisted of a set of known transformations that were applied to the MRI. The goal was to recover the known transformations when matching the MRI to the 3DRX. For the mean squared errors similarity measure only, we computed the edge images of the MRI and 3DRX and use those as inputs to the image matching method. The image matching algorithm, described in [5], was implemented using the C++ programming language and the Insight Toolkit (ITK, www.itk.org) [6], a set of open-source set of libraries for medical image processing, registration, and segmentation. To evaluate the proposed approach, the quality of the resulting matching was obtained quantitatively by computing the difference between the known transformation parameters and the computed transformation parameters. Small differences imply higher quality.

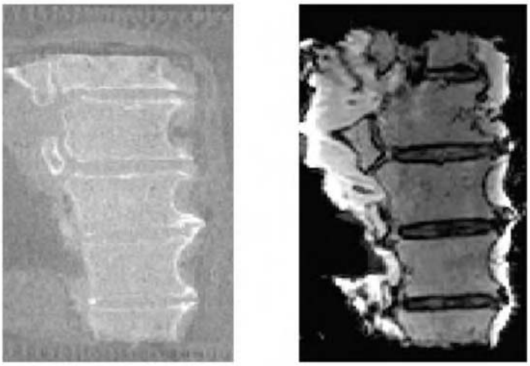

Fig. 2 Left: 2D slice of a 3DRX image of a spine phantom. Right: 2D slice of a MR image of a spine phantom.

3. Results

Table 1 summarizes the results. The normalized mutual information and the mean squared errors similarity measures had similar performance. This performance is slightly better than the performance of the mutual information measure. All three measures had the higher error in the translation in the Z axis.

TABLE 1. Differences between the known transformation parameters and the transformation parameters computed using three similarity measures

Transformation Parameters.	Absolute value of differences		
	Mutual Information	Normalized Mutual Information	Mean Squared Error on Edge Images
Translation in X	1.8 mm	0.8 mm	0.6 mm
Translation in Y	0.2 mm	0.7 mm	0.5 mm
Translation in Z	3.5 mm	3.3 mm	3.6 mm
Rotation in X	0.1 °	0.3 °	0.2 °
Rotation in Y	0.2 °	0.3 °	0.3 °
Rotation in Z	0.1 °	0.5 °	0.5 °

4. Discussion

For our dataset, all the similarity metrics had similar performance. Therefore, experiments with other datasets are needed before making conclusions about the effect of these similarity metrics on image matching for image guided spine surgery.

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Research into Spinal Deformities 5
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Right Convex Thoracic Female Adolescent Scoliosis in the Light of the Thoracospinal Concept

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Abstract. The most common form of idiopathic scoliosis affects perimenarcheal girls who show either a primary or secondary right convex thoracic curve. The patient displays signs of sympathetic dysfunction, morphological and histochemical abnormalities of muscle fibres and platelets and a persisting osteoporosis. Mechanisms that have been proposed for the causation and the development of these features are supported by the evidence in results of studies into the thoracospinal concept of the etiopathogenesis of this form of scoliosis. The interrelation of these late integrated signs and symptoms suggests that this particular form of IS is a disparate clinical nosological entity rather than a mere orthopedic deformity of the spine. Known characteristics of the infantile and this form of adolescent scoliosis further suggest that the juvenile form is an intermediate rather than a separate group and that the use of the term "idiopathic" is, therefore, obsolete. Deciphering the etiopathogenesis of the pathological complex of the right convex female adolescent scoliosis demands research from new standpoints which demands fresh approaches.

Introduction

By applying the age at diagnosis, idiopathic scoliosis (IS) can be classified into infantile (IIS) juvenile (JIS) and adolescent (AIS), in the context of the curve pattern, it may be classified into thoracic, thoraco-lumbar and double structural and, using its magnitude, a curve can be classified as major and minor or as primary and secondary. Some reported differences between and within the groups related to age, gender and pattern of the curve are presented in Table 1.

1. Right Convex Thoracic Female Adolescent Scoliosis

The majority of all cases of IS are characterized by a combination of specific morphological manifestations and signs of physiological abnormalities.

1.1 Specific morphological manifestations

1.1.1 Laterality and pattern of the curve

The means of the reported percentages of variables presented in Table 1 show that the ratio of right to left convex curves in IIS is 86 to 18 with 11 per cent resolving. 42% are thoracic, about 16% lumbosacral and lumbar respectively and 22% are double primary.

1.1.2 Height and Weight

AIS girls with double primary and thoracolumbar curves counted together have been reported to be significantly taller at the time of menarche than girls with Rcx-T curves. The weight of the girls with all curve patterns considered together with those with Rcx-T curves was significantly lower than that of the controls [3]. These relations are essentially different in IIS and JIS.

1.2 Specific physiological characteristics

1.2.1 Gender

The mean reported percentage of the girls to boys ratio in Table 1 is 8 to 52 in IIS, 76 to 24, in JIS and 85 to 15 in AI S.

1.2.2. Menarche

The age at menarche between girls with all curve patterns considered together and control counterparts has been reported not to differ, neither is there any difference in this respect between girls with Rcx-T-AIS and matched normal controls. However, AIS girls with either a double primary or thoracolumbar curve were significantly older at the time of menarche than the normal controls or girls with Rcx-T curves. They were also significantly taller than the control girls at the time of menarche [3].

1.2.3 Sympathetic dysfunction

The vascularity of the breasts in girls with AIS and matched normal controls was quantified using a diaphanographic method. The results indicated that *i)* in normal girls there was no significant side difference in the vascularity of the breasts, *ii)* in scoliotic girls the left breast was significantly more vascularised than the corresponding breast of normal controls and *iii)* that in girls with Rcx-T- F-AIS , as well as with other curve patterns, the vascularity of the left breast on the concavity of the thoracic curve was significantly increased as compared with the right one [14].

To investigate the impact of increased vascularity of the concave hemi-thorax on the etiopathogenesis of Rcx-T-F-AIS, the length of three pairs of ribs was measured from cadaveric specimens of ten elderly women and eight men with normal spines and from fifteen women with scoliosis - six of whom with Rcx-T idiopathic curves.

The results showed that *i)* in the female control group the mean length of the *right* ribs was 3 mm longer than the left ones while in the male group the mean length of the *left* ribs was 1 mm longer than the right ones; the difference between the two groups was significant; *ii)* in the 6 patients with Rcx-T- IS the ribs on the concave side were, on average, 4 mm longer than those on the convex side; the difference in this small sample was not significant, and *iii*) a difference of 7 mm between the mean *left minus right* rib length in the women of the normal control group and *concave minus convex* rib length in the women with Rcx-T curves was found to be significant [16].

1.2.4 Abnormalities of muscle fibres and platelets

A decreased number of type II fibers in paravertebral muscles [24] and an increased number of type I fibers on the concavity rather than the convexity of the curve have been reported and considered as an etiological factor in IS [25].

Larger platelets than normal [25], decreased activity of intracellular contractile proteins with decreased platelet aggregation [26] and increased platelet calmodulin levels [12] have been reported in patients with AIS.

1.2.5 Osteoporosis

In 1968, Wynne-Davies reported that amongst second degree scoliotic relatives to children with IS, there were many elderly individuals with osteoporosis [28]. Subsequent reports have provided evidence that girls with AIS are affected by osteoporosis [8] which persists until late in life [23].

3. The Thoracospinal Concept

Scoliosis was induced by shortening of three ribs on the one side of the lateral aspect of the thorax in a group of growing rabbits, resulting in the developement of a slight scoliosis immediately after the operation, with the concavity to the side of the rib shortening, which successively regressed. In a second group of animals, the same procedure was combined with simultaneous osteotomy of the contralateral ribs. In this group, the initial scoliosis developed progressively to become a severe deformity, with a concavity to the side of the shortened ribs and having characteristics of human scoliosis.

The results of the two experiments were considered to indicate that rib length asymmetry, caused by disturbed rib growth, at the level of the apical segment may be one of the factors that triggers the deformity of the spine and the thoracic cage in IS [24].

A subsequent series of alternate, anthropometric, experimental and biomechanical studies did provide accumulated support to the thoracospinal concept of the etiopathogenesis of the Rcx-T-**F-A** S [18,19] (see Table 2).

4. Discussion

The classification of IS, created by surgeons for use in clinical practice, is based on patho-anatomical manifestations of the deformity and not on physiological considerations .

The data presented in Table 1 show that: i) the mean percentage of boys decreases from 52 in IIS to 48 in JIS and then to 14 in AIS ; resolving curves decrease from 54 in IIS to 11 per cent in AIS b) the mean percentage of double primary, thoracolumbar and lumbar curves, counted together, increases from 5.5 in IIS to 42 in AIS and d) that the mean ratio Rcx to Lcx curves is 16 to 85 in IIS and 82 to 18 in AIS. With regard to the curve patterns the data show that curves, other than thoracic ones, are rare in IIS as compared with AIS, which may indicate that they appear at later stages of the development of the thoracic curve. Support for this assumption is provided by the observation that in girls with AIS, Rcx thoracic curves appear in younger patients than curves of other patterns [13].

These data suggest that JIS may not be a separate group of IS, but rather a transient modality of non-resolving, persisting IIS curves, progressing and then diagnosed at school age and associated with the juvenile or the adolescent endocrine spurt at the ages of 3 to 11 or 12 to 15 years, according to the infant-childhood-puberty growth model of Karlberg.

The concept of two groups of IS has been supported by the identification of two peaks of incidence of IS, the one in infancy and the other in adolescence i.e., the early, under eight years, and the late, over eight years, onset scoliosis [28]. Other opinions suggest early infantile scoliosis is a postural deviation of the spine regressing parallel with the development of the postural balance mechanisms [4] and as a result of abduction contracture of the right hip [11].

More recently, morphometric studies have provided evidence of left-right skeletal asymmetries in adolescent girls with right or left convex lower spine scoliosis [6].

Analysis of our research data implies further that AIS is composed by two subgroups; the first, with 85 per cent, affects almost exclusively adolescent perimenarcheal girls with an either primary or secondary Rcx thoracic curve in combination with some particular pathophysiological characteristics. The second subgroup, amounting to some 10 per cent of AIS, includes adolescent boys and girls with Lcx or Rcx thoracic curves displaying radiographic morphometric signs of skeletal side-asymmetries of the pelvis and the lower extremities, probably representing non-regressing cases of IIS.

The consensus view of this evidence, based on etiopathogenetic mechanisms on the one hand the infantile and on the other the Rcx-T-F-A scoliosis, raises the question of what it is today is termed "idiopathic" when applied to scoliosis.

The results of studies supporting the thoracospinal concept of the pathogenesis of IS provide evidence that hyperaemia of the left hemi-thorax occurs early in the natural history followed by increased growth of the ipsilateral ribs. Then, the normal thoracic spine, if predisposed to rotate to the right as is the case in about 50 per cent of normal spines [20], rotates further in the same direction and triggers the development of the complex deformity of the thoracic cage and the spine simultaneously in the three cardinal planes (see Fig 1) [20,18].

Dysfunction of the ANS may be directly or indirectly related to hormonal and neuro-humoral influences, such as impaired function of the hypothalamic-pituitary-adrenocortical axis, sex hormones, neurotransmitters and other humoral factors.

In this way, for the first time, the thoracospinal concept presents a link between the pathogenesis and the etiology of the deformity in girls with Rcx-T-AIS. The earlier previously unreported differences between AIS girls with different curve patterns may imply either that the etiopathogenesis of the different curve patterns in girls with AIS is different or that lumbar, thoracolumbar and double primary curves develop and are diagnosed at a later age of the patient than the Rcx-T-F-AIS. In other words, the former are secondary to the latter, and share the same etiopathogenesis. The observation that vascularity of the left anterior hemi-thorax is increased, not only in girls with Rcx-T curve but also with other curve patterns, supports a common pathogenetic factor.

The strength of this sequence of events is endorsed by the results of a series of new experimental studies where scoliosis with all the characteristics of human IS can be induced in growing rabbits by unilateral resection of 3 to 4 intercostal nerves carrying the sympathetic fibres [1-3].

5. Conclusions

The unknown aetiology of IS has generated numerous hypotheses supported by clinical observations, the results of experimental studies or by pathophysiological concepts.

Our current state of knowledge of the etiopathogenesis of IS, based as it is on old classifications of spinal deformity and on paradigms pertaining to clinical empiricism, has led to poorly supported hypotheses and therefore to ambiguous conclusions.

Viewed in perspective, the thoracospinal concept *i)* brings into focus new aspects of the etiology of the by far largest group of all cases of scoliosis, i.e., the Rcx-T-F-AS, *ii)* provides a link between the etiology and the mechanisms of the pathogenesis of the spinal deformity *iii)* explains the unique combination of specific morphological characteristics and a tetralogy of pathophysiological symptoms of this form of scoliosis, *iv*) is challenging the view that juvenile IS is a separate group of scoliosis *v)* is evidence that classing the Rcx-T-F-AS as a disparate clinical entity rather than as a mere deformity of the spine of idiopathic causation and development, and, finally, *vi*) proposes new simple risk-free method for treatment by surgery on the ribs.

Research to identify relations between the etiopathogenenesis of the Rcx-T-F-AS and the multiplicity of complex pathophysiological mechanisms of the growing scoliotic child along new tracks is now essential in order to effectively prevent the progress of the deformity and ultimately offer prophylaxis.

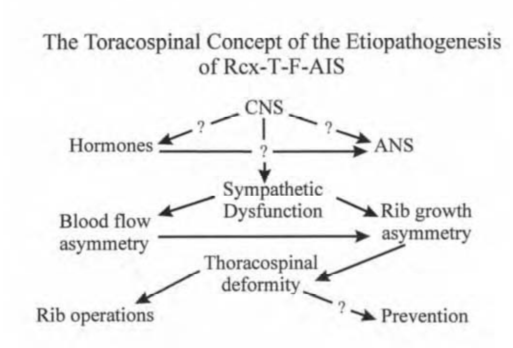

Figure 1. Proposed course of pathophysiological involvement in the causation, the development and the treatment of the RCx-T-F-AIS according to the thoracospinal concept based on indications (?) and evidences

Table 1. Variations between and within IIS, JIS and AIS groups. Bold in parenthesis mean values of reported percentages; suprescript the number of the report; in brackets number of reference Lcx = Left convex curves; Rcx = Right convex curves

	IIS	JIS	AIS
Boys	5[1] 50[2] 56[7] 43[9] **(52)**	32[2] 19[14] 21[15] **(24)**	9[2] 16[3] 18[7] (**15)**
Girls	42[1] 50[2] 44 57[9] **(48)**	68[2] 81[14] 79[15] **(76)**	91[2] 84[3] 82[7] **(85)**
Resolving	361 52[5] 64[8] 65[9] **(54)**		3[10] 22[12] 9.5[11] **(11)**
Proresing	64[1] 30[5] 25[8] (**40)**		
Thoracic	82[1]	22[3] 67[4] 60[6]	18[11] **(42)**
Rcx	29[1] 8[7] **(18)**		75[3] 88[4] 87[6] 90[7] 77[13] 75[11] **(82)**
Lcx	81[1] 92[7] **(85)**		25[3] 12[4] 13[6] 10[7] 23[13] 25[11] **(18)**
Double prim.	9[1]		37[3] 17[4] 14[11] **(23)**
Thor-Lumb.	6[1]		16[3] 9[4] 23[6] 34[11] **(16)**
Lumbar	2[1]		24[3] 6[4] 17[6] 33[11] **(15)**

1 James et al 1959, 2, Burwel let al 1977, 3.Ponseti & Friedman 1950 4. Normelli et al 1985.5. Fereira & James1972, 6.Aaro & Dahlborn 1981, 7 James 1954. 8. Conner 1969, 9.Cebalos et al.1980 10.Rogala et al, 1978, 11. Soukakos et al. 1997, 12. Brooks et al.1975 13. Goldberg et al. 1944,14.Tolo & Gillespie, 1978, 15.Mannetz et al 1988

Table 2. Indicated (?) and evidenced phases of the etiology, the pathogenesis, the pathomechanism(s) and subsequent treatment of the Rcx-T-F-AIS according to the thoracospinal concept. Number of reference in brackets.

	Clinical	*Experimental*	*Biomechan.*
Etiology :			
CNS –ANS-hormonal disorder	?	?	
Pathogenesis :			
a)Sympathetic dysfunction	[15]	[1]	
b) Blood flow asymmetry	[15]	[3]	
c) Rib growth asymmetry	[16]	[2]	
Pathomechanism :			
Simultaneous development of the 3D thoracospinal deformity	-	[27]	[20]
Treatment :			
Rib operations	-	-	[10,8]

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Instrumentation Loosening and Material of Implants as Predisposal Factors for Late Postoperative Infections in Operated Idiopathic Scoliosis

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Abstract. Introduction: Instrumentation loosening and metal corrosion are predisposal factors under investigation for late Postoperative infections
Purpose of the study: To investigate the contribution of the instrumentation material (stainless steel versus titanium implants) and the mechanical loosening in the development of late postoperative spinal infection.
Patients and methods: The first group of patients involves 50 idiopathic scoliotic patients who were treated with first generation posterior stainlessteel spinal segmental multihook instrumentation. The minimum post operative follow up was 4 years. Five patients presented with late infections1to 5 years post operatively. Removal of instrumentation was the effective solution to this problem. Common intraoperative findings were some degree of instrumentation loosening and corrosion. The second group involves 40 idiopathic scoliotic patients who were treated with newer generation posterior titanium spinal segmental multihook-multiscrew instrumentation system. More extensive use of pedicle screws was performed to the second group resulting in a more stable mechanical construct. Follow up ranged from 2 to 5 years. None of those patients presented late postoperative infection or any evidence of instrumentation loosening or failure.
Conclusion: We believe that newer multihook-multiscrew titanium spinal instrumentation systems have smaller incidence of late postoperative infections because they provide a more stable construct (pedicle screws) with fewer tendencies for micro motion or failure, and they may give the advantage of greater bone adhesion on the implant resulting in the production of thinner biofilm, thus decreasing the chances of infection

Keywords. spinal instrumentation, late infections

Introduction

Multihook-multiscrew segmental instrumentation systems offer increased versatility in the treatment of spinal deformities (1, 6, 14, 21, and 29), however, these systems involve the implantation of a substantial and bulky amount of hardware. Late postoperative infections in patients who were treated with multihook-multiscrew segmental instrumentation systems have become recognized in the last few years (4, 10, 12, 24, 28, 32, 33, and 35).

Although postoperative acute infection is a well-recognized complication of instrumented spinal fusion (0,7%-8,5%), only several series of delayed infections have been described. The exact incidence of this complication has not yet been established and the exact predisposal factors are still under research.

Hegeness et al. (17) described six cases of late spinal infection due to hematogenous seeding that presented 1-7 years postoperatively. Richards et al. (28) analyzed 10 cases of postoperative infections after posterior spinal instrumentation for scoliosis and he proposed the intraoperative inoculation as the cause. The incidence in that study was 7% (10 patients of 149). Schofferman et al. (31) described 7 lumbar spine infections associated with failed fusion. Dubousset et al. (10) reported 18 patients with late infections that required removal of the instrumentation, although 14 of those patients had normal ESR and 16 had negative intraoperative cultures. Viola et al. (35) described 8 cases with delayed infections after elective spinal instrumentation and fusion. Clark et al. (4) described 22 patients with the late development of infection in instrumented scoliotic patients, the incidence being 1,7%.

According to Viola et al. (35), delayed infection after elective posterior or combined anterior and posterior spinal instrumentation and fusion is characterized by an interval of normal postoperative recovery followed by the onset of diffuse pain, malaise, or discomfort from several months to many years after surgery.

Soultanis et al (33) described a delayed deep wound infection developed in five patients who had been managed with multihook instrumentation system (TSRH) because of scoliotic deformities. The infections were diagnosed one to five years after the initial operation.

The exact mechanism of bacterial seeding is not yet clearly defined (23). Two possible options are considered. Hematogenous seeding was described by Heggeness et al. (17) and intraoperative seeding followed by a quiescent period, is an other (very difficult to prove) theory.

Dubousset et al. (10) suppose that perhaps a combination of hematoma formation, soft-tissue reaction to increased amounts of implanted hardware, and fretting corrosion promotes a favorable environment for bacterial microorganisms. The bulk and the great surface of two-rod multihook constructs considers to be a predisposal factor to late infection due to great extend of glucocalyx.

Although various predisposal factors are described we have tried to examine the correlation with the instrumentation material and the instrumentation loosening.

Patients and Methods

In this study we include a first group of 50 patients(41 females, 9 males) with idiopathic scoliosis (mean age 21,5 years) who were treated surgically using multiple level hook and screw stain steel spinal instrumentation system (TSRH). The postoperative period of all patients until the end of this study was at least 4 years.

The bone graft that was used was autologus graft from the decorticated posterior elements and bovine xenografts (Lubboc). The duration of the operation varied from 3 to 7 hours (average 4.5 hours). Intraoperative blood loss varied from two to ten blood units (average 4.5 units). The blood that was used for transfusion came from a blood bank, while blood saver was available during the last year (7 patients). No patient had a preoperative infection or a positive urine culture. No predisposal factors to infection such as immunodeficiency or drug abuse, defined in any patient. There were no early wound postoperative infections. Perioperative chemioprophylaxis (2nd generation cephalosporin plus aminoglycoside) were used in all patients. All patients were operated from the same surgical team using similar techniques. Two drainage tubes with continuous suction were placed deeply in the wound under the muscle layers. The drainage was removed after 48 hours.

There have been 5 patients who have presented with late deep wound postoperative infections. The postoperative period up to the occurrence of the infection varied from 1 to 5 years. Two patients presented a local subcutaneous abscess while the rest had a local drainage. None of these patients had signs of generalized septic condition (all had normal leukocyte count, light elevated sedimentation rate, low CRP concentration). Two of the idiopathic patients presented a broken rod. The initial pus cultures were negative in three patients, while two patients revealed the pathogen bacteria after further culture. Exploration of the instrumentation site took place in all patients. Common finding was pus lining on the instrumentation surface, with increased pus concentration under the cross-links. In all patients there was a sinus duct that was leading straight to a crosslink plate. All patients had at least one loose cross-link nut. Local corrosion of the hardware and metal infiltration of the surrounding tissues was present at the sites of hardware loosening. There was marked tissue infiltration from metal in the patients with the broken rods. The underlying bone tissue had no involvement, as there was no pus drainage or dead bone.

All patients had a satisfactory bony fusion so removal of the instrumentation took place. The wound was closed at first stage in all patients after careful debridment. Continuous irrigation system with antibiotics (gentamycin) was placed for 5 days in all patients

Intraoperative cultures revealed a variety of pathogens (three coagulase negative staphylococcus and one acinetobacter baumani). Iv antibiotics administrated for 7 days. Additional oral antibiotics were administered for a total period of 45 days.

All patients had an uneventful postoperative course. No recurrence of the infection occurred in any patient.

The other group of patients involved 40 scoliotic patients that were treated with newer titanium implants. The instrumentation systems that were used were MOSSMIAMI, XIA and CD. These patients were operated with combination of screws and hooks. Surgical team, surgical technique and perioperative care were similar with the first group. Operative time was somewhat more prolonged (4 – 7 hours, mean 5, 5 hours) due to more extended pedicle screw placement. More extended use of pedicle screws was due to the increased experience of the particular surgical team. Intraoperative blood loss was less in that group, 2 to 6 blood units (average 3,5 units), because blood saver was available in the majority of those patients. Follow up ranged 2- 4 years.

None of the patients of the second group presented with proved instrumentation failure, loosening or signs of late infection. No additional surgical procedure was necessary for those patients.

Discussion

The bulk and the great surface area of two-rod multihook constructs considers to be a predisposal factor to late infection due to great extend of glucocalyx (3, 13, and 15).

Modern spinal instrumentation systems are being developed in an effort to minimize the bulk of the implant. Comparing the bulk of our early multihook spinal implant in the first group of patients with the newer generation spinal implants of the second group, there is a marked advantage (less bulk) in the second group.
Some degree of instrumentation loosening as identified intraoperatively (usually loose crosslink plates) or marked instrumentation failure seems to be a stable and mandatory predisposal factor to late infections (8). Dubousset et al. (10) defined as infection a late inflammatory reaction, with spontaneous drainage, that had occurred as a result of metal corrosion. The estimated prevalence of late infection approached 1%. Dubousset et al. (10) suppose that perhaps a combination of hematoma formation, soft-tissue reaction to increased amounts of implanted hardware, and fretting corrosion promotes a favorable environment for bacterial microorganisms (36).
These findings of Dubousset et al. seem to be in agreement with our findings. The most affected area was under the crosslink's in all our patients.

In our second group of patients no radiologic or clinical prove of implant failure or loosening was noticed. None of those patients was reoperated. We believe that modern correct mechanical design and production give an advantage over early design spinal instrumentation systems. Secure locking of connecting mechanisms gives a superior mechanical stability to the overall construct. Another reason for superior mechanical stability in our second group of patients may be the more extended use of pedicle screws (7) in the lumbar and the thoracic spine. There is a strong belief that mechanical stability and avoidance of corrosion is a mandatory factor to avoid late infections (5, 25).

In summary, newer multihook spinal instrumentation systems include great amounts of hardware. As a result, delayed postoperative deep wound infections seem to become an increasing and not well-defined problem. The incidence of such infections seems to vary from 1% to 7% in reported series (4, 10, 12, 24, 28, 32, 33, and 35). If such an infection has been occurred, the most efficient treatment is to remove the instrumentation and debride the wound. Primary closure of the wound seems that can be performed safely as Richards et al and other investigators have indicated.
In our study we found the use of a continuous irrigation system in combination with primary closure to be effective. Cultures of intraoperative specimens should be reviewed carefully for 10-14 days before they are considered negative (9, 11, and 18). Low-virulence organisms, particularly Propionibacterium acnes (2,27), should not be dismissed as contaminants. After the removal of the hardware, a course of antibiotics should be administered. In an effort to diminish the occurrence of this problem in the future, we are exploring methods to decrease the amount of hardware that is implanted by using less bulky instrumentation systems. Also we are trying to reduce every dead space by careful packing of bone graft.

The material of the instrumentation is an other interesting question to be answered. There is specific evidence about the correlation of late postoperative infections with stainless steel versus titanium implants (19, 30). It seems that titanium implants present a lower rate of late infections, and less loosening of instrumentation. Fretting corrosion (19) seems to be less in titanium implants. We believe that the use of titanium implants may give the advantage of greater bone adhesion on the hardware resulting in the production of thinner biofolm, thus decreasing the chances of infection (20, 22, and 26).

Conclusion

We believe that newer multihook-multiscrew titanium spinal instrumentation systems have a smaller incidence of late postoperative infections due to two reasons. Firstly they may give the advantage of greater bone adhesion on the hardware resulting in the production of thinner biofolm, thus decreasing the chances of infection. Secondly we noticed less instrumentation loosening or failure. We believe that modern mechanical design and construction provides a more stable construct with fewer tendencies for micro motion or failure and we also believe that the extended use of pedicle screws contribute to the overall stability and stiffness.

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Variations of the Position of the Cerebellar Tonsil in Adolescent Idiopathic Scoliosis with Severe Curves: A MRI Study

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Abstract. This study is an investigation into the position of the cerebellar tonsils in AIS with severe curves and any relationship it has with age, sex, curve severity and curve pattern. Sagittal magnetic resonance imaging (MRI) of hindbrain was performed on both of 205 AIS patients with a Cobb angle greater than 40° and 86 healthy controls. The position of the cerebellar tonsil relative to the line connecting the basion and opisthion (BO line) was measured. In AIS and controls, the mean position of the cerebellar tonsil was 0.9 and 2.9 mm above the BO line, respectively. The incidence of tonsillar ectopia in AIS was found to be significantly higher than controls (34.5% versus 5.8%, $p<0.001$). No significant correlations were found between the position of the cerebellar tonsil with age or sex in AIS and controls. It was shown the position of the cerebellar tonsil was not significantly different among AIS patients with deferent curve severity. However, a significant lower incidence of tonsillar ectopia ($p=0.049$) was found in patients with lumbar curves when compared to those with thoracic or thoracolumbar curves. In conclusion, there was a relatively lower position of the cerebellar tonsil together with a significant higher incidence of tonsil ectopia in AIS patients. There was a trend that tonsillar ectopia was more often in thoracic or thoraco-lumbar curves, suggesting that a lower position of the cerebellar tonsil may play an important role in the etiopathogenesis of AIS.

Keywords. Idiopathic scoliosis, Cerebellar tonsil, MRI, Tonsillar herniation, Adolescent

1. Introduction

Adolescent idiopathic scoliosis (AIS) is a complex 3-dimensional spine deformity, affecting growth and development of adolescents. Despite a large research effort, the etiology and pathogenesis of AIS remains unclear [1-3]. Whereas defects of proprioception, impaired sensation of spatial orientation, and abnormal somatosensory envoked potentials (SSEPs) were observed in some of AIS patients [4-7], this implies that AIS patients may present with subtle or sub-clinical neurological dysfunction. Moreover, it has been recently reported that there is a higher than expected incidence of tonsillar ectopia documented in AIS patients [7-8]. As reported by Cheng et al [8], 17.9% of AIS patients were found to have lower tonsils below the foramen magnum, and the extent of tonsil ectopia inceased with curve severity. The above observations

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suggest that there might be associations of proprioception defects and abnormal SSEPs with tonsillar ectopia in AIS. In AIS patients with a severe curve, however, the position of the cerebellar tonsil and the relationships with age, sex, curve severity and curve patterns have not been clearly demonstrated. Thus, this study was performed as an attempt to investigate the position of the cerebellar tonsil in AIS with a Cobb angle greater that 40° and to determine the relationships of that with age, sex, curve severity and curve patterns.

2. Subjects and Methods

A retrospective radiographic study was performed on all patients initially diagnosed as AIS, who received surgical interventions at our hospital during the period from January 2004 to December 2005. The diagnosis of AIS was based on physical examination and standing postero-anterior (PA) roentgenography of the whole spine with a Cobb angle above 10°. All AIS patients were aged from 12 to 18 years. Age-matched healthy adolescents were selected to serve as controls. The controls were admitted to this study after differential diagnoses of scoliosis, based on detailed physical examinations. All the subjects enrolled in this study were considered not to have disorders that would affect the position of cerebellar tonsils, namely diseases of the posterior fossa, hydrocephalus or evidence of increased intracranial pressure, and supratentorial tumors. Subjects with syringomyelia on magnetic resonance (MR) examinations were excluded.

On the PA and lateral radiographs available for all AIS patients, the evaluation focused on both curve severity and the overall pattern. According to the Cobb angle in coronal plane, AIS patients were divided into three subgroups: Group A with a Cobb angle 40°~ 60°, Group B 60°~ 90° and Group C greater than 60°. Only the major curve with the greatest magnitude was evaluated. Furthermore, curves were classified according to their apical vertebra as defined by the Scoliosis Research Society.

MRI examinations of the whole spine, from the foramen magnum to sacrum, were performed in both AIS and control adolescents, by means of 1.5-T MRI systems (Gyroscan Intera, Philips Medical Systems, Best, the Netherlands). Sagittal images were taken from the cervico-occitipital joints using a Turbo spin-echo T1-weighted sequence (recovery time 400 msec, echo time 20 nsec) with sections 3mm thick. A 2.5mm intersection gap was determined for each subject as a part of routine imaging protocol. Because the cerebellar tonsils are parasagittal structures, three images, including the most sagittal and the two adjacent images, were selected for the analyses of the positions of the cerebellar tonsils. For the convenience of measurements, the images were magnified by a factor of two or greater on a computer-assisted video console.

The basion and the opisthion were identified as the most inferior cortex of the clivus and occipital bone, respectively. The line connecting the basion and the opisthion (BO line) were drawn, representing the level of the foramen magnum. Then, the most inferior part of cerebellum or tips of the cerebellar tonils were identified in the most sagittal and the two adjacent images. Of the three images mentioned above, the one with the most inferior position of the cerebellar tonsils was selected for further measurements. According to the method described by Aboulezz et al [9], the perpendicular distance (recorded as d) from the inferior part of the cerebellar tonsil to the BO line was determined. If the inferior parts of the cerebellar tonsil located above

Table 1 Physical characteristics of AIS patients and healthy controls

Group	No.	F/M	Age（y）	d value	Incidence of tonsillar ectopia
Controls	86	43/43	15.7±1.8	-2.9(-9.1-1.8)	5.8%
AIS	205	178/27	14.6±1.6	-0.9(-9.2-5.2) *	35.1% *

Age is shown as mean ± S.D., and d value as mean (range). * p<0.05 indicates significant difference.

or below the BO line, d was defined negative or positive, respectively, and if right at the BO line, d was equal to zero. Tonsilar ectopia was considered with a positive d.

Comparison of d values was performed in subjects with or without AIS. Correlation and Chi-square test analyses were used to analyze the relationships of age, gender, curve severity and curve pattern versus the tonsil position. SPSS version 11.5 was used for all statistical analyses. Statistical significance was considered when P< 0.05.

3. Results

3.1. The Tonsil Position in AIS and Controls

A total of 205 AIS patients, consisting of 27 boys and 178 girls, were included in this study. There were 86 healthy adolescents (43 boys and 43 girls) in controls. Table 1 shows physical characteristics of AIS and control adolescents, as well as the positions of cerebellar tonsil in both groups. ANOVA analysis showed that a greater d value was found in AIS than in controls (p<0.001), indicating AIS patients had a rather lower position of cerebellar tonsils. The incidences of tonsillar ectopia in AIS and controls were 35.1% (72/205) and 5.8% (5/86), respectively. Additionally, extent of tonsillar ectopia greater than 2 mm and 5mm below the BO line was found in 13.3% (27/205) and 1.0%(2/205) of AIS patients, respectively, yet in none of healthy adolescents. The distributions of the tonsils position showed significant difference (p < 0.001).

The tonsil positions were not different among adolescents of different ages (p=0.434 and 0.584, respectively), neither of different sexes (p=0.893 and 0.167, respectively), both in AIS and in controls.

3.2. The Tonsil Positions in Relation to Curve Severity and Curve Patterns in AIS Patients

In AIS, there were 152 patients in Group A, 41 in Group B and 12 in Group C. No significant correlation was found between the tonsil positions and curve severity (r=0.028, p=0.692). The incidences of tonsillar ectopia were 36.2% (55/152), 36.6% (15/41) and 16.6% (2/12) in Group A, B and C, respectively. And the tonsil positions in 14.2% (21/152) patients of Group A, 12.2% (5/41) of Group B and 8.3% (1/12) of Group C were found to be caudal than the level of 2 mm below the BO line.

Of all AIS patients, curve patterns were listed in Table 2. According to Spiegal *et al*'s proposal [10], there were 17 patients with atypical curve patterns, that is, 8 with a double thoracic curve, 8 with a long right thoracic curve and 1 with a left thoracic curve. The most frequent incidence of tonsillar ectopia was 62.5% in patients with a double thoracic curve, and the following patterns were listed in decreasing order of prevalence of tonsillar ectopia, a right thoracic and left lumbar curve (39.3%), a right thoracic curve (37.3%), a thoraco-lumbar curve (36.4%), a lumbar curve (21.6%), and a long thoracic curve (12.5%). In the patient with a left thoracic curve, the tonsil position

Table 2 The position of cerebellar tonsils in AIS patients of various curve patterns

Curve patterns	No	d value	No.(incidence) of patients with tonsil ectopia			
			Total	0<d<=2	2<d<=5	d>5
AIS total	205	-0.9(-9.2/5.2)	72(35.1%)	43(21.0%)	27(13.2%)	2(1.0%)
D thoracic	8	0.1(-6.0/2.6)	5(62.5%)	4(50.0%)	1(12.5%)	0
S thoracic	52	-1.0(-9.2/5.2)	19(36.5%)	11(21.2%)	6(11.5%)	2(3.8%)
L	1	-3.2	0	0	0	0
R	51	-1.0(-9.2/5.2)	19(37.3%)	11(21.6%)	6(11.8%)	2(3.9%)
Long thoracic	8	-2.45(-7.0/2.1)	1(12.5%)	0	1(12.5%)	0
R thoracic and L Lumbar	89	-0.7(-7.4/4.8)	35(39.3%)	19(21.3%)	16(18.0%)	0
Thoraco-lumbar	11	-1.0(-4.3/4.5)	4(36.4%)	3(27.3%)	1(9.1%)	0
L	9	-0.5(-4.3/4.5)	4(44.4%)	3(33.3%)	1(11.1%)	0
R	2	-3.9(-4.2/-3.1)	0	0	0	0
Lumabr	37	-1.3(-7.5/3.1)	8(21.6%)	6(16.2%)	2(5.4%)	0
L	33	-1.3(-7.5/3.1)	7(21.3%)	5(15.2%)	2(6.1%)	0
R	4	-0.9(-2.7/1.3)	1(25.0%)	1(25.0%)	0	0

d value is shown as as mean (range). D=double, S=single, L=left, and R=right.

was identified to be 3.2 mm above the BO line. It turned out that patients with a lumbar curve had a significantly lower incidence than with thoracic and thoraco-lumbar curves ($p=0.049$). In patients with or without atypical curve patterns, the total incidences of tonsillar ectopia were 35.3% and 35.1%, and the tonsil position were 1.0 mm and 0.9 mm above the BO line, respectively, without significant difference.

4. Discussion

We analyzed the tonsil positions of 205 AIS patients with a Cobb angle greater than 40 degrees. Comparing to age-matched controls, AIS patients had a lower tonsil position and a more frequent prevalence of tonsillar ectopia. Since the tonsil position in none of controls exceeds caudal to the BO line, the extent of tonsillar ectopia greater than 2 mm should be considered abnormal. The current study showed that both in AIS and in controls, the position of cerebellar tonsils was not impacted by the age and the sex. Moreover, the tonsil positions were not correlated with curve severity of AIS patients, and were not different between patients with or without atypical curve patterns. It was shown, however, that patients with thoracic and thoraco-lumbar curves had a significant incidence than with a lumbar curve, suggesting a higher risk of tonsillar ectopia.

Association of tonsillar ectopia and AIS has been demonstrated by results of many clinical studies [7-8]. Cheng *et al* [8] reported abnormal tonsil positions below the BO line in 17.9% of AIS patients and found an association between curve severity and tonsil positions. In the present series, of all AIS patients with a Cobb angle greater than 40 degrees, 35.1% were found to be tonsillar ectopia, among which the extent of caudal displacement turned out to be more than 2 mm and 5 mm below the BO line in 13.2% and 1.0% of patients respectively. However, we failed to detect an association between curve severity and tonsillar ectopia. Whereas, in AIS patients with thoracic and thoraco-lumbar curves, we found a higher prevalence of tonsillar ectopia and a much lower prevalence in patients with lumbar curves, patients with a double thoracic curve being at the greatest risk of tonsillar ectopia. Therefore, the trend that tonsillar ectopia is more often in thoracic or thoraco-lumbar curves suggests that the presence of tonsillar ectopia might be associated with etiopathogenesis of AIS.

Previous studies have reported the positions of cerebellar tonsils in adolescents [8, 14]. Further, it has been postulated that ethnic factors might play a role in tonsil positions [8,14,15]. In the current study, we detected no significant associations of tonsil positions with age or sex, but found that up to 5.8% of healthy adolescents had a tonsil position below the BO line with an inferior extent of less than 2 mm. Therefore, we believe that, in Mainland China, there are as few as 5.8% of healthy adolescents with a tonsil position lower than the foramen magnum yet within 2 mm below the BO line, and a finding of a tonsillar ectopia greater than 2 mm in AIS should be considered abnormal.

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Correction of Scoliosis using Segmental Pedicle Screw Instrumentation *versus* Hybrid Constructs with Hooks and Screws

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Abstract. Eighteen consecutive patients with scoliosis surgically treated by posterior correction and fusion were recruited. The major coronal curve averaged 65.8° (range 51° -87°). Eight patients were treated by hybrid constructs and four of them had anterior release before posterior surgery. Ten patients were treated by posterior correction and fusion alone with pedicle screw instrumentation. Flexibility was assessed by radiographs using the active bending and the fulcrum bending techniques. Two correction indices were not statistically different between the two groups. However, there was a tendency towards better correction in the screw group: mean surgical correction was 62.6±11.8% in the hook group and 71.6±12.3% in the screw group (p=0.07). Comparable pre- and post-operative radiographic results may indicate the advantages of posterior-only segmental pedicle screw instrumentation over hybrid constructs.

Keywords. Scoliosis, posterior instrumentation, pedicle screw

Introduction

Pedicle screw instrumentation has been widely used for various kinds of spinal disorders. By its strong bone interface, segmental pedicle screw instrumentation is expected to correct the deformity better than traditional constructs, but few studies have validated this belief [1]. The purpose of this study was to compare the posterior correction of scoliosis achieved by the segmental pedicle screw fixation with that of hybrid constructs with hooks and screws.

1. Materials and Methods

Eighteen patients with scoliosis, surgically treated by posterior correction and fusion from 2001 to 2005, were recruited: fifteen had adolescent idiopathic scoliosis and three had Chiari-syrinx related scoliosis. All three Chiari malformations had been treated by decompression of the foramen magnum and duraplasty at least three months before scoliosis surgery. The sample included 2 male and 16 female patients with an average age of 17.5 years (12 to 29 years) at the time of surgery with a major coronal curve averaging

65.8º (51º -87º) (Table 1). According to the surgical classification of AIS by the Lenke system [2], six subjects were Type 1 (main thoracic), six had Type 2 (double thoracic), one was Type 3 (double major), one was Type 4 (triple major), one had Type 5 (thoracolumbar/lumbar), and three were Type 6 (major thoracolumbar/lumbar and minor thoracic). Flexibility was assessed by radiographs using active bending and the fulcrum bending techniques [4]. Flexibility was calculated by two indices as follows:

$$\text{Active Bending flexibility (\%)} = \frac{\text{preop Cobb angle} - \text{Active Bending Cobb angle}}{\text{preope Cobb angle}} \text{ X 100}$$

$$\text{Fulcrum Bending flexibility (\%)} = \frac{\text{preop Cobb angle} - \text{Fulcrum Bending Cobb angle}}{\text{preope Cobb angle}} \text{ X 100}$$

Hybrid instrumentation consisted of a proximal construct using hooks, pedicle screws distally and sublaminar wiring in-between. Eight patients were treated by hybrid instrumentation, four of which had a thoracoscopic anterior release before posterior correction and fusion. Our indication for the anterior release in the hybrid instrumentation was a residual curve of more than 40 degrees on the active-bending film. Ten patients were treated by posterior correction and fusion alone using segmental pedicle screw instrumentation. We routinely use the CT-based navigation system (Stealth Station: Medtronic Sofamor Danek, Memphis, TN) in placing pedicle screws. Spinal cord monitoring was performed after induction of anesthesia, before and after screw placement and after correction of the deformity.

Surgical correction was analyzed statistically by the package software (JMP 6.0J: SAS institute, Cary, NC). Statistical analysis was performed by t-test. Parameters compared between the two constructs were Correction Rate, Active Bending Correction Index (ABCI), and Fulcrum Bending Correction Index (FBCI) by following formulas:

$$\text{Correction Rate (\%)} = \frac{\text{preop Cobb angle} - \text{postop Cobb angle}}{\text{preope Cobb angle}} \text{x100}$$

$$\text{ABCI} = \frac{\text{Active Bending Flexibility}}{\text{Correction Rate}}$$

$$\text{FBCI} = \frac{\text{Fulcrum Bending Flexibility}}{\text{Correction Rate}}$$

Table 1. Patient Profiles

ID	**Age Sex**	**Diagnosis**	**Lenke**	**Surgical type**	**Standing approach**	**Active Cobb**	**Fulcrum Bending**	**AB Bending**	**FB flexibility**
	flexibility								
Hybrid group									
2	17F	Chiari	3	A&P	74	63	NA	14.9	NA
3	15M	idio	1	A&P	73	43	NA	41.1	NA
4	15F	Chiari	2	A&P	72	49	32	31.0	55.6
5	16F	idio	1	P	59	35	20	40.7	66.1
6	14F	Chiari	6	P	82	32	32	61.0	61.0
7	21F	idio	2	P	53	30	32	43.4	39.6
8	17F	idio	1	P	53	25	14	52.8	73.6
9	18F	idio	1	A&P	64	45	37	29.7	42.2
Average	16.6				66.3	40.3	27.8	39.4	56.3
Std Dev	2.2				10.7	12.3	8.8	14.2	13.4
Screw group									
10	15M	idio	2	P	68	37	29	45.6	57.4
11	19F	idio	2	P	63	35	23	44.4	63.5
12	19F	idio	2	P	83	70	43	15.7	48.2
13	20F	idio	1	P	51	37	21	27.5	58.8
14	16F	idio	5	P	44	17	5	60.8	88.9
15	19F	idio	1	P	57	10	10	82.5	82.5
19	29F	idio	6	P	68	42	32	38.2	52.9
21	12F	idio	4	P	87	44	44	49.4	49.4
22	16F	idio	2	P	75	35	28	53.3	62.7
23	17F	idio	6	P	62	31	25	50.0	59.7
Average	18.2				65.8	35.8	26.0	46.7	62.4
Std Dev	4.5				13.5	16.0	12.5	18.1	13.4

*A&P: Thoracoscopic anterior release followed by posterior correction and fusion
**P: Posterior correction and fusion
Idio = Idiopathic scoliosis

2. Results (Table 2)

2.1. Surgical correction

There was a trend towards a better Correction Rate in the screw group: mean surgical correction was 62.6% (Standard deviation 11.8%) in the hybrid group and 73.1% (11.9%) in the screw group (p=0.07). ABCI was 1.75 ±0.59 in the hybrid group and 1.78 ±0.72 in the screw group. FBCI was 1.15 ±0.13 in the hybrid group and 1.19 ±0.16 in the screw group. ABCI and FBCI were not statistically different though the screw group had better average indices.

2.2. Other surgical results

The mean number of screws inserted was 5.1 ±1.4 in the hybrid group and 17.2 ±3.9 in the screw group. There were significantly more number of pedicle screws in the screw group ($p<0.01$). Surgical duration was 7 hours 39 min ±1 hour 39 min in the hybrid group and 7 hours 55min ±1 hour 8 min in the screw group, a difference which was not statistically significant ($p=0.69$). The similar times for surgical procedures for the two groups may be due to the fact that half of the hybrid patients had an anterior release. Estimated blood loss was 1207 ±414ml in the hybrid group and 1658 ±574ml in the screw group. There was a tendency for more blood loss in the screw group ($p=0.09$). We assume this increase came from time-consuming maneuvers of the surface-matching registration of the navigation system.

Table 2. Surgical Outcomes

ID	**Preop Cobb**	**Postop Cobb**	**Correction Rate**	**ABCI**	**FBCI**	**Surgical Time** (min)	**Estimated Blood Loss** (ml)
Hybrid group							
2	74	41	44.6	3.00	NA	620	1100
3	73	17	76.7	1.87	NA	500	1299
4	72	27	62.5	1.96	1.13	425	770
5	59	16	72.9	1.79	1.10	360	1250
6	82	28	65.9	1.08	1.08	355	1060
7	53	24	54.7	1.26	1.38	435	2110
8	53	14	73.6	1.39	1.00	395	1250
9	64	32	50.0	1.68	1.19	580	820
Average	66.3	24.9	62.6	1.75	1.15	459	1207
Std Dev	10.7	9.1	11.8	0.59	0.13	99	414
Screw group							
10	68	29	57.4	1.26	1.00	480	1700
11	63	17	73.0	1.64	1.15	575	2510
12	83	39	53.0	3.38	1.10	525	1600
13	51	13	74.5	2.71	1.27	400	1880
14	44	2	95.2	1.57	1.07	360	960
15	57	11	80.7	0.98	0.98	500	2340
19	68	21	69.1	1.81	1.31	405	920
21	87	24	72.4	1.47	1.47	530	2210
22	75	19	74.7	1.40	1.19	510	1310
23	62	12	80.6	1.61	1.35	460	1150
Average	65.8	18.7	73.1	1.78	1.19	475	1658
Std Dev	10.7	10.4	11.9	0.72	0.16	68	574

3. Discussion

3.1. Segmental pedicle screw instrumentation

Kim and colleagues reported better outcomes for radiographic parameters and pulmonary function using segmental pedicle instrumentation rather than employing hybrid instrumentation from their matched cohort study [1]. In contrast, Storer et al [6] in their series concluded that a comparable correction for the two constructs was achieved but with higher costs in the screw group. Others have indicated the risk of damaging the spinal cord [5] and the aorta [3]. However, surgeons can easily control the spine against these risks during three-dimensional correction and many spinal surgeons determine that the advantage of using segmental pedicle screws outweigh the potential risk. Our study showed equivalent correction can be obtained by posterior-only segmental pedicle instrumentation, without thoracotomy.

3.2. Navigation surgery and blood loss

Cautious surgeons are still concerned with the complication resulting from screw mal-placement in a scoliotic rotated spine as the rotation of the vertebral body and the pedicle,as well as the deformity of these elements, make proper placement of the pedicle screws more difficult. Preoperative CT data of the spine for the navigation informs the surgeon not only of the direction, size, and length of screws, but also the feasibility of placing screws into the individual pedicles. It was found that several pedicles would not accommodate a pedicle screw. Though the surface-matching registration of the navigation is time-consuming and, in our data resulted in more blood loss, we suggest that the improved safety of placing a screw in a narrow pedicle can fully justify this disadvantage.

4. Conclusion

Comparable pre- and post-operative radiographic results for the two constructs indicate the advantages of the posterior-only segmental pedicle screw instrumentation when compared with hybrid constructs.

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Changes of Three-dimensional Back Contour Following Posterior Fusion for Idiopathic Scoliosis

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Abstract: Twenty-nine patients received both pre and post operative Quantec evaluation (Raster stereophotograph) and spinal radiography. Mean age at surgery was 13.9 years and mean age at follow-up was 15.9 year old. Patients have been followed at least 6 months post-surgically, ranging from 6 months to 5 years. The study found that except for an improvement of Cobb angles (from 49.64° to 24.81° in the thoracic; from 56.08° to 20.08° in the thoracolumbar), corrections of rib hump (from 16.88 to 11.40 vs. normal range 0 to 10.) and truncal asymmetry (from 36.97 to 21.92 vs. normal range 5 to 20) are critical factors in successful spinal surgery.

Keywords: Idiopathic scoliosis, back contour, posterior fusion, raster stereophotograph

Introduction

Surgical correction is necessary for many patients that demonstrate progressive and severe idiopathic scoliosis. Postoperative change in Cobb angle has been used as an indicator of change in deformity. However, the change in Cobb angle represents a change in radiographic alignment as demonstrated by plain radiographs, which may not closely reflect three-dimensional correction of truncal deformity.

The Quantec Spinal Image System provides a way to more accurately quantify three dimensional truncal changes [1]. Three-dimensional topography has also become a powerful method for assessing a child with scoliosis and its treatment [2]. It has been used to reproducibly monitor the degree of patient's kyphosis and lordosis [3]. The topographic assessment of the spine has been used in some centers to classify patients into children who need to be examined once per year and those with more significant deformity needing assessment 3 to 4 times per year [4].

The goal of the study is to investigate 3-D differences of the back contour before and after patients undergoing posterior spinal fusion and instrumentation.

Materials and Methods

Twenty-nine patients received both pre and post operative Quantec evaluation (Raster stereophotograph) and anterior-posterior spinal x-ray film. Mean age at surgery was

13.9 years and mean age at follow-up was 15.9 year old. All patients were girls. Patients have been followed at least 6 months post-surgically, ranging from 6 months to 5 years. Twenty-three were treated with posterior spinal instrumentation and fusion alone, while 6 patients underwent posterior spinal instrumentation and fusion with thoracoplasty.

All children were evaluated using the Quantec Spinal Imaging System (Quantec Spinal Image System, Leigh, UK), an apparatus which utilizes computerized raster stereography technology. Informed consent was obtained from each participant. Patients with neuromuscular disease, or marked obesity were excluded. Following the scan, the technician used the Quantec computer to obtain three sets of digitized measurements for each parameter. During digitization, the technician would point out anatomical landmarks using the Quantec computer, directing the cursor to the same point on the monitor. Twelve parameters were provided from Quantec evaluation:
1) T1-S1 angle (the angle between laboratory vertical and the anterior-posterior (AP) projection of the line passing through T1 and S1); 2) T1-NC angle (the angle between laboratory vertical and the AP projection of the line passing through T1 and the top of the natal cleft); 3) AP-Q angle (the difference between the maximal angles of tilt of each side of the AP curve); 4) Pelvic Tilt Angle (the angle between the laboratory horizontal and the PSIS in the AP plane); 5) Area-Left and Area-Right % (each lateral back area divided by the total back area defined by the line from T1 to T12); 6) T1-S1 Deviation (the horizontal distance (mm) at S1 between the laboratory vertical and AP projection of the line passing through T1 and S1); 7) T1-NC Deviation (the horizontal distance at the natal cleft between the laboratory vertical and AP projection of the line passing through the top of the natal cleft); 8) Vertical height (the distance between T1 and the bisector of the PSIS); 9) Kyphosis and Lordosis; 10) Axial Surface Rotation in transversal plane; 11) Suzuki Hump Sum (a sum of differences of bilateral rib hump); 12) trunk asymmetry index (differences of bilateral trunk height from waist to the top of shoulder).

T-test for dependent sample was performed to compare 3D rotations and displacement changes in both radiography and raster stereophotograph.

Results

Postoperative Cobb angles from X-ray demonstrated significant reduction following posterior spinal fusion (table 1). Cobb angle in the thoracic region was decreased from 49.6° to 24.8° (P=0.003) and Cobb angle in the thoracolumbar region was significantly reduced from 56° to 20° (P=0.002). Figure 1 illustrates one patient before and after posterior spinal fusion in X-ray, where there were reductions of Cobb angle (from 45° to 25°) as well as an axial rotation (from 15° to 6°), and rib hump height (from 27 mm to 20 mm) recorded by Scoliometer.

As results of Quantec analysis, there were no significantly changes in the pelvic tilt, T1-S1 angle and deviation, vertical height, kyphosis and lordosis before and after surgery, however, trunk asymmetry index (differences of bilateral trunk height), T1-Natal cleft angle, T1-Natal cleft deviation, thoracolumbar Q angle (analog to Cobb angle), thoracic Q angle, and Suzuki (sum of rib hump differences at three levels) showed significant reduction postoperatively ($P<0.05$) (table 1). Figure 2 presents measurements from raster stereophotograph, including a reduction of curvature from 40° to 13° (Q angle), trunk asymmetry index from 65 to 14.7, and axial surface rotation from 8° to 8°. However, Suzuki increased from 9.9 to 13.8 as compared to a normal range (0 to 10).

Table 1. Significant differences of 3D back contour and Cobb angles before and after surgery (P<0.05)

Parameters	Pre Mean ±SD	Post Mean ± SD	P-Value
Radiographs			
Thoracic Cobb angle (degree)	49.64 ± 5.43	24.81 ± 9.93	.003
Thoracolumbar Cobb angle (degree)	56.08 ± 11.37	20.08 ± 5.92	.002
Quantec parameters			
T1NC angle (degree)	2.14 ± 1.89	1.13 ± 1.08	.01
T1NC deviation (mm)	14.84 ± 12.65	9.08 ± 8.59	.03
Thoracic Q angle (degree)	36.42 ± 5.11	11.75 ± 4.20	<0.0001
Thoracolumbar Q angle (degree)	38.79 ± 13.01	13.57 ± 4.19	<0.0001
SUZUKI	16.88 ± 12.42	11.40 ± 7.63	.02
Trunk Asymmetry index	36.97 ± 18.50	21.92 ± 8.86	.0004

Figure 1. Comparison of Cobb angle from AP view of X-ray in the thoracic region before (left) and after (right) posterior spinal fusion in one girl: it showed an improved Cobb angle from 45° to 25°, correction of trunk rotation measured by Scoliometer from 15° to 6°, and reduced rib hump height from 27 mm to 20 mm.

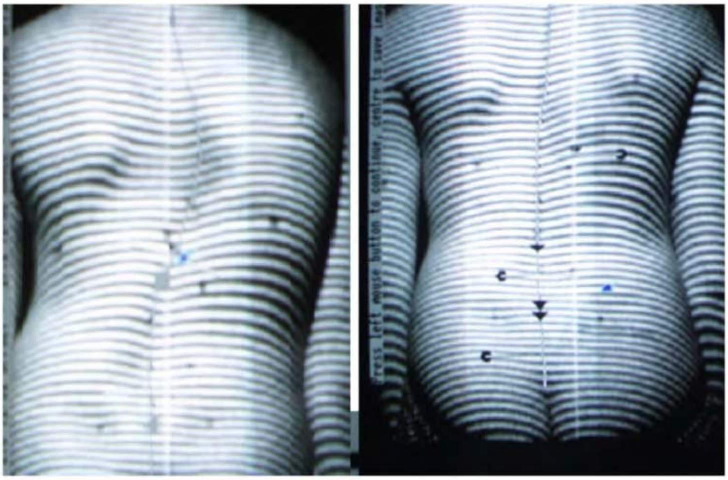

Figure 2. Comparison of Q angle from Quantec measurement in the thoracic region before and after posterior spinal fusion in the same girl: It displays a reduction of curvature from 40° to 13° (Q angle), trunk asymmetry index from 65 to 14.7, and axial surface rotation from 8° to 8°. However, Suzuki increased from 9.9 to 13.8 (normal is ranging from 0 to 10).

Discussion

One of the goals of surgical treatment for idiopathic scoliosis is to improve the patient's back appearance and prevent further deterioration of the spine (5). It is important to evaluate the patients before and after spinal fusion with the Quantec system and to analyze the trunk changes. In order to objectively evaluate the results of surgical correction of the spinal deformity, Drs Asher and Suzuki have developed the POTSI system (trunk asymmetry index) (6), which evaluates a number of parameters that cause a distortion of the trunk in patients with scoliosis. Parameters assessing trunk imbalance, shoulder asymmetry, imbalance between the levels of the axilla and hump asymmetry were all used to create an equation describing the child's deformity. This provides some quantification of the correction of the deformity, which then allows for scientific discussion of the benefits of the various types of surgical correction. As a result of the study, two hundred fifty patients with scoliosis were followed and their POTSI were significantly reduced from pre-surgical value of 46.9 to post-surgical value of 24.3.

Our study confirmed that the posterior fusion with instrumentation provides not only significant reduction of radiographic Cobb angle, but improvement of trunk deformities in the coronal and transversal plane as well. The correction of the scoliosis deformity radiographically, and of the trunk deformity clinically, are two separate parameters for evaluation. Change in the trunk deformity reflects cosmetic correction (7), which parents and patients may be more understandable and acceptable. X-ray can not quantify trunk appearance but raster stereophotograph.

Our case study indicated that variable evaluation methods results in different outcomes. Data from Scoliometer found there are corrections of the rib hump and rotations, but raster stereophotograph detected no changes of axial surface rotation and no improvement of the rib hump following surgery. The results suggested that the posterior fusion with instrumentation is not always coupling with derotation of the transversal trunk deformity. The further study will investigate the effects of the thoracoplasty in the correction of trunk deformity.

It is important to note that surface topography cannot completely replace the use of radiographs. It does not work well with obese patients and one cannot always make a direct correlation of the patient's Cobb angle with the surface topography. However, surface topography may be used to supplement x-ray assessment to diminish the total number of x-rays. One study of 268 children had a total of 474 visits in a scoliosis clinic demonstrated a significant reduction (about 50%) in the number of x-rays needed during the period of study (2).

Conclusion

The study demonstrates 3D back surface contour improvements, along with corresponding Cobb angle correction. Corrections of rib hump and truncal asymmetry are critical factors in successful spinal surgery. This nonradiographic method can quantify cosmetic changes of the patient post spinal instrumentation.

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First Results of Pain Treatment in Scoliosis Patients Using a Sagittal Realignment Brace

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Abstract. For adult scoliosis patients with chronic pain bracing is indicated before spinal surgery is considered. The treatment with the "sagittal realignment brace" (physio-logic® brace) has clearly improved chronic low back pain in a short test period. Thus we started a prospective study to estimate also medium term effects.
Material and Methods. 29 Patients (Cobb angle 37°; age 41 years) have been treated with the physio-logic® brace for an average of 7,5 Months (SD 5,6). Before brace prescription the brace action was simulated using the sagittal realignment test. Pain intensity was recorded before brace treatment, within the 1st week after brace adjustment and at follow-up using the Roland and Morris VRS. Period of daily wearing time as well as total wearing time / day was left up to the patients.
Results. Pain intensity was high (3,38) before treatment (scale 0-5) and low (1,28) in the brace after adjustment. The differences where highly significant in the Wilcoxon test (z = – 4,29; p < 0,0001). After follow-up the pain intensity was moderate to severe (2,69; ns). There was a clear reduction of pain severity, however in most of the cases the compliance has been lost during the follow-up period. Only 7 Patients continued to wear the brace for a considerable time (> 4 hrs.).
Conclusions. The brace action of the sagittal realignment brace leads to promising short-term effects. A better compliance might be achieved by prescribing the total wearing time / day and though a better efficiency of pain reduction in the long-term.

Keywords. Scoliosis, low back pain, brace treatment, physio-logic® brace

Introduction

For adult scoliosis patients with chronic pain bracing is indicated before spinal surgery is considered. The success rate of such a treatment in general seems not very high and compliance is generally described as moderate or even poor [1,2,3], however a significant pain reduction has also not yet reported in literature [3,4].
The treatment with the "sagittal realignment brace" [5] (physio-logic® brace; patent pending EP 1 604 624 A1) has improved chronic low back pain in a short test period [6]. Because the brace impairs patterns of movement leading to a lumbar kyphosis, sitting requires reeducation and car driving with the brace is uncomfortable. For those reasons the brace is not appreciated by the patients very much, however all of them at

first appreciated the immediate pain reduction in the brace. Thus we started a prospective study to estimate also medium term effects of the treatment with the physio-logic® brace.

The latest standard of this sagittal realignment brace was developed in Summer 2004 from a prototype first adjusted to an adult scoliosis patient with pain in spring 2004 [6]. It has meanwhile been applied in mature adolescents as the last brace before final weaning, in a few patients at risk for progression in adolescence where the application of a Chêneau brace has not been possible, and for the treatment of chronic pain in scoliosis patients [6].

In adolescents with lumbar scoliosis, a curve correction has been demonstrated, showing a 29° lumbar curve in a female patient with scoliosis and Guillan Barré Syndrome corrected to 19° in the brace, however as to our believe a Rigo-Chêneau brace would have acted better in this case. Our experience is that structural thoracic curves cannot be corrected just by using this small brace without additional lateral pads.

In a preliminary study, involving scoliosis patients with pain, the physio-logic® brace has proven effective at reducing pain intensity, while wearing the brace. The results, when compared to other brace types, usually applied for pain treatment as reported in international literature, seem superior [6].

Additionally we found that this brace also effectively reduces back pain in non-scoliotic subjects.

Figure 1. First 2004 design of the physio-logic® brace can be seen on the left. A patient in a physio-logic® brace of the actual 2006 standard can be seen on the right.

Material and Method

29 Patients (females only) with an average Cobb angle of 37° (SD 22) and an average age of 41 years (SD 21) have been treated with the physio-logic® brace for an average of 7,5 Month (SD 5,6) so far. Before brace prescription the brace action was simulated and pain reduction was tested using the sagittal realignment test [6]. The brace only was prescribed when a significant reduction of pain intensity was registered in this test. Pain intensity was recorded before brace treatment, within the 1st week after brace

adjustment and at follow-up using the Roland and Morris VRS. Frame of daily wearing time as well as total wearing time / day was left up to the patients choice, however all patients agreed to wear the brace at least 8 hrs. / day.

The physio-logic® brace is manufactured using CAD technique as provided by Ortholutions OHG, Rosenheim, Germany.

After the anthropometrical data (circumferential and longitudinal trunk measurements) are registered, the foam model is milled from a blank hard foam block. This hard foam model is wrapped in a heated PE-plate, which is vacuumed to the models surface.

Results

Pain intensity was high (3,38) before treatment (scale 0-5) and low (1,28) after adjustment. The differences where highly significant in the Wilcoxon test ($z = -4{,}29$; $p < 0{,}0001$). After follow-up the pain intensity was moderate to severe (2,69). The difference to the pre-treatment value was not significant. There was a clear reduction of pain severity, and in some patients quality of life increased extremely, however in most of the cases described compliance has been lost during the follow-up period. Only 7 Patients indicated to wear the brace for a considerable time (> 4 hrs.) at follow-up.

Discussion

The role of the sagittal profile in the development of a lumbar scoliosis is not yet clear [7]. Correction of the lumbar sagittal profile in a sagittal realignment brace however, leads to an improvement of 3D correction and can in short-term be compared to a Chêneau brace aiming at a 3D correction [8]. Today we have to recognize that the severity of symptoms in patients with back pain increases in a linear fashion with progressive sagittal imbalance [9]. The results of this study also show that kyphosis is more favorable in the upper thoracic region but very poorly tolerated in the lumbar spine [9].

This is why the physio-logic® brace may be regarded as the gold standard for bracing of patients with pain in combination with a reduced lumbar lordosis, because the physiological sagittal profile is restored, at least improved, when the brace is applied.

However compliance was poor in this study as in other studies about brace treatment in patients with low back pain. This might be due to the fact that the brace wearing time was left up to the patients preference.

Therefore, from 2006 on, the guideline given to the patients has been changed: The brace should be worn for 20 hrs. / day within the first 6 month. After that time (1) the sagittal deformity can be expected to be mobilized enough to gain the functional improvement desired, and (2) the patient has learnt to cope with the brace and the impairment of posture and movement while wearing the brace. So we expect that the patient can then start a first brace free interval as long as pain reduction is stable without the brace on.

In case the pain in the brace free interval starts to increase again, the procedure of brace treatment can be started another time.

Conclusions

The brace action of the sagittal realignment brace leads to promising short-term improvements of chronic low back pain. A better compliance might be achieved prescribing the frame of daily wearing time as well as total wearing time / day, and though, a better efficiency of pain reduction in the long-term.

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The authors appreciate the patients permission to publish the photos taken with her showing the brace.

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Brace Treatment of Spinal Claudication in an Adult with Lumbar Scoliosis – A Case Report

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Abstract. Although spinal claudication may arise from narrowing of the spinal canal, not all patients with narrowing develop symptoms. The reason why some patients develop symptomatic stenosis and others do not is still unknown. Therefore, the term lumbar spinal stenosis refers to a clinical syndrome of lower extremity pain caused by mechanical compression on the neural elements or their blood supply. Some studies have shown effectiveness of brace treatment with a common supportive LSO. At our Centre the sagittal realignment brace is used for the treatment of chronic low back pain. This is a lumbar lordosing brace theoretically leading to a reduction of the volume in the spinal canal. However a patient with a significant increase in walking distance due to the application of this brace will be presented here.
Material and Method. A 47 year old woman with a 55° lumbar scoliosis, 30° upper lumbar kyphosis and with highest pain levels under medication (Durogesic® 25 mg, Ibuprofen® 800, Mirtazapin® 15 mg) has been treated with a sagittal realignment brace. Self reported walking distance was at around 800 steps before the pain appeared unbearable (since 5 years). Self reported walking distance was recorded (Patients counts) in the brace 2 days and 10 days after adjustment.
Results. Walking distance increased to 8000 steps after 2 days and to 12000 after 10 days while pain intensity decreased only one point in the VRS, however without any further medication.
Conclusions. In contrary to current hypotheses about the aetiology of spinal claudication augmentation of lordosis may lead to a significant improvement of symptoms associated with spinal stenosis and lumbar scoliosis.

Keywords. Adult scoliosis, low back pain, spinal claudication, brace treatment, physio-logic® brace

Introduction

Stenosis is the narrowing of a hollow tube, in this case the central lumbar spinal canal, lateral recessus, or foramen. Clinically, this narrowing produces neurovascular compression that may lead to pain. Lumbar spinal stenosis may be classified by etiology (for example, congenital or acquired) or by symptom complex (radiculopathy, neurogenic claudication, or mechanical back pain). Stenosis can also be classified radiographically, by the location of the stenosis (for example, central canal, lateral recessus, or intervertebral foramen) or by the presence of deformity such as spondylolisthesis or scoliosis. Overlap occurs in these schemes of classification in that central stenosis with thecal sac compression typically leads to neurogenic claudication, whereas lateral recessus compression is associated with compression of an individual nerve root and, therefore, radiculopathy. Because radiographic changes associated with stenosis are very common with aging, understanding the pathophysiology of lumbar spinal stenosis is critical in the assessment and management of related symptom complexes. Although symptoms may arise from narrowing of the spinal canal, not all patients with narrowing develop symptoms. The reason why some patients develop symptomatic stenosis and others do not is still unknown. Therefore, the term lumbar spinal stenosis refers not to the pathoanatomic finding of spinal canal narrowing, but rather to a clinical syndrome of lower extremity pain caused by mechanical compression on the neural elements or their blood supply [1].

Degenerative lumbar scoliosis is a lateral deviation of the spine that typically develops after the age of 50 years. Clinical presentation varies, but the deformity frequently is associated with loss of lordosis, axial rotation, lateral listhesis, and spondylolisthesis. Although the etiology is unclear, degenerative scoliosis is associated with degenerative disk disease, facet incompetence, and hypertrophy of the ligamenta flava, typically leading to neurogenic claudication and back pain [2,3]. Rarely, sagittal or coronal imbalance may develop. Indications for treatment include pain, progressive deformity, radiculopathy or myelopathy, and cosmetic deformity. Nonsurgical care focuses on patient education, exercise, and nonnarcotic medication. Surgical management should be considered carefully, balancing the benefits and risks for the patient [2].

Studies comparing conservative and surgical treatment are rare, and only few of them report long-term results [4]. Most studies favor operative over non-operative tretment [5,6,7]. The rates of reoperation after surgical decompression vary from 5 to 23% [4].

Few studies have shown effectiveness of brace treatment with a common supportive LSO [3]. The outcome of one study [8] showed statistically significant improvement in walking distance and decrement of pain score in daily activities with and without brace respectively. This result supports the positive effect of the lumbosacral corset in pain relief and functional improvement of the degenerative lumbar spinal stenosis condition.

At our centre the sagittal realignment brace is used for the treatment of chronic low back pain. This is a lumbar lordosing brace theoretically leading to a reduction of the volume in the spinal canal [9]. However a patient with a significant increase in walking distance due to the application of this brace can be presented here.

Figure 1. The patient in the physio-logic® brace.

Material and Method

A 47 year old woman with a 55° lumbar scoliosis, 30° upper lumbar kyphosis and with highest pain levels (VRS 5) under medication (Durogesic® 25 mg, Ibuprofen® 800, Mirtazapin® 15 mg) has been treated with a sagittal realignment brace, known as the physio-logic® brace (patent pending EP 1 604 624 A1, see Figure 1). Self reported walking distance since 5 years was at around 800 steps (Grade II spinal claudication with less than 500 m.) before the pain appeared unbearable. Self reported walking distance was recorded (Patients counts) in the brace 2 days and 10 days after adjustment.

The physio-logic® brace is manufactured using CAD technique as provided by Ortholutions OHG, Rosenheim, Germany.

After the anthropometrical data (circumferential and longitudinal trunk measurements) are registered, the foam model is milled from a blank hard foam block. This hard foam model is wrapped in a heated PE-plate, which is vacuumed to the models surface.

Results

Walking distance increased to 8000 steps after 2 days and 12000 after 10 days while pain intensity decreased only one point in the VRS, however without any further medication. At the last follow-up 8 weeks after brace adjustment the improvement of the symptoms remained stable and the patient still was satisfied.

Discussion

Only one study showing successful brace treatment in a patient with adult scoliosis and spinal claudication has been found in a PubMed search. In most of the studies brace treatment is not even considered [1,2,4,5,6,7].

Signs and symptoms of this condition have been reduced drastically to the patients satisfaction even though the mechanism of the brace, increasing lordosis, is regarded as diminishing the cross sectional area of a stenosis [9]. On the other hand it is well established in literature that lumbar scoliosis and spinal claudication correlate with a loss of lumbar lordosis or with lumbar kyphosis.

Consequently we will proceed with this concept of treatment in patients with spinal claudication, low back pain and scoliosis, when lordosis is reduced. Symptomatic sagittal spondylolisthesis has to be regarded as a contraindication for the treatment with the physio-logic® brace.

Conclusions

In contrary to current hypotheses about the aetiology of spinal claudication, augmentation of lordosis may lead to a significant improvement of symptoms associated with spinal stenosis and lumbar scoliosis.

Acknowledgement

The authors appreciate the patients permission to publish the photos taken with her showing the brace.

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Brace Treatment of Spinal Claudication in an Adolescent with a Grade IV Spondylosisthesis – a Case Report

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Abstract. Although spinal claudication may arise from spondylolisthesis, little information exists about successful conservative treatment of this condition. However there are studies describing pain reduction due to physiotherapy and bracing. Significant improvement of walking distance and pain intensity in an adolescent with scoliosis, spondylolisthesis and spinal claudication while wearing a delordosing spondylogic® brace is presented here.
Material and Method. A 14 year old girl with a 25° thoracic scoliosis (2 years postmenarchial), grade IV spondylolisthesis and spinal claudication underwent treatment with a delordosing spondylogic® brace. Walking distance without brace was at around 300 steps before intolerable pain appeared. Self reported walking distance was recorded in the brace 14 days after adjustment.
Results. Walking distance increased to an unlimited number of steps after 14 days while pain intensity decreased three points in the VRS. However, no correction effect of the orthosis on the degree of slippage was found.
Conclusions. Although there is evidence that pain in patients with spondylolithesis can be reduced using exercises and bracing in mild to moderate symptomatic cases, this case demonstrates that bracing can also improve signs and symptoms of spinal claudication in patients with spondylolisthesis of higher degrees. A prospective case series study seems desirable.

Keywords. AIS, spondylolisthesis, spinal claudication, brace treatment, spondylogic® brace

Introduction

The natural history of spondylolisthesis is poorly described in literature [1]. There are only few population studies and because the incidence is low, the number of cases observed is low as well [1]. Progression occurs in a low percentage of cases [2] and it appears that progression is unlikely after adolescence [3]. Pain is the most common initial symptom [2] and in symptomatic cases with a slippage of less than 50% physiotherapy and brace treatment are recommended while in a symptomatic spondylolisthesis with a slippage of more than 50% surgery is widely regarded to be indicated. Surgical complications are regarded as considerably low [1], however in the later literature the risk for non-union is above 10% [4]. A general, standardized surgical concept has still not been established [5]. Although spinal claudication may arise from spondylolisthesis [6,7], little information exists about successful conservative treatment of this combined condition.

However there are studies describing pain reduction due to physiotherapy and bracing in patients with a slippage of less than 50% [1].

Figure 1. The patient in the spondylogic® brace on the left. On the right: Lateral view of the patients x-ray.

A significant improvement of walking distance and pain intensity while wearing a delordosing spondylogic® brace in an adolescent patient with scoliosis, grade IV spondylolisthesis and spinal claudication is presented.

Material and Method

A 14 year old girl with a 25° thoracic scoliosis (2 years postmenarchial), grade IV spondylolisthesis and spinal claudication underwent treatment with a delordosing spondylogic® brace. Walking distance was at around 300 steps before intolerable pain appeared. Self reported walking distance was recorded in the brace 14 days after adjustment. Additionally the patient had a four weeks intensive in-patient rehabilitation programme at our centre with a daily programme lasting 6 hours. The patient refused to undergo surgery.

The spondylogic® brace provides a three-point pressure with a sacral pad form dorsal, a ventral pressure zone at the level of the lower ribs and from dorsal at the level of Th. 8 (Figure 1.). The sacral pad has to be regarded as the main pressure pad whereas the other two pressure zones act as the stabilizing ones. The brace is manufactured using CAD technique as provided by Ortholutions OHG, Rosenheim, Germany.

After the anthropometrical data (circumferential and longitudinal trunk measurements) are registered, the foam model is milled from a blank hard foam block. This hard foam model is wrapped in a heated PE-plate, which is vacuumed to the models surface.

Results

Walking distance increased to an unlimited number of steps after 14 days while pain intensity decreased three points, from 4 to 1 in the VRS (0 – 5). However, no correction effect of the orthosis on the degree of slippage was found in the in-brace lateral x-ray. At the last follow-up 8 weeks after brace adjustment the improvement of the symptoms remained stable.

Discussion

No study showing successful brace treatment in a patient with a spondylolisthesis, a slippage of greater than 50% and spinal claudication has been found in a PubMed search. Signs and symptoms of this condition unexpectedly have been reduced drastically to the patients total satisfaction. Consequently we will proceed with this concept of treatment in patients with symptomatic spondylolisthesis.

Conclusions

Although there is evidence that pain in patients with spondylolithesis can be reduced using exercises and bracing in mild to moderate symptomatic cases, this case demonstrates that bracing can also improve signs and symptoms of spinal claudication in patients with spondylolisthesis of higher degrees. A prospective case series study seems desirable before final conclusions can be drawn.

Acknowledgement

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ADL Based Scoliosis Rehabilitation – The key to an Improvement of Time-Efficiency?

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Abstract. A new ADL (Activities of Daily Living) approach in scoliosis rehabilitation has been designed. The ADL approach uses Side-Shift, physio-logic®, 3D-ADL exercises and Schroth exercises according to current standard. It was compared to an exercise based scoliosis rehabilitation that mainly uses Schroth exercises and as an add-on the training of ADL. The ADL approach in practice seems to be easier to teach and the treatment needs fewer theoretical modules leading to a better time-efficiency. Aim of this study was to test whether the gain in time-efficiency is at the loss of outcome.
Materials and methods: We studied 13 patients having had a 2 weeks ADL based rehabilitation (ABR) and compared their clinical outcome parameters (surface topograhy & Scoliometer angle) to a group of 13 diagnosis-, age-, sex-, Cobb-angle and curve pattern-matched controls having a 4 weeks programme of exercise based rehabilitation (EBR) only. Average age in the study group was 15 years and average Cobb-angle 39°.
Results: Lateral deviation in the study group already after 2 weeks of ABR decreased 2mm (Formetric). Lateral deviation in the control group (EBR) decreased 1,9 mm. The changes were not significant. Thoracic as well as lumbar Scoliometer angle decreased highly significantly in both groups (ABR: 1,8° thoracic, 2,3° lumbar; EBR: 2,1° thoracic, 2,6° lumbar). The differences of outcome between the two groups were not significant.
Conclusions: ABR (2-week programme) seems to provide similar results as EBR (4-week programme). ABR seems to provide a better time efficiency, however a prospective controlled study with a larger sample of patients is desirable before final conclusions can be drawn.

Keywords. Scoliosis, Schroth, side-shift, physio-logic® exercises, rehabilitation, activities of daily living, surface topography, ATR

Introduction

Scoliosis Intensive Rehabilitation (SIR) employs an individualized exercise programme combining corrective behavioural patterns with physiotherapeutic methods, based on sensomotor and kinesthetic principles. Goals of the programme are (1) to facilitate

correction of the asymmetric posture, and (2) to teach the patient to maintain the corrected posture in daily activities.
Referrals are from spine centers, general orthopedic surgeons, pediatric physicians and general practitioners. A four-week minimum is required for the first treatment, and may be up to six weeks; return treatments are three to six weeks in length, depending on symptoms and prognosis. Patients are admitted in groups, with the first day of the programme devoted to diagnosis and evaluation of the three dimensional deformity, supervised by nine staff physicians (Two orthopedic surgeons, and six general practitioners or specialists for Physical Medicine and Rehabilition) who also provide oversight for each patient's programme. On the second day, instruction in basic human anatomy, spinal deformity, and principles of postural balancing therapy is provided to the group. Each patient receives a detailed summary of his/her own condition, and those with matching diagnoses (based on age, degree and pattern of curvature) work together in groups. Evening social activities provide a sense of community and foster development of psychological support systems that can be maintained after treatment is complete.
The treatment programme consists of correction of the scoliotic posture with the help of proprioceptive and exteroceptive stimulation, and begins on the third day after admission. Each weekday, after a twenty-minute group warm-up session, the patients exercise in matched groups for two hours in the morning and two hours in the afternoon and receive shorter more individual training sessions in between. Central to the individual and group exercise programmes is therapist assistance, by a staff of 25 physical therapists and sports therapists who supervise all exercises and provide exteroceptive stimulation needed to obtain desired correction. Depending on individual curve patterns, the patients are assigned to special exercise groups for an additional two hours daily. Development and maintenance of the corrected posture is facilitated using asymmetric standing exercises designed to employ targeted traction to restore torso balance and mobility.
Long-term controlled studies indicate that spinal fusion for Adolescent Idiopathic Scoliosis (AIS), the largest of scoliosis populations does not lead to an improvement of lung function [1], to less pain [2], better „General Health“ [3] and less degeneration [4]. So the only clear indication for spinal fusion in AIS patients and many other forms of scoliosis is severe deformity related stress [5], when the possible long-term risks of spinal surgery are respected [6].
At the same time we have gained evidence that Scoliosis Intensive Rehabilitation (SIR) and the application of correcting braces of the best up to date standard lead to a reduced rate of progression and to a significant reduction of the incidence of surgery [7,8,9].
Scoliosis Intensive Rehabilitation (SIR) improves signs and symptoms of scoliosis [10,11,12,13,14], while surgery generally does not affect health related symptoms [1,2,3,4].

A new ADL (Activities of Daily Living) approach in scoliosis rehabilitation has been designed in order to improve time efficiency. The ADL approach uses Side-Shift, physio-logic® [15], 3D-ADL exercises [16] and Schroth exercises according to current standard (Figure 1.). It was compared to an exercise based scoliosis rehabilitation that mainly uses Schroth exercises and as an add-on the training of ADL. The ADL approach in practice seems to be easier to teach and the treatment needs fewer theoretical modules leading to a better time-efficiency. Aim of this study was to test whether the gain in time-efficiency is at the loss of outcome.

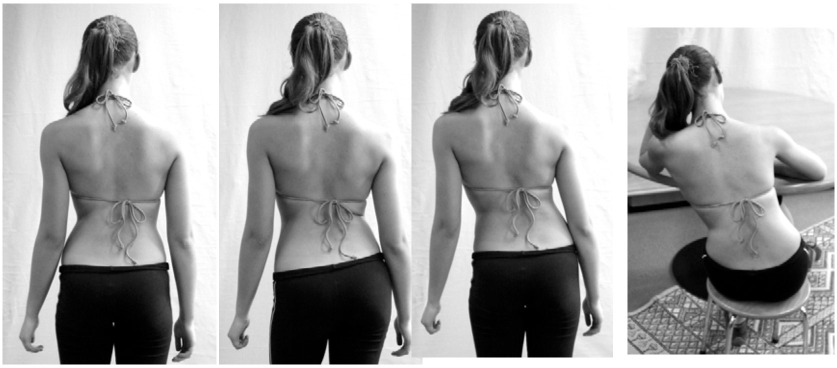

Figure 1. Possibilities of postural correction in frontal plane used in the Activities of Daily Living (ADL) rehabilitation approach. In this patient with pelvic prominence on the left the pelvis is recompensated firstly before the shoulder girdle is tilted and the thoracic part of the trunk is shifted. On the right a sitting position for this patient is demonstrated. A wedge additionally supporting pelvic tilting in sagittal plane can be used to support the preservation or correction of lumbar lordosis.

Material and Method

We studied 13 patients having had a 2 weeks ADL based rehabilitation (ABR) and compared their clinical outcome parameters (surface Topograhy & Scoliometer angle) to a group of 13 diagnosis-, age-, sex-, Cobb-angle and curve pattern-matched controls having a 4 weeks programme of exercise based rehabilitation (EBR) only. Average age in the study group was 15 years and average Cobb-angle 39°.

Results

Lateral deviation in the study group already after 2 weeks of ABR decreased 2mm (Formetric). Lateral deviation in the control group (EBR) decreased 1,9 mm. The changes were not significant. Thoracic as well as lumbar Scoliometer angle (ATR) decreased highly significantly in both groups (ABR: 1,8° thoracic, 2,3° lumbar; EBR: 2,1° thoracic, 2,6° lumbar). The differences of outcome between the two groups were not significant.

Figure 2. The “Catwalk” is one of the ADL exercises to restore or correct the physiological sagittal profile necessary to be attributed to modern scoliosis physiotherapy.

Discussion

The complexity of the Schroth approach does not allow to start the programme without at first teaching functional anatomy and the special Schroth-terminology to the patients. After these first steps the first exercises can be performed with the help of the PT.
Starting the ADL approach with side-shifting and -tilting exercises right away, the patients may gain postural competence from the first hour of treatment on. Those exercises are of course specifically related to the individual curve pattern. Secondly already on the first day physio-logic® exercises are applied in sitting, walking and standing positions. The patient may start with breathing exercises on the second day and from the third day on the patient may, step by step, start with the during the rehabilitation time, steadily improved Schroth concept after the basic 3D principles of correction have been acquired during the first two days. With this approach already after 2 days time a true 3D-correction can be performed by the patient, while in patients without any experience the single pattern specific 3D corrective movements can be taught within a few minutes [16]. Therefore the further development in exercises for the treatment of scoliosis will have to include the application of simple corrective movements, which can be performed during daily activities without loosing sight for the “Gold Standard” of treatment, the Schroth-exercises have been regarded to be [17].

Conclusions

ABR (2-week programme) seems to provide similar results as EBR (4-week programme). ABR seems to provide a better time efficiency, however a prospective controlled study with a larger sample of patients is desirable before final conclusions can be drawn.

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Lower Degree of Mineralization Found in Cortical Bone of Adolescent Idiopathic Scoliosis (AIS)

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Abstract. A lowered bone mineral density (BMD) was observed in trabecular bone in a significant number of AIS patients. The present study aims at investigating whether lower BMD is a systemic phenomenon, which would also be present in the cortical component of long bone. Subjects and Methods. 78 AIS girls (age:15-18y.o) with either moderate (Cobb: 20-40) or severe (Cobb: >40) curve and 44 age-matched controls were recruited. The BMD of the distal region and the mid-shaft of radius were measured with a multi-layer peripheral quantitative computed tomography (pQCT). The trabecular bone and cortical bone BMD and the morphology of mid-shaft were compared. Results. Both trabecular and cortical BMD in severe AIS group was significantly lower than the control by 8.7% and 1.7% ($p<0.05$ for both), respectively. However, the cortical bone area of the mid-shaft did not show any differences from the normal control subjects. Discussion. This study demonstrates a systemic low BMD including the cortical bone. It is suggested that AIS girls may have disturbance in mineralization and ossification during peripubertal growth.

Introduction

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional (3-D) deformity of the spine that most commonly occurs in girls between ages 10-16 during the pubertal growth spurt. Recently, osteopenia in AIS girls was revealed using dual energy x-ray absorptiometry (DXA) and peripheral quantitative computed tomography (pQCT). Our previous studies [1,2] showed that the bone mineral density (BMD) of AIS girls between age 12 -14 was generally lower than the health subjects. When the BMD of the greater trochanter of the proximal femur was measured by DXA, 37.8% of AIS girls were found to be below -1 SD of the normal control BMD value. When vBMD was measured by pQCT, 36.5% of AIS girls had vBMD below -1SD of the controls [1]. Similar to the diagnostic criteria of osteoporosis, the osteopenia in AIS girls may be characterized as low bone mass and micro-architectural changes of bone [3] and led to lower peak bone mass at maturation. [4]. To further dissect the problem of osteopenia in AIS, the degree of bone mineralization in term of cortical BMD (cBMD) was investigated.

In studying the degree of mineralization of the bone matrix, BMD measurement of the cortical bone becomes the surrogate marker since accurate measurement of the mineral content is not available without actually removing bone and submitting it for laboratory testing. To avoid the complication of structural factor involved in the BMD measurement at the ends of long bone which content both trabecular and cortical bone, the midshaft of long bone which consists of pure cortical bone was chosen to measure as the material property of the bone. In addition, the thin cortical bone at the ends of the long bone which may influence the measurement of the BMD due to the partial volume effect [5-8]. Due to incompletely filled voxels at the periosteal and endocortical borders of the cortex, the actual cortical bone BMD is underestimated [9]. Thus, to measure the midshaft of long bone with thick cortical bone would minimize the technical error introduced by all the QCT measurement. Neglect of this technical problem has led to erroneous conclusions about cortical bone development in the past, as pointed out by Augat et al. [5]. Thus, cortical thickness must be taken into account when measuring the cortical bone BMD by pQCT. With the high resolution and multi-layer pQCT, the size of the cortical bone and the mineral density could be assessed.

Accordingly to our previous report on higher bone turnover rate and abnormal anthropometry in AIS [10,11], it is hypothesized that the higher turnover and growth rate would reduce the time for bone mineralization which would manifest in the cBMD of long bone. Thus, the aim of the present study was to evaluate the degree of mineralization in cortical bone of AIS girls and compare it with that of normal healthy subjects.

Subjects and Methods

Subjects

Seventy-eight AIS girls aged 15 to 18 were recruited from the Scoliosis Clinic at the Prince of Wales Hospital. They were divided into 2 groups according to their Cobb angle. The moderate group was AIS girls with Cobb angle between 20° and 40° while the severe group had Cobb angle greater than 40°. All the subjects underwent a clinical and radiological examination to rule out other scoliosis other than AIS. These included (exclusion criteria) scoliosis of congenital, neuromuscular, metabolic etiology, and others with skeletal dysplasia and known endocrine and connective tissue abnormalities. Forty-four age-matched healthy girls were recruited from local communities as a control group for comparison and they were confirmed without any associated medical diseases, spinal deformities, or neurological problems when entered to the study. The study protocol was approved by the Clinical Research Ethics Committee of the University. Informed consent was taken from all the subjects and their parents before any examination or measurement.

BMD Measurement

The midshaft and the distal region of non-dominant radius were measured with a high precision peripheral quantitative computed tomography (pQCT) (Densiscan 2000, Scanco Medical, Bassersdorf, Switzerland). For the midshaft of radius, the midpoint of the radius was marked on skin and a radiolucent marker was placed around for pQCT scanning reference line. The radius length was measured as the distance from the radiale to the stylion [12]. A single slice of pQCT image at the midshaft of radius was taken for the determination of the cross-sectional area (CSA) and the cortical bone area ($Area_{cortical}$) of midshaft radius. The vBMD of the midshaft radius ($BMD_{midshfaft}$) was calculated with CSA (organ level) while the pure cortical bone BMD (cBMD) was with the [13,14]. The cortical bone thickness (Cort.Th) of the midshaft was calculated according to the equation ((Total bone area/π)$^{0.5}$ – [(total bone area – cortical bone area)/π]$^{0.5}$) [9]. For the distal radius BMD measurement, a standard four-layer evaluation program was used to measure the integral BMD (iBMD; cortical + trabecular bone).

Statistical Analysis

All the parameters were presented as mean and standard deviation. The inter-group difference of the BMD measurement was tested by one-way ANOVA. In all tests, an α-level <5% was considered statistically significant. SPSS/PC 13.0 was used or all statistical computation.

Results

The age of the AIS girls with different severity was similar to the control healthy girls (Moderate AIS: 16.7±0.9y.o.; Severe AIS 16.4±1.1y.o.; Control: 16.8±1.1). The Cobb angle of the moderate AIS girls was 30.0±5.9° while severe AIS 52.7±9.5°. There is no significant difference between the length of the non-dominant radius between AIS girls and healthy controls (Moderate AIS: 24.7±1.4; Severe AIS: 24.4±1.5Control: 24.5±1.2cm; p>0.05).

BMD measurement

Table 1 shows the different measurements of the non-dominant radius by pQCT. The distal radius BMD (iBMD) shows that there was a significant difference between AIS groups and control group by 8.7%. the $BMD_{midshaft}$ at organ level had no difference between AIS girls and control although numerically, the values of AIS girls were smaller than the control.

Table 1: The bone mineral density (BMD) and cross sectional area (CSA) of the cortical bone of midshaft radius in girls with adolescent idiopathic scoliosis (AIS) and healthy control subjects.

	Healthy Control		Moderate AIS girls		Severe AIS girls		
	Mean±SD	CV	Mean±SD	CV	Mean±SD	CV	p
iBMD (mg/cm³)	669.7±79.7	11.9%	629.2±91.7	14.6%	611.16±133.4	21.8%	0.039*
$BMD_{midshaft}$(mg/cm³)	1448.8±99.6	6.9%	1433.0±101.2	7.1%	1415.4±118.6	8.4%	0.329
cBMD (mg/cm³)	1636.7±35.8	2.2%	1633.5±39.7	2.4%	1608.8±48.6	3.0%	0.047*
Midshaft CSA (mm²)	90.2±10.0	11.1%	91.27±10.8	11.9%	87.45±10.1	11.5%	0.288
$Area_{cortical}$ (mm²)	79.1±7.3	9.2%	79.2±7.2	9.1%	76.1±6.0	7.9%	0.088
Cort.Th (mm)	3.52±0.32	9.1%	3.47±0.27	7.8 %	3.44±0.36	10.5%	0.326

However, the cBMD of AIS girls was significantly lower than that of the control subjects by 1.7%. In term of morphological changes, the CSA of midshaft, the cortical bone area, and the cortical bone thickness of AIS were not different from the control subjects.

Discussion

In the present study, it was shown that the cortical bone mineral density (cBMD) was lowered in AIS girls. Previous studies showed that AIS girls had generalized low bone mass [1].This study further characterized the osteopenia in AIS girls and found that the degree of mineralization of the cortical bone, namely cBMD, was significantly lower in AIS girls than their healthy peers. Hence, it is speculated that the abnormal mineralization of the bone matrix in AIS girls when previous report [11] showed that the AIS patients had abnormal bone turnover rate during pubertal growth.

The finding of lowered cBMD by 1.7% in AIS girls adds additional information in the nature of osteopenia in AIS girls. In the previous study [1], 36.8% of AIS girls had a lower vBMD value than their peers at the trabecular bone rich region of distal radius. It was also shown that the age-adjusted vBMD of the distal radius was lower in AIS patients than in the controls. However, the previous data suggested potentially insufficient mineralization of the bone matrix or the reduction of structural density within the region of interest in AIS girls. Hence, this study demonstrating that the degree of bone mineralization is lower in AIS patients than in the control subjects implies that having the same unit of bone, AIS patients may retain fewer minerals in the bone matrix than their peers during the pubertal growth.

The lower degree of mineralization of cortical bone in AIS girls can be explained by the rate of bone modeling during puberty. Bone matrix has a mineral density of zero when it is released from the osteoblast, and mineralization starts only about 2 weeks later at a typical remodeling site [15,16]. Within a few days after the start of mineralization, inorganic material has filled 75% of the matrix volume [16-18]. During the following 6 months, mineral continues to be incorporated slowly into the matrix. Because of this time-dependent increase, recently deposited bone matrix has a lower mineral density than "old" matrix. From this, the vBMD of the cortical bone is related inversely to bone remodeling activity: When remodeling activity is high, there will be more unmineralized osteoid and there will be more "young" bone matrix, which has not yet completed mineralization [19]. The measured BMD values by pQCT would be lower when the remodeling activity is high. From this study with the previous observation [10,20-23], it was shown that the AIS girls tended to be taller than their peers. It is indirectly indicating that the AIS girls may have a higher remodeling rate to cope with the rapid growth [11]. Hence, vBMD of AIS girls may be manifested to be lower than the control subjects. With the abnormality in bone turnover marker in AIS girls [11], the authors speculate that it is very likely that the low cortical bone BMD in AIS girls is the manifestation of abnormal bone remodeling in AIS girls.

Although the percentage decrease of cortical bone BMD is small (1.7%), the implication on the bone strength can be significant [24-26]. Bone mineralization level have been shown to significantly contribute to bone strength, stiffness, and fracture toughness [27]. Moreover, studies showed that cortical bone material density was more or less the same with different ages [28,29]. Thus, the low cBMD in AIS girls indicates that there is a possible disturbance in the mechanism of bone formation during puberty. Moreover, the 8.7% difference in iBMD between AIS and healthy subjects may indicate that there is structural difference of trabecular bone from AIS patients in addition to the 1.7% difference in cortical bone density. To further investigate the structural difference, the ultra-high resolution CT for detection of trabecular bone structure in human [30] would elucidate the trabecular bone structure in the extremities.

In summary, the present study has shown that the areas of cortical bone in AIS girls was not different significantly from the control subjects. The distal radius BMD and the cortical bone BMD were however lower than those of controls. It confirmed that the osteopenia phenomena in AIS girls was at a more mature stage and further showed that the bone mineralization in AIS was abnormal. During the pubertal growth, the bone modeling of the cortical bone is mainly through membranous ossification which regulates the bone size and the quantity of bone. The low cortical bone BMD in AIS girls indicates the presence of an abnormality in membranous ossification.

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Research into Spinal Deformities 5
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Gamma Subunits Expression of Junctional Acetylcholine Receptor of Paraspinal Muscles in Scoliosis Associated with Syringomyelia

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Abstract To investigate the denervation of paravertebral muscles in scoliosis associated with syringomyelia via detecting the subunit expression of junctional acetylcholine receptors. **Methods:** All the cases were divided into three groups: Group A consisted of 20 patients with scoliosis associated with syringomyelia, Group B included 10 adolescents with idiopathic scoliosis, and Group C was 10 cases without scoliosis. Bilateral biopsy of the paraspinal muscles was performed during scheduled spinal surgery. The mRNA expression of junctional acetylcholine receptor (AchR) subunits were detected by RT-PCR method. **Results:** 13 patients（65％）in Group A had a positive expression of the mRNA for the γ subunit. The positive rate of γ subunit expression was 40％ on the convex side of the curve, and 25％ on the convex side. The γ subunit expression was absent from all samples in Group B. In Group C, only one patient had the γ subunit expression on the left side. **Conclusion:** The γ subunit expression of the junctional acetylcholine receptor is changed in scoliosis associated with syringomyelia, suggesting the presence of denervation in paravertebral muscles. The denervation of paravertebral muscles may play an role in the pathogenesis of scoliosis.

Key words. Scoliosis; Syringomyelia; Paravertebral muscle; Acetylcholine

1. Introduction

The mechanism by which scoliosis develops secondary to syringomyelia is yet to be determined. Several authors hypothesize the scoliosis may be caused by an alteration in the innervation of the trunk musculature, attributing to the syrinx causing injury either to the lower motor neurons or to the dorsomedial and ventromedial nuclei of the anterior horn of the spinal cord. Chuma et al reported that if kaolin was injected percutaneously into the cisterna magna of 11 dogs, scoliosis developed in three dogs, and histological examination demonstrated that damage of the anterior horn cells was more marked in the scoliotic dogs than in the non-scoliotic dogs. However, to our knowledge, little research has been undertaken to test for the presence of denervation of the paraspinal muscles and any correlation to the curve in scoliotic patients with syringomyelia. The current study was undertaken to evaluate the subunits expression of junctional AChRs in paraspinal muscles in patients with scoliosis associated with syringomyelia using the reverse-transcription polymerase chain reaction (RT-PCR), and to further analyze its association with scoliosis in patients with syringomyelia.

2. Materials and methods

2.1. Subjects

All the children were divided into three groups. Group A consisted of 20 patients with scoliosis associated with syringomyelia and Chiari I malformation (17 males, 8 females; age range, 8–18 years; mean age, 13.1 years). Both Chiari I malformation and syringomyelia were confirmed in all the patients, and none of them had evidence of other intraspinal anomalies. The Cobb angle ranged from 15° to 100° (mean, 51.8°).

Group B included 10 adolescents with idiopathic scoliosis. There were 3 males and 7 females with mean age of 14.6 years (range, 12–17 years). The Cobb angle ranged from 42°to 70° (mean, 54.3°). Physical examination and whole-spine MRI were performed to exclude any other potential disease or malformation of the nervous system in these patients.

Group C comprised of 10 cases without scoliosis, including 4 males and 6 females. Their average age was 17.5 years (range, 16-20 years). Group C included a case of lumbar spondylolisthesis, one case of lumbar intradural neurilemoma, and eight cases of lumbar disc herniation.

2.2. Specimen preparation

Biopsy specimens (approximately 1cm^3) were obtained from bilateral erector spinae muscles during posterior spine surgery. In Group A, the biopsy site was located within the spinal innervation region involved by the syrinx and near to the apical vertebral level of the scoliotic curve. In Group B, the muscle sample was taken at the apical vertebral level of the curve. The chosen site for biopsy in Group C was cephalic to the spinal innervation region involved in the lumbar lesions. Each specimen (about 100mg) was rapidly stored in liquid nitrogen until needed for total RNA extraction.

This study has been approved by the Committee of Ethics at Nanjing University Medical School. All subjects gave their informed consent prior to their inclusion in the study.

2.3. Expression of AChR subunits

Total RNA for the analysis of α- and γ-AChR expression was extracted from snap-frozen tissues using one-step RT-PCR kits from the Clontech Company (USA). The primers of β-actin and α- and γ-AChR subunits were synthesized by the Biochemistry Institute of Chinese Academy of Sciences in Shanghai, China. The primer sequences were showed in **Table 1**.

The cDNA synthesis and amplification were performed following the manufacture's instructions. PCR products (10μl) were run on 2% agarose gel and observed by EB staining under UV light. The images were captured using a Kodak digital camera and were analyzed with molecular analyst image analysis software.

Table. 1 RT-PCR primer sequences and expected size of amplified products

Primer	Sequence	Size
α subunit forward	dTCATCAACACACACCACCGCTCAC	331bp
α subunit reverse	dCCATTGCAACGTACTTCCACTCTGC	
γ subunit forward	dAGCTGCTGAGGATGCACGTTC	199bp
γ subunit reverse	dGCCTTTCTCTAGCTTCTCCAGC	
β-actin forward	dCCAAGGCCAACCGCGAGAAGATGAC	587bp
β-actin reverse	dAGGGTACATGGTGGTGCCGCCAGAC	

3. Results

The mRNA expression for α-AchR was present in each sample. 13 patients（65％）in Group A had the positive mRNA expression for the γ subunit, including on the convex side in five cases, on the concave side in two, and bilateral in six. The positive rate of γ subunit expression was 40％ on the convex side of the curve and 25％ on the concave side. The expression of the mRNA for γ subunit was absent from all samples in Group B. In Group C, only one patient had the γ subunit expression on the left side.

4. Discussion

The concomitant rate of syringomyelia in scoliosis is 4% to 8%, whereas the concomitant rate of scoliosis in syringomyelia is 25% to 85%. Classic features, such as dissociated sensory loss, loss of tendon reflexes, pain, limb asymmetry, and muscle wasting, have all been reported in patients with syringomyelia. However, clinicians may usually be confronted with children and adolescents who record a spinal deformity as their first complain at presentation, with only very subtle or entirely absent signs or symptoms suggesting syringomyelia. In the present study, all the 25 patients in Group A visited the hospital to undergo treatment for scoliosis as the presenting sign, no neurological abnormalities were detected except for weak or absent abdominal reflexes in nineteen patients. A syrinx extending from the cervical to the thoracic area (cervicothoracic syrinx) is the most common type. It is well known that the cervical enlargement of the spinal cord extends from C4 to T1, which includes two groups of nuclei: the medial nuclear group innervating paraspinal muscles, and the lateral nuclear group innervating upper limb muscles. In the area of the cervical enlargement, the cervicothoracic syrinx is more likely to involve the medial nuclear group than the lateral nuclear group, which is consistent with the fact that patients with asymptomatic syringomyelia have a scoliotic curve as the presenting sign, supporting the hypothesis that scoliosis may be caused by the denervation of the trunk musculature.

The AChR of skeletal muscle is composed of five subunit proteins that combine to form the pentameric unit[1,2]. These subunits interact to form a transmembrane pore as well as the extracellular binding pockets for acetylcholine. Prior to innervation of muscle cells, the receptors, termed “fetal” because of their expression early in development, are assembled from five subunits termed α, β, δ, and γ. Following innervation, subsynaptic myonuclei selectively begin to express a new AChR subunit, ε, at the synapse, giving rise to a new, functionally distinct AChR subtype (termed “adult”) with the subunit composition α2βεδ in the synaptic muscle membrane. Fetal AChRs gradually disappear both from synaptic and nonsynaptic muscle membranes.

This substitution is generally completed by three weeks after birth[3~5].

The distribution and subunit composition of AChRs also changes in response to chronic denervation of mature muscle. Neurologic diseases, such as amyotrophic lateral sclerosis, peripheral neuropathy, and infantile spinal muscular atrophy, will result in an up-regulation of AChRs in skeletal muscle attributed to neuronal input decreaseing[6~8]. This up-regulation is characterized by the junctional AChRs containing the ε subunit which is again replaced by the embryonic γ-subunit containing AChRs. Therefore, in the current study, the presence or absence of γ-subunit expression of AChRs was examined in order to testify whether the denervation of paraverspinal muscles occurred in patients with scoliosis and syringomyelia. Our results demonstrated the positive γ subunit expression was demonstrated in 65％ patients in Group A， and the positive rate was 40％ on the convex side and 25％ on the convex side respectively. These findings revealed that the denervation of paraspinal muscles is present in some patients with scoliosis associated with syringomyelia, suggesting that scoliosis be caused by the strength imbalance of paraspinal muscles in these patients.

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Superior Mesenteric Artery Syndrome Following Scoliosis Surgery: Its Risk Indicators and Treatment Strategy

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Abstract From July 1997 to October 2003, 640 patients with adolescent scoliosis who had undergone surgical treatment were evaluated prospectively, 7 patients of whom suffered from SMAS post-operatively. The height of the 7 patients who developed SMAS was above the mean of sex- and age-matched normal population, with the height percentile ranging from 5% to 50%. On the contrary, their weight was below the mean of the normal population with a weight percentile ranging from 5% to 25%. Among the 7 patients, 4 had a thoracic hyperkyphosis ranging from 55° to 88° (average 72°) and 2 had a thoracolumbar kyphosis of 25° and 32° respectively. The 7 patients were all treated with fasting, antiemetic medication and intravenous fluids, a nasogastric tube was passed and aspirations commenced. Reduction or suspense of traction was adopted in three patients who had SMAS during Halo-femoral traction after anterior release of scoliosis. All the patients recovered completely with no sequelae.

Key words syndrome; superior mesenteric artery; scoliosis; surgery

1. Introduction

Superior mesenteric artery syndrome (SMAS) results from compression of the third portion of the duodenum as it crosses underneath the superior mesenteric artery (SMA), the second anterior branch of the abdominal aorta. Several authors have reported series or individual cases of the condition after the trunk was immobilized with a cast, so it has also been called cast syndrome[1] or Wilkie's syndrome[2,3]. It is rarely reported that

SMAS occurs after scoliosis correction with newly-developed 3-dimensional derotation techniques. Clinically, the syndrome may progress to serious sequelae or follow a benign course. In early reports, the mortality rate of SMAS could reach to 33%[4]. Thus, the importance of early diagnosis and appropriate management should be emphasized. We report seven cases of SMAS following surgery for scoliosis to alert clinicians and identify the risk indicators, the pattern of clinical presentation and evaluate the treatment strategy.

2. Materials and methods

From July 1997 to October 2003, 640 patients (228 boys and 412 girls) with adolescent scoliosis who had undergone surgical treatment at the authors' institution with 3-dimensional correction technique were evaluated prospectively, Of these, 7 cases suffered from SMAS post-operatively, comprising 3 males and 4 females, with age ranges from 13 to 16 years. 3 cases were congenital scoliosis and 4 were idiopathetic scoliosis, with Cobb angles ranging between 45° and 116° (average, 82°). Among these 7 patients, three developed SMAS during halo-femoral traction following anterior spinal release, three developed the problem after posterior correction with 3-dimensional TSRH (Texas Scottish Rite Hospital, Sofamor-Danek, USA) derotation technique, and one after an anterior correction with CDH (CD-Horizon, Sofamor-Danek, USA) instrumention.

Charts were reviewed for weight and height at the time of admission. Each patient was assigned a percentile for weight and a percentile for height. The percentile was obtained referring to the normal data reported by the National Center for Student Status and Health Statistics in 2001, and the tabulated data are sex- and age-specific. Values of the 5th, 10th, 25th, 50th, 75th, and 95th percentiles were selected to divide the observations. The sagittal Cobb angle across the involved segments was used to quantify thoracic or thoracolumbar kyphosis. Values were interpreted with respect to normative data for sagittal alignment in adolescents.

All of the 7 patients presented with nausea and intermittent vomiting about 5 days post-operatively. The vomit was brown green and turbid liquid. Between bouts of vomiting, the patients felt hungry. On examination, the epigastrium was distended and soft with mild tenderness, a resonant percussion note were present, and bowel sounds were often active. An upper gastrointestinal barium contrast study with findings specific for SMAS was required for inclusion in the series, which showed a barium-filled dilatation of the proximal part of the duodenum and a straight-line cutoff at the third part of the duodenum representing extrinsic compression of the superior mesenteric artery.

3. Results

In the 7 patients， the correction rate of the coronary Cobb angle ranged from 57% to 74%, with an average of 66%. Their height increased 4~15cm after surgery.

All the 7 patients who developed SMAS had a disproportionately thin habitus in relation to their height. Their height was above the mean for the sex- and age-matched normal population, with the height percentile ranging from 5% to 50%. In contrast, the weight of the 7 patients was below the mean for the sex- and age-matched normal population with their weight percentile ranging from 5% to 25%. Four patients had a thoracic hyperkyphosis ranging from 55° to 88° (average 72°), one had a thoracic alignment of 48°, falling within the normal range of thoracic kyphosis but closing with the upper boundary of the normal value; a thoracolumbar kyphosis were identified in the other two patients with the sagittal Cobb angle of 25° and 32° respectively.

The seven patients were treated by fasting, antiemetic medication and intravenous fluids, and a nasogastric tube was passed and aspirations commenced. A left lying position was mandatory, and reduction or suspension of the traction was initiated in three patients who had SMAS during Halo-femur traction following anterior release of scoliosis. Symptoms were allivated after 5~7 days in five patients. The other two (patient 4 and 7) continued to have obstinate and repetitive vomiting, so conservative management was continued; feeding was not commenced until days 12 and 18. by this time, their weight loss was 7 kg and 11kg respectively. All the patients recovered completely with no sequelae and there was no requirement for operative intervention by laparotomy.

4. Discussion

Since 1990s, 3-Dimensional derotation techniques have been widely used and have improved the corrective rate of scoliosis greatly [5,6]. Although the reports of the SMAS decreased sharply due to the adoption of this technique, superior mesenteric artery compression of the duodenum is still a potentially life-threatening complication of surgery to correct scoliosis[7]. The incidence of adverse sequelae from the syndrome remains alarmingly high. Aspiration pneumonia, acute gastric rupture, and cardiovascular collapse have all been documented as morbid or fatal complications of SMAS[8,9]. Surgery intended to correct the scoliosis also relatively lengthens the spine, displacing the SMA origin cephalad at the expense of lateral mobility. Crowther has shown there can be an acute increase in vertebral column length with spinal instrumentation, resulting in traction on the SMA and narrowing of the arteriomesenteric angle, and postoperative weight loss results in loss of the retroperitoneal fat that protects the duodenum from compression [10,11].

We emphasize the importance of identifying those patients at risk and maintaining a high index of suspicion. Paying attention to the various risk factors that may be present before surgery may be beneficial to the understanding and treatment of SMAS. Munns et al [12] identify high-risk patients as "those with a thin, asthenic habitus". Hutchinson and Bassett [13] reported on SMAS in five patients undergoing operative treatment of scoliosis, all of whom were "disproportionately thin in relation to their height." However, there are no clinically useful parameters to identify individuals susceptible to SMAS. In order to quantify the degree of asthenia, we calculated the absolute difference of these patients' height percentile and weight percentile compared to a sex- and age-matched normal population. In our series, all the seven patients who developed SMAS also had a disproportionately thin habitus in relation to their height. Their height was above the mean for the normal population with the height percentile ranging from 5% to 50%, and weight was below the mean for the normal population with the weight percentile ranging from 5% to 25%. We propose that patients with a height percentile of <50% and a weight percentile of <25% might have potential risk indicators for SMAS if undergoing correction surgery for adolescent scoliosis. Attention should also be given to sagittal kyphois. Scoliosis associated with sagittal kyphosis is usually accompanied by severe trunk collapse. Following scoliosis correction or powerful skull-femur traction, the trunk elongation becomes more extreme. This may lead to further narrowing of the arterio-mesenteric angle. In this series, six of the patients all had this sagittal abnormity including four with thoracic hyperkyphosis and two with thoracolumbar kyphosis. In addition, the high-risk patients includes those who underwent rapid halo--femoral traction after the spinal anterior release (three patients in our group).

The treatment for SMAS varies from conservative non-operative to operative procedures. Anderson reported on nine cases; five required exploratory laparotomy. Crowther[8] proposed that most patients recover with conservative measures, but occasionally surgical intervention may be required. Van Brussel[3] stated that the first choice of SMAS is conservative therapy. In our series, through fasting, gastrointestinal decompression, changing posture, maintaining the electrolytic balance or relieving the halo-femoral traction, all seven patients recovered without operative intervention and internal fixation removal. We consider that conservative management should be effective if early diagnosis, appropriate supportive measures, and gastrointestinal physicians' input into management are obtained.

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