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Preface

The International Research Society for Spinal Deformities (IRSSD) was founded in 1994. The first concepts of forming the Society were raised by a group of researchers who had first gathered in Vermont in 1980 to hold what subsequently became a series of biennial meetings devoted to surface topography and deformity. At a meeting held in 1992 in Montreal, focussed on 3 dimensional interpretations of spinal deformities, discussions were held into whether a formal Society should be formed, and while debate rejected this concept at the time, it was two years later at a meeting in Pescara, Italy 1994 that the IRSSD finally came into being.

The Society has its roots in mathematical modelling, biomechanics and medical research and has always encouraged researchers to report their on-going projects in all aspects of the spinal deformities associated with scoliosis and other spinal deformity conditions. The biomechanical approach led to a better understanding of how the vertebral column behaves under stresses and how the surface shape related to the underlying columnar deformity. Developments in imaging and electronics allowed researchers to develop systems such as ISIS as a non-invasive method of recording back shape in out patient clinics as well as a tool for researchers.

Biologically based studies were also reported. It was appreciated early on by the membership that children with scoliosis have a range of growth disturbances associated with a marked skeletal asymmetry. While the biological approach has enabled a considerable amount of data to be amassed which relates to etiology and pathogenesis, no actual breakthrough into fully understanding why the spinal column rotates and curves to cause scoliosis has yet occurred.

The biennial meetings of the Society chart this research progress in each of the volumes of proceedings, with some reports being final papers while others are progress reports. This is a unique resource for the researcher, holding the key to many different aspects of the problems of the spine. However, some authors choose not to submit to the volumes as they are publishing elsewhere in peer-reviewed Journals, a trend which is inevitably going to challenge the way conference proceedings are reported in the future. There is therefore a challenge to the IRSSD to find an answer to this issue.

2008 could be viewed as a time of potentially exciting breakthroughs in our understanding of the deformity of scoliosis. The rapid advances in imaging technology will allow better and more detailed images of the spine, both on its surface and deeper internally, using techniques such as Laser scanning, Magnetic Resonance Imaging and ultrasound. There is little doubt these technologies are going to advance massively, new ones will come into the hands of clinicians and researchers and a better understanding of the complex functional anatomy of the spine will be developed. This will undoubtedly aid biomechanicians to model the spine and its function, under gravity and movement, allowing new insight into progressions of curves and ways to surgically control deformities.

However, it is probably the potential of biology and medical research which offer the greatest opportunities to further our understanding. The incredible advances at the molecular level, the expanding knowledge of genetics and the recent discoveries in the field of neurophysiology offer for the first time real potential for unravelling the puzzles of etiology. The discovery of molecular biochemical pathways, signalling agents, hormones such as leptin, genetic markers and a greater appreciation of the role of the nervous systems, both central, peripheral and autonomic, all indicate that the research field could expand dramatically with new ideas and inputs from research workers in fields outside the traditional ones devoted to the spine.

It is thus clear that to find a solution, we must build on these new developments and look beyond the spine to the whole body to discover if its biological functions are disturbed. A growing child is a dynamic environment internally, with rapid growth changes reflected in adolescence and these are known to result in tall, thin and asymmetrical children. These changes point to a whole body biological involvement. Researchers must reflect on this totality since it must ultimately allow us to explain the etiology and pathology of what are probably going to prove to be secondary events manifest as spinal curvatures.

These are exciting times and I hope the participants in the Liverpool meeting in 2008 will look back on it as a watershed in our understanding of the spinal deformities. Let's hope this is true, since a therapeutic intervention must surely be better than surgery or external bracing from the purely psychological, if not cosmetic, view of a growing child.

I would like to thanks all participants and authors for submitting their work to the meeting and to my colleagues Professor Nachi Chockalingam, Mr. Ashley Cole and Mr. El-Nasri Ahmed, for their help and support and to our sponsors who supported the meeting in Liverpool, European Capital of Culture 2008.

Peter Dangerfield
Liverpool, UK
April 2008

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Genetics

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Cytogenic abnormalities in buccal cells during spinal deformities in children

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Abstract. Evaluation of the incidence of nucleus abnormalities in buccal epithelium allows detecting the presence and intensity of the effect of various ecological conditions and pathologies of the musculoskeletal system. Two coefficients were used: mean number of NA per cell and ratio of cells with karyolysis to the total number of cells with NA. Coefficient of karyolysis decreases with increasing anthropogenic load In pupils of a special school in Moscow these coefficients were similar. Analysis of coefficients showed that karyolysis coefficient was reduced in mothers of children with spinal deformities. **e-mail:** mkarganov@mail.ru

Keywords. Buccal epithelial cells, cytogenetic abnormalities, laser correlation spectroscopy, metabolic shifts, musculoskeletal disorders

1. Introduction

Enhanced cytotoxic and genotoxic load manifests in increased number of cells with abnormal nuclei. The incidence of nucleus abnormalities and the corresponding metabolic shifts were found to depend on the presence of spine deformities and ecological factors. The most dynamic parameter was number of cells with karyorrhexis. The problem of formation of risk groups for spine deformities in ecologically unfavorable regions is discussed.

2. Objective and Methods

The method used was the counting nucleus abnormalities (NA) in buccal epithelial cells (BEC) [1]. We examined 9-12-year-old children in three schools: general education school (25 pupils) and their parents (n=31), Moscow boarding school for children with scoliosis and kyphosis (61 pupils), country school in ecologically clean Novgorod region (23 pupils). A peculiarity of NA counting in buccal epithelium is availability and simple procedure of cell isolation. Oral mucosa is lined by stratified squamous epithelium, which is renewed due to division of basal cells. Maturing cells are displaced first to the intermediate and then to the surface layer and then they are desquamated. Cytogenetic abnormalities appearing in the basal layer remain in maturing cells can be then detected in surface layers [2].

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.

Two coefficients were used: mean number of NA per cell and ratio of cells with karyolysis to the total number of cells with NA.

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 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. The samples were obtained and the measurements were performed as described previously [3].

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

3. Results.

Analysis of buccal epithelial cells is a method of evaluation of the effect of environmental factors on human organism. In most studies, the incidence of cells with micronuclei is used as a criterion; spontaneous level of these aberrations is low. The incidence of other nucleus abnormalities (karyorrhexis, karyolysis, karyopyknosis, binuclear cells) is considerably higher. Their ratio varies in different individuals, but the mean parameters in the group allow evaluation of the adaptive capacities.

Two coefficients were used: mean number of NA per cell and ratio of cells with karyolysis to the total number of cells with NA. The first coefficient characterizes the quality of reparation mechanisms. The second coefficient was introduced on the assumption that cells with any NA variant should proceed to the karyolysis stage. Low percent of karyolysis can be considered as insufficiency of mechanisms responsible for elimination of damaged cells.

Coefficient of karyolysis decreases with increasing anthropogenic load: the ratios of these coefficients in the group of children in most ecologically clean territory (n=23) and in Moscow (n=25) were 0.040/0.241 and 0.187/0.018, respectively (Figure 1).

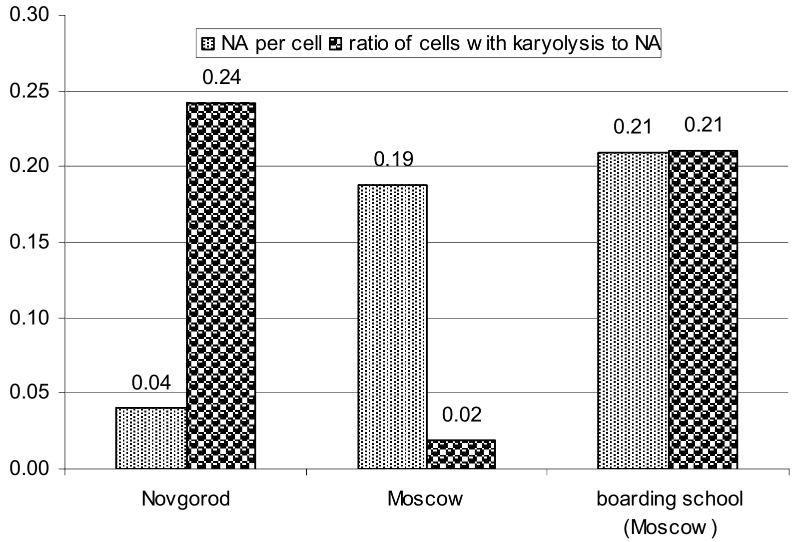

Figure 1. The ratios of coefficients in various group of children.

Analysis of spectra with consideration for the predominant type of metabolic processes 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%). In children from 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 examined groups differed by the distribution of predominant direction of metabolism ($P<0.001$). The most drastic differences were demonstrated for the contribution of catabolic shifts.

Examination of patients (n=61) with musculoskeletal disorders in Moscow showed that these coefficients for the whole sample were similar (0.21/0.21). When the whole sample was divided into groups with scoliosis (n=38; 0.17/0.14) and kyphosis (n=23; 0.17/0.22), the percent of cells with NA was similar, while the percent of cells with karyolysis was considerably higher in patients with kyphosis.

Examination of parents of children with spinal deformities revealed no differences in LCS spectra between healthy individuals and individuals with pathologies of the spine. Analysis of coefficients of buccal epithelium showed that karyolysis coefficient was reduced in mothers of children with spinal deformities (0.18 vs. 0.55 in the control).

4. Discussion.

High NA coefficient, which can be determined by both ecological and pathological factors, attests to insufficiency of reparation mechanisms; under these conditions calls with karyolysis constitute 20% of all NA. Musculoskeletal disorders change the ratio of coefficients for the BEC and allow indirect evaluation of the children adaptation capacities. Developing spine deformities modulate the ratio of coefficients of buccal epithelium, which reflects both the progressing pathological process and its directionality.

Analysis of buccal epithelial cells and LCS analysis make it possible to detect differences between children groups, because they reflect dynamic processes in the organism. These methods are ineffective in adults, because the process is stabilized in this case. We previously showed that changes in the direction of metabolic shifts were observed only in children with detected sharp changes in Cobb angles.

5. Conclusions

The incidence of musculoskeletal diseases directly correlates with the degree of environmental pollution. 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 spine deformities under conditions of ecological hazard.

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Chapter 2

Growth

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Body mass index of girls in health influences menarche and skeletal maturation: a leptin-sympathetic nervous system focus on the trunk with hypothalamic asymmetric dysfunction in the pathogenesis of adolescent idiopathic scoliosis?

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Abstract. Lower body mass index (BMI) and lower circulating leptin levels have been reported in girls with AIS. In this paper we evaluate skeletal sizes and asymmetries by higher and lower BMI subsets about the means for each of three groups of girls age 11-18 years: 1) normals, 2) school screening referrals, and 3) preoperative girls. Higher and lower BMI subsets, likely to have separated subjects with higher from those with lower circulating leptin levels, identify: 1) girls with relatively earlier and later menarche; 2) trunk width size greater in the higher than in the lower BMI subset, of all three groups; 3) abnormal upper arm length (UAL) asymmetries (right *minus* left) in the lower BMI subset of the preoperative girls; and 4) in thoracic AIS of screened and preoperative girls, Cobb angle and apical vertebral rotation each significantly and positively correlate with UAL asymmetry in the lower BMI subset but not in the higher BMI subset. In preoperative girls, the lower BMI subset shows the combination of relatively reduced pelvic width and abnormal UAL asymmetry, suggesting that both are linked to lower circulating leptin levels. An earlier puberty with hormonal changes provides a plausible explanation for the larger trunk width at the shoulders and pelvis especially at the younger ages in the higher BMI subsets. At the shoulders, this widening is driven by the ribcage which, in human evolution was acquired with decoupling of head and trunk movements required for efficient bipedal gait. The UAL asymmetry patterns within the groups and BMI subsets are not explained by hormonal mechanisms. It is hypothesized that 1) normal trunk widening of the thoracic cage by hormones in human adolescence is supplemented via the sympathetic nervous system under leptin-hypothalamic control influenced by energy stores (metabolic fuel); and 2) hypothalamic dysfunction with altered hypothalamic sensitivity to leptin through a SNS-driven asymmetric effect may create skeletal length asymmetries in upper arms, ribs, ilia and vertebrae, and initiate AIS. Additional mechanisms acting in the spine and trunk may be required for AIS to progress including 1) somatic nervous system dysfunction, 2) biomechanical spinal growth modulation, and 3) osteopenia.

Key words.. Idiopathic scoliosis, pathogenesis, spine, body mass index, leptin, shoulder girdle, pelvis, ribcage, human evolution

1. Introduction

Lower body mass index (BMI) has been detected in girls with AIS by some [1-7] but not by all [8] and BMI is normal before developing scoliosis [9]. Qiu et al [7] reported that low body mass index in AIS girls is associated with a marked decrease in circulating leptin compared with controls and leptin was found to correlate positively with corrected height. They comment [7] on clinical and experimental evidence strongly suggesting that leptin acts on bone tissue through both central and peripheral pathways; a central pathway driven by hypothalamic nuclei and the sympathetic nervous system (SNS), and peripherally by stimulating osteoblastic differentiation and inhibiting osteoclastic activity, resulting in enhanced bone formation and reduced bone resorption, and that leptin may regulate body growth during childhood and adolescence.

There are no other reports on how skeletal size in AIS girls may relate to BMI. In this paper we evaluate skeletal sizes and asymmetries by higher and lower BMI subsets. The findings give some support to our *leptin-SNS concept* for the pathogenesis of adolescent idiopathic scoliosis [10].

2. Methods and subjects

2.1 Three groups of subjects

Data from three groups of female subjects age 11-18 years were studied: 1) normals (n=274, mean age 13.4 years); 2) school screening referrals (n=137, mean age 14.8 years, mean Cobb angle 15.8 degrees, mean apical vertebral rotation (AVR) 12.6 degrees, thoracic 37, thoracolumbar 41, lumbar 41, double 15, straight 3); and 3) preoperative subjects (n=110, mean age 14.8 years, mean Cobb angle 55.6 degrees, mean apical vertebral rotation 27.1 degrees, thoracic 81, thoracolumbar 25, lumbar 4). The numbers include subjects with a complete set of upper arm lengths, standing height and weight but tibial lengths were not recorded in some of the screened and preoperative girls. The normal subjects were examined by one observer (RGB) in 1973-1981. The scoliosis screening girls were referred to hospital by a routine quantitative protocol [11] and examined by the same observer in 1988-1999. The preoperative subjects were examined by one of three observers (RGB, AAC or RKP) in 1993-1999.

2.2 Anthropometry (Figure 1)

The anthropometric techniques utilized the Harpenden Anthropometric Instruments (Holtain Ltd, Crosswell, Crymych, Pembs. SA41 3UF UK)[12,13]. Standing and sitting heights were recorded and subischial height calculated as standing height *minus* sitting height. Corrected standing and sitting heights for the screened and preoperative girls were calculated with the Bjure-Nachemson Formula [14]. A Harpenden anthropometer was used to measure biacromial width, biiliac width, upper arm lengths (UALs) forearm-with-hand lengths and tibial lengths. UAL asymmetry and tibial length asymmetry were calculated as right *minus* left. An association between AIS thoracic curve AVR and UAL asymmetries was detected in a previous study [15,16]. Tibial length [TL] provided a model for the lower limbs in a previous study [17,18]. Menarcheal age was recorded.

2.3 Anthropometric error studies

Intra-observer errors for RGB are (n=126): [19-21]:
Standing height: Technical error of measurement (TEM)=2.1mm, coefficient of reliability R=0.99,
Sitting height: TEM=1.9 mm R=0.97
Biacromial width: TEM= 3.3 mm
Biiliac width: TEM=1.99 mm
Upper arm length (right): TEM=2.9 mm, R=0.95,
Upper arm length asymmetry: TEM=3.6 mm, R=0.39
Tibial length (right) TEM=3.2 mm, R=0.96
Tibial length asymmetry TEM=3.7mm, R=0.38.

2.4. Body mass index

Body mass index (BMI=weight in kg/stature in metres) above and below the BMI mean for each group was used to define two subsets of subjects with higher and lower BMIs. Skeletal parameters were plotted against decimal age for these two BMI subsets of each group, including stature, sitting height, subischial height, biacromial width, biiliac width and for paired structures right and left for each of upper arm length (UAL), forearm-with-hand length, and tibial length (TL). Differences between each skeletal parameter by BMI subset was evaluated by analysis of variance (ANOVA) with age correction. Skeletal length asymmetries of UALs and TLs for the two subsets above and below the mean for each group were evaluated by an independent t-test. (The findings for each skeletal parameter by standard deviation scores will be reported separately).

2.5 Spinal radiographs

The spinal radiographs were read by one observer (RGB) for the screened and 42 of the preoperative girls for Cobb angle and apical vertebral rotation (AVR)[22], and for the other preoperative girls by another observer (RKP). The intra-observer error for RGB fpr measuring Cobb angle is TEM=1.3 degrees, R=0.82, n=10; and for AVR, TEM=3.3 degrees, R=0.63, n=10 [15].

3. Results

3.1 Body mass index.

BMI means and standard deviations for the three groups are respectively 19.2±2.7, 19.6±2.7 and 19.6±3.3 and not significantly different between any of the groups (analysis of variance, correcting for age). BMI increases significantly with age in each of normals (ρ=0.408, p<0.001). screening referrals (ρ=0.181 p=0.026) and preoperative girls (ρ =0.271, p=0.002)(Spearman rank correlation coefficients).

3.2. General skeletal growth (Figures 1 and 2) and menarche

In each of the three groups, normals, screened and preoperative girls, significantly larger size is attained in those subjects in the higher BMI subset than in those in the lower BMI subset with respect to biacromial width and biiliac width (ANOVA with correction for age). Figure 1 for the screened girls shows for the anatomical regions the statistical levels of significance between the higher and lower BMI subsets. In preoperative girls, the biacromial and biiliac widths are significantly larger in the higher BMI subset than in the lower BMI subset (p<0.001), but not in sitting height, upper arm length or tibial length. In the normals, the effect is present in biiliac width (p=0.014) and biacromial width (p=0.0.036) and not in sitting height or upper arm length. The mean age at menarche for the screened girls, is significantly earlier in the higher BMI subset, than in the lower BMI subset (12.5 and 13.1 years, p=0.003, n=51 and 60 respectively) (Figure 2) (overall, premenarcheal 23, postmenarcheal 111, not known in 3).

3.3 Extra-spinal skeletal length asymmetries by higher and lower BMI subsets

In asymmetries of upper arm length and tibial length differences by higher and lower BMI subset were calculated by independent t-test and by analysis of variance (ANOVA) without and with correction for age respectively.

3.3.1 Upper arm length asymmetries (Figure 3)

a) Normal girls not significantly different (higher BMI 2.4 mm, lower BMI 2.1 mm, p=0.623, n=131 and 143 respectively), ANOVA p=0.960, p=0.910.
b) Screened girls not significantly different (higher BMI 1.3 mm, lower BMI -0.5 mm, p=0.070, n=54 and 83 respectively), ANOVA p=0.062, p=0.146.
c) Preoperative girls significantly different (higher BMI 3.4 mm, lower BMI 7.0 mm, p=0.017, n=54 and 56 respectively), ANOVA p=0.063, p=0.503

Figure 3 shows that UAL asymmetries of girls with higher BMI subsets are not significantly different between groups but for lower BMI subsets are significantly different between the preoperative and each of the screened and normal girls (each p<0.001).

3.3.2 Tibial length asymmetries

a) Normal girls not significantly different (higher BMI -0.2 mm, lower BMI -0.3 mm, p=0.805, n=131 and 142 respectively), ANOVA p=0.486, p=0.570.
b) Screened girls not significantly different (higher BMI 1.4 mm, lower BMI 2.4 mm p=0.214, n=55 and 78 respectively)., ANOVA p=0.227, p=0.770.
c) Preoperative girls not significantly different (higher BMI 0.4 mm, lower BMI 1.1 mm, p=0.561, n=41 and 44 respectively), ANOVA p=0.973, p=0.905.

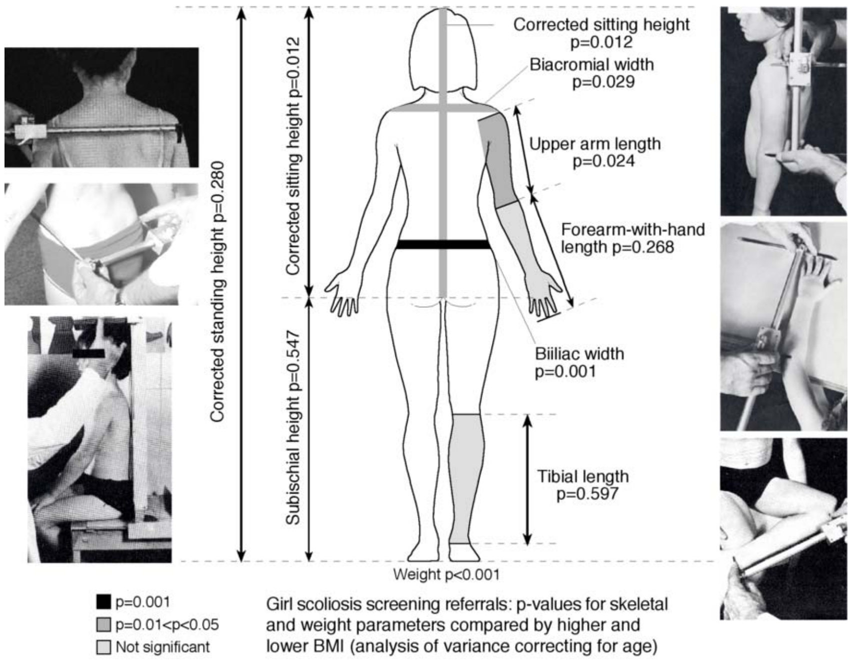

Figure 1. Photographs of six anthropometric techniques and a drawing for scoliosis screened girls showing statistical findings by analysis of variance with correction for age. Some skeletal regions show relatively larger sizes for the higher than for the lower BMI subset with p-values given; these are: biacromial width, biiliac width, upper arm length and sitting height. Findings are shown only for right limbs. A similar pattern of trunk features is present in normal and preoperative girls at different levels of statistical significance.

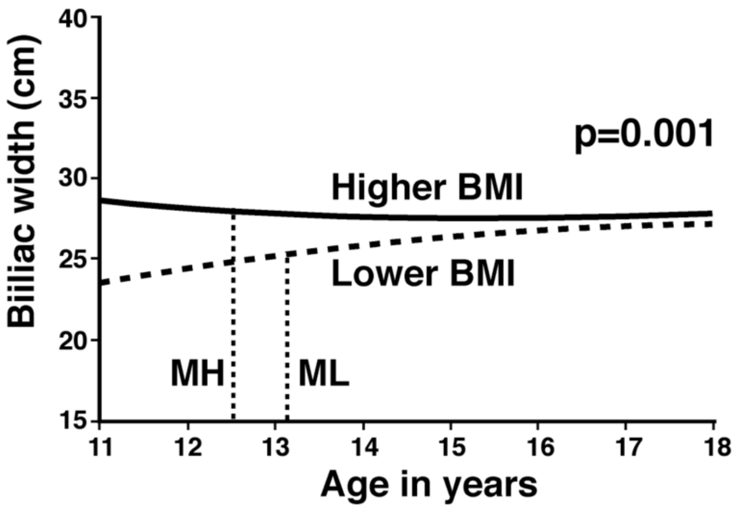

Figure 2. Scoliosis screened girls. Graph showing best-fit quadratic regression lines for biiliac widths by age in years for girls in the higher and lower BMI subsets. The girls in the higher BMI subset have relatively larger biiliac widths than the girls in the lower BMI subset especially at the younger ages. (p=0.001, analysis of variance with correction for age). Mean menarcheal ages are shown for the higher BMI (MH) and lower BMI (ML) subsets.

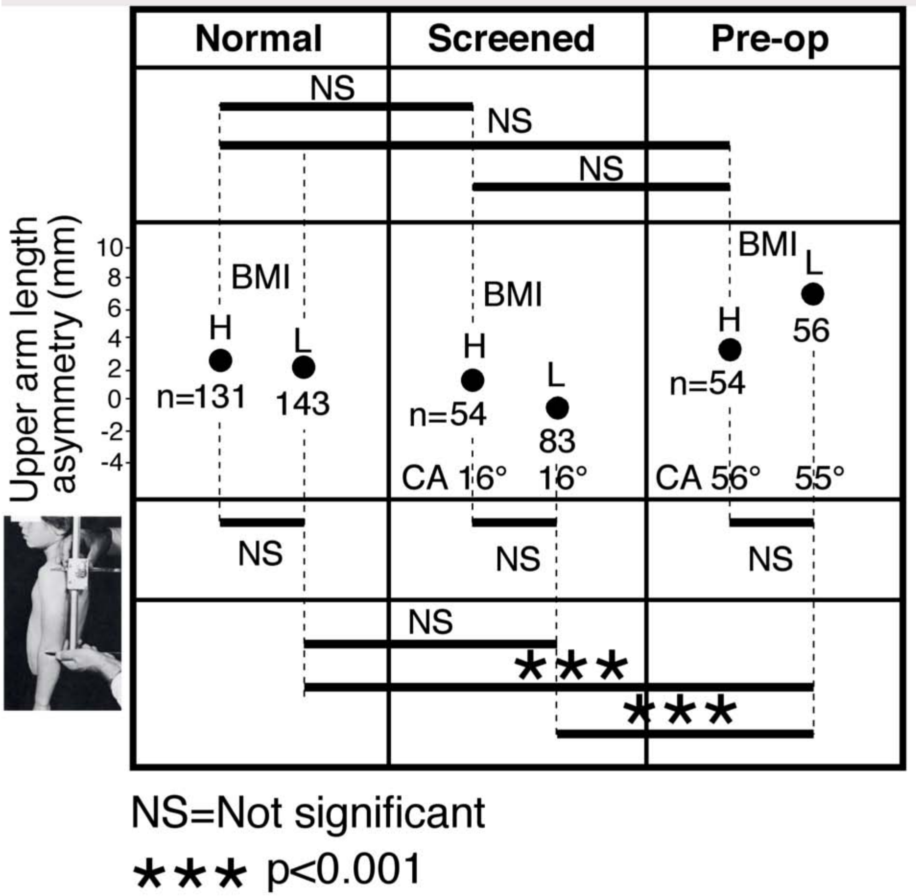

Figure 3. Plots of mean asymmetries for upper arm length (UAL mm. right *minus* left) for the three groups – normal, screened and preoperative girls by higher and lower BMI subsets; the numbers beneath the means show the number by group in each subset and below the mean Cobb angle (CA). BMI=body mass index, H=higher BMI subset, L=lower BMI subset. The statistical significances levels for the comparisons are indicated above the horizontal bars (ANOVA with correction for age). Note, that the mean UAL asymmetries associated with the higher BMI subset (upper block) are not significantly different for any of the comparisons, while the UAL asymmetry associated with the preoperative lower BMI subset (lower block) is significantly more than that of the screened and normal girls [see 10].

3.4. Thoracic curves: Cobb angles and AVRs

3.4.1 Mean values of AVR and Cobb angles

In thoracic AIS of screened and preoperative girls (to provide a range of curve severities) absolute AVR (but not absolute Cobb angle) is significantly larger in the *higher BMI subse*t than in the *lower BMI subset* (mean AVR 23.3 degrees and 19.8 degrees, p=0.026 independent t-test; mean Cobb angle 45.4 degrees and 43.9 degrees, p=0.680 independent t--test, n=57, with 6 left curves, and n=61 with 6 left curves respectively). Comparing the higher with the lower BMI subsets by ANOVA with age correction for AVR p= 0.811 and for Cobb angle p=0.944.

3.4.2. AVR and Cobb angle are each associated with upper arm length asymmetry.

In the same group of thoracic AIS screened and preoperative girls, in the *lower BMI subset*, but not in the higher BMI subsets, both AVR and Cobb angle correlate significantly with UAL length asymmetry – *lower BMI subset* AVR r=0.459 p<0.001; Cobb angle r=0.526, p<0.001 n=61; *higher BMI subse*t AVR r=0.145, p=0.287; Cobb angle r=0.032, p=0.857, n=57.. Comparing the higher with the lower BMI subsets by ANOVA without age correction for AVR p=0.001 and for Cobb angle p=0.102, and with age correction for AVR p= 0.689 and for Cobb angle p=0.655.

4. Discussion

4.1. Body mass index.

The mean BMIs for screened and preoperative girls (each 1990s) are not different from the mean BMI for normals (1973-1981). Using normal BMI findings obtained in the mid-1990s (Aujla RK and Kirby AS, unpublished observations) the screened, but not the preoperative, girls have significantly lower BMIs (p=0.014 and p=0.230 respectively).

4.2. General skeletal growth features, focus on the trunk and relatively earlier skeletal maturation especially of trunk width in subjects with higher BMIs

4.2.1. Broadening of the human shoulder girdle held on the ribcage (Figure 1).

The higher and lower BMI subsets are likely to have separated subjects with higher from those with lower circulating leptin levels [7]. Supposed higher circulating leptin levels in all three groups are associated with relatively larger growth in the trunk - biacromial and biiliac widths and statistically most evident in the preoperative girls. Contrariwise, supposedly lower circulating leptin levels are associated with relatively less growth in trunk widths. Biacromial width reflects the shoulder girdle which is held on the broad human thoracic cage [23]; the width of the shoulder girdle in human evolution was acquired with the decoupling of head and trunk movements [24,25] required for efficient bipedal gait [26]. Hence, biacromial widths are evidently associated with the lateral growth of the human thoracic cage and clavicles; and our findings suggest that the growth of both widths may be affected by circulating leptin levels in humans but may not in non-human primates and quadrupeds.

4.2.2. Relatively earlier menarche and relatively earlier skeletal maturation in the biacromial width and pelvic width with higher BMIs

In the screened girls, the relatively earlier menarche by about 6 months of the higher-to- lower BMI subset respectively is in keeping with knowledge of a link between body fat and the timing of puberty with leptin playing a permissive role [27,28] and kisspeptin activation of the G-protein coupled receptor-54 [28-31] providing a critical metabolic signal initiating puberty through pulsatile GnRH secretion [29]. Hence, relatively earlier skeletal maturation in the higher BMI subset due to relatively earlier puberty with hormonal changes provides a plausible explanation for the trunk width differences by BMI subset at the shoulder (pectoral) girdle) and pelvis. The adult human pelvis is wider than it is high [32].

4.2.3. How to explain the skeletal asymmetries – trunk width and human bipedal gait

While this hormonal interpretation is a plausible explanation for the relative differences in trunk width growth by higher and lower BMI subsets, it does not explain:

a) The upper arm length (UAL) asymmetry patterns which differ between preoperative and each screened and normal girls (Figure 3). This UAL asymmetry effect is evident in the preoperative lower BMI subset composed of taller and thinner girls, in whom trunk width growth is reduced relative to higher BMI girls suggesting both are linked to lower circulating leptin levels.
b) In thoracic AIS, Cobb angle and apical vertebral rotation are each associated with upper arm length (UAL) symmetry in the lower, but not the higher, BMI sunset.

These patterns with respect to UAL asymmetry can be explained by postulating asymmetry from asynchrony in the upper arm growth plates from intrinsic or extrinsic mechanisms. There is no evidence for an intrinsic mechanism, but there is clinical and experimental evidence to suggest that a SNS-driven asymmetry mechanism in right thoracic AIS in girls determines concave periapical rib relative overgrowth [33-35] and in AIS of the lower spine (thoracolumbar and lumbar curves) determines the concave ilium relative overgrowth [36]. If this putative SNS-driven effect may create skeletal asymmetries, it may also supplement the hormonal contribution to trunk width by an SNS-driven general effect on trunk width growth. This SNS effect may be particular to humans and, as already stated, at the shoulders be driven by the ribs in a process that evolved with decoupling of head and trunk movements [24,25] required for efficient bipedal human gait [26,37].

4.3. A leptin-sympathetic nervous system (SNS) effect on biacromial and pelvic widths?

We propose the hypothesis that the hormonally-driven skeletal width growth in the human trunk is supplemented by a normal leptin-hypothalamic-SNS-driven mechanism related to energy stores (metabolic fuel) with leptin as a signal to the hypothalamus. In general, the coupling of skeletal growth to energy balance [38,39] involves leptin and Y2-receptors on neuropeptide Y (NPY-ergic) hypothalamic neurons [40,41].

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4.4. Hypothalamic dysfunction and altered sensitivity to circulating leptin?

In the *lower BMI subset* of the screened with preoperative girls with thoracic AIS, larger Cobb angles and larger AVRs are each associated with a longer right-to-left

upper arms. This pattern suggests a mechanism linking each of 1) circulating leptin levels, 2) growth of humeri, ribs and vertebrae, and 3) development of the scoliosis deformity.
In the preoperative girls, the presence of abnormal UAL asymmetry *with* the *lower BMI subset* (Figure 3) is consistent with a putative dysfunction of the hypothalamus [10] with stress in response to lower circulating leptin levels and expressed as *'upper arm wide asymmetry',* defined as affecting upper arms, ribs and vertebrae. The absence in preoperative girls of abnormal UAL asymmetry with the *higher BMI subset* suggests a protective effect of circulating leptin levels on the dysfunctional hypothalamus, with the breadth of the induced skeletal asymmetry being limited to the ribs and/or spine as *'trunk wide asymmetry'*, defined as affecting spine and/or ribs but not humeri. For the spine these concepts may be evaluated, in part, by combined MRI and histological studies of periapical vertebral growth plates [42] in relation to BMI.

4.5. Tibial length asymmetries

The absence of tibial length asymmetries being significantly associated with *higher and lower BMI subsets* suggests a *focus on the trunk of girls* for the putative SNS-driven effect that may determine the asymmetries of each of UAL, periapical ribs and spine.

4.6. SNS-driven asymmetries in 3D?

The postulated SNS-driven effects on growing bones may exert their asymmetries in the spine in 3D. Sagittal plane severity of thoracic AIS needs to be evaluated by *higher and lower BMI* subsets.

5. Other mechanisms in curve progression

In addition to the hormonal and putative leptin-hypothalamic-SNS-driven effects on certain growing bones (humeri, ribs and vertebrae) in the screened and preopertative girls, we suggest that somatic nervous system dysfunction (? Relative postural maturational delay) may also be needed for progression of AIS curves to the severity requiring surgery [37,43].

6. Conclusions

1. In terms of general skeletal growth, significantly larger size in trunk widths (biacromial and biiliac) is attained in girls in the higher BMI subset than in those in the lower BMI subset..
2. Higher and lower BMI subsets are likely to have separated girls with elevated from those with reduced circulating leptin levels.
3. In the screened girls, the relatively earlier menarche by about 6 months of the higher–to-lower BMI subset is in keeping with knowledge of a link between body fat and the timing of puberty with leptin as a signal playing a permissive role [27,28].
4. Relatively earlier skeletal maturation in the higher BMI subset due to an earlier puberty with hormonal changes provide a plausible explanation for the relatively larger

trunk width at the shoulders and pelvis.

5. This interpretation does not explain the abnormal upper arm length (UAL) asymmetry differences in the lower BMI subset between preoperative and each of screened and normal girls (Figure 3). Nor does it explain in thoracic AIS in the *lower BMI subset* the statistically significant association between each of Cobb angle and AVR with UAL asymmetry and not in th*e higher BMI subset*.

6. In the lower BMI subset composed of taller and thinner girls, UAL asymmetry is most evident in the preoperative group (Figure 3), and in whom trunk width growth for age is reduced relative to the higher BMI girls, suggesting that both UAL asymmetry and the relatively reduced trunk width growth are linked to lower circulating leptin levels.

7. These UAL asymmetries can be explained by postulating asymmetry from asynchrony in the upper arm growth plates from intrinsic or extrinsic mechanisms. There is no evidence of mechanisms intrinsic to humeral growth plates but clinical and experimental evidence [10] suggests that a SNS-driven asymmetric mechanism in AIS girls may determine concave periapical rib relative overgrowth in right thoracic AIS in girls [33-35] and concave ilium relative overgrowth in lower spine AIS (thoracolumbar and lumbar curves) [36].

8. If this putative SNS-driven asymmetric effect can create such skeletal length asymmetries, it may also supplement the hormonal contribution to trunk width growth

9. We propose the hypothesis that the hormonal stimulus to normal human trunk width growth is supplemented by a normal leptin-hypothalamic-SNS-driven stimulus related to energy stores (metabolic fuel) with leptin as a signal to the hypothalamus [10].

10. Biacromial width reflects the breadth of the human thoracic cage [23]. The width of the shoulder (pectoral) girdle was acquired in human evolution with decoupling of the head and trunk movements [24,25] required for efficient bipedal gait [26], as was pelvic widening [32].

11. It is suggested that the thoracic AIS of screened and preoperative girls was initiated by dysfunction of a normal hypothalamic control of trunk width growth associated with altered hypothalamic sensitivity to leptin (Figure 3).

12. Our hypothesis for AIS in girls states that [10] given adequate nutrition and energy stores, circulating leptin talks to the hypothalamus where dysfunction leads to an *altered sensitivity to lepti*n *resulting in increased SNS activity* contributing with neuroendocrine mechanisms to: 1) earlier age at, and increased peak height velocity, 2) general skeletal overgrowth, 3) earlier skeletal maturation, 4) extra-spinal skeletal length asymmetries, including periapical ribs, and the ilia, 5) generalized osteopenia, and 6) lower BMI.

13. In AIS girls, a dysfunctional hypothalamus under stress from lower circulating leptin levels, expresses skeletal length asymmetry through the SNS in the upper arms, ribs and spine *('upper arm wide asymmetry')* but, with high circulating leptin levels, is not expressed in the upper arms *('trunk wide asymmetry')* where the asymmetry is limited to vertebrae and/or rib*s.*

14. In addition to the hormonal and the putative leptin-hypothalamic-SNS-driven asymmetric effects [10] that may initiate AIS in girls, other mechanisms required for curve progression may include 1) somatic nervous system dysfunction (? Relative postural maturational delay) [37,43], 2) spinal growth modulation [44], and 3) osteopenia. [45].

15. Evidence suggests that right thoracic AIS in females is initiated by the sympathetic nervous system [33-35]. Left thoracic AIS in females in a pilot study showed MRI changes in the somatic nervous system (cerebral hemispheres and corpus callosum)[46]. Does this imply different relative contributions of the autonomic and somatic nervous systems to the pathogenesis of right and left thoracic AIS respectively in females?
16. Compared with the brains of non-scoliotic girls, may the brains of girls who develop AIS have other differences of asymmetric functions [47] some sexually dimorphic and possibly linked to raised testosterone levels [10], of which the scoliosis is a solitary expression?

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Volumetric thoracic growth in children with moderate and severe scoliosis compared to subjects without spinal deformity

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Abstract. Idiopathic scoliosis leads to a three-dimensional thoracic deformity. The purpose of this study is to measure thoracic dimensions and volume related to growth and to verify the influence of moderate and severe scoliosis. 176 children (36 boys, 140 girls; 4-16 years) with scoliosis < 45 degrees and 17 patients (2 boys, 15 girls) with scoliosis > 65 degrees were compared to 239 children without spinal deformity (97 boys, 142 girls) using an optical system. Thoracic volume, perimeter, anterior-posterior and transversal diameters, T1-T12 and sternal lengths were calculated. These measurements were related to age and sitting height. Thoracic volume (3-16 dm^3) did not differ significantly over growth between reference and moderate scoliosis groups. At 4 years, it represents 33%, at 10 years it represents 55% of its volume compared with age 16. It triples from 4-16 years and doubles during puberty. In severe scoliosis, the age related thoracic volume was always lower than volumes in reference and moderate scoliosis groups. During growth, the transversal diameter corresponds to 30%, the anterior-posterior diameter represents 20% and the thoracic perimeter 100% of sitting height. In severe lordoscoliosis the anterior-posterior diameter represents less than 20%. Scoliosis < 45 degrees does not influence thoracic volume significantly. Severe deformities seem to inhibit volumetric growth. Thoracic parameters should be related to growth parameters such as sitting height rather than age because of possible height variations in one age section. The established relationships offer a reliable orientation of thoracic proportions. They help to understand the global deformity and represent a baseline for surgical treatment using vertical expandable prosthetic titanium ribs.

Keywords. Idiopathic scoliosis, Thoracic growth, Volume, Optical trunk molding

1. Introduction

Idiopathic scoliosis represents a three-dimensional (3D) spinal deformity which involves thoracic and lumbar curves in the frontal plane, the balance between thoracic kyphosis and lumbar lordosis in the sagittal plane and vertebral rotation in the transversal plane. This complex 3D deformity of the spine does also lead to an associated deformity of the thorax by means of an interaction mechanism at the costovertebral joints. In severe scoliosis, the thoracic development and lung growth can be severely inhibited which affects proper cardiopulmonary function. Campbell et al. [1] defined the inability of the thorax to support normal respiration or lung growth in relation to congenital scoliosis and fused ribs as “thoracic insufficiency syndrome”. Dubousset et al. [2, 3] defined the “spinal penetration index” for severe thoracic lordoscoliosis which quantifies the vertebral body protrusion into the thorax creating airway compression. Modern concepts such as expansion thoracoplasty and vertical expandable prosthetic titanium rib distraction [4, 5] primarily treat the thoracic deformity. This allows an indirect treatment of the scoliosis in younger children, and also creates better conditions for vertebral and pulmonary growth [6, 7].

Three-dimensional thoracic growth has been studied by Diméglio and Bonnel [8] who estimated volumetric proportions clinically from the thoracic perimeter. Nevertheless, accurate thoracic volume assessment remains difficult. The purpose of this study is to measure thoracic dimensions and volume related to growth and to verify the influence of severe and moderate scoliosis on thoracic growth.

2. Materials and Methods

A group of 176 patients (140 girls and 36 boys) with moderate idiopathic scoliosis (Cobb angle between 15 and 45 degrees) and 17 patients (2 boys and 15 girls) with severe idiopathic scoliosis (Cobb angles 68 to 104 degrees) were compared to a reference group of 239 children (97 girls and 142 boys) without spinal deformity. The ages of these children ranged from 4 to 16 years and were homogenous in moderate scoliosis and reference groups for girls and for boys.

The principle of the ORTEN system (Lyon, France) for trunk surface data acquisition is based on a technique of light band projections and analysis of band deformations on the body [9, 10]. This system is normally used for brace confection of patients with scoliosis and allows the creation of a digitized mold of the trunk with a millimeter-range precision [11]. During the process of trunk surface acquisition, the children wore a skintight white disposable stockinet on which standardized anatomical landmarks were drawn: the anterior superior iliac spines, the jugular notch, the inferior extremity of the xiphoid process, the inferior border of the 10th rib in the projection of the anterior axillary line and the spinous processes of T1 and T12. The child was positioned at the center of a scanning unit, arms raised backwards with the hands crossed behind the head, which allowed the thoracic surface to be totally exposed. For the scanning procedure, the child was asked to expire and to stop breathing. The scanning unit was composed of 4 columns which were equipped with 2 electro-optical light band projectors and a charge-coupled device camera. During the optical molding process, 2 consecutive projections and records were performed in 1.6 seconds by means of which the trunk was able to be molded without any motion artifact.

The second step consisted of working on the stored data using the COMFORTAD software version 1.0 (ORTEN, Lyon, France). The recorded video images were converted into a digitized 3D image. This image was then refined by the acquisition of anatomical landmarks and by a superposition of a theoretical model of the spine and the thorax, as in Figure 1. The thoracic anterior-posterior and transversal diameters as well as the thoracic perimeter at xiphoid level could then be calculated from this 3D reconstruction.

Furthermore, thoracic volume from a transverse section of the body at the 10th rib marker up to the jugular notch could also be calculated. The volume corresponding to the breast in adolescent girls was subtracted manually at this stage in order to avoid a bias of the volume of the rib cage.

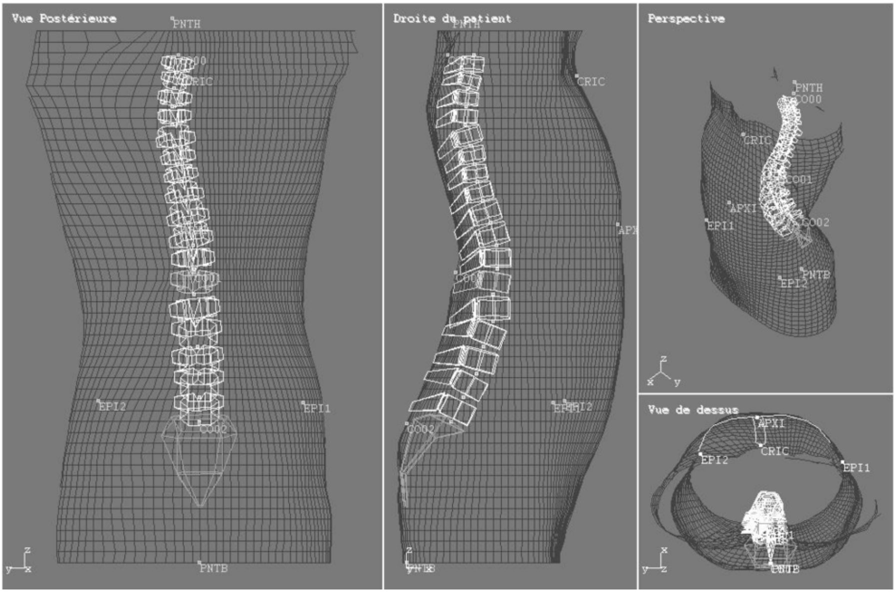

Figure 1. Anatomical 3D reconstruction of the trunk with theoretical spine model

Thoracic parameters were compared in moderate scoliosis and reference groups, for girls and boys separately, using the Kruskal-Wallis test. The number of patients in the severe scoliosis group was too small to obtain an adequate statistical comparison. Median values of thoracic volumes were then related to children's chronological ages in scoliosis and reference groups for boys and girls separately. The relationship between direct thoracic measurements (cm) and percentages of sitting height measurements (cm) was studied by calculating intra-class correlation coefficients. The degree of correlation was considered as: very good if $r \geq 0.91$, good if $r = 0.90 – 0.71$, moderate if $r = 0.70 – 0.51$, poor if $r = 0.50 – 0.31$ and very poor if $r < 0.30$. The significance level in this study was set at $p < 0.05$.

3. Results

Average values and standard deviations of thoracic volume, thoracic perimeter, anterior-posterior diameter, transversal diameter, T1-T12 length and sternal length are demonstrated in Table 1 for boys and in Table 2 for girls. When comparing reference and scoliosis groups in boys and girls respectively, it appears that there is no significant difference between the thoracic volumes of children without spinal deformity and those with moderate scoliosis < 45 degrees.

Parameter	Reference group Average ± SD	Moderate scoliosis Average ± SD	P-value
Thoracic volume (dm^3)	8.7 ± 3.2	7.9 ± 2.1	0.37
Thoracic perimeter (cm)	67.2 ± 8.3	66.9 ± 7.4	0.52
AP-diameter (cm)	16.9 ± 2.2	16.4 ± 2.6	0.12
Transversal diameter (cm)	24.4 ± 4.2	23.8 ± 5.1	0.37
T1-T12 length (cm)	24.1 ± 4.3	23.6 ± 2.9	0.41
Sternal length (cm)	16.1 ± 2.4	15.7 ± 2.0	0.82

Table 1. Comparison of thoracic parameters between reference and moderate scoliosis groups in boys

Parameter	Reference group Average ± SD	Moderate scoliosis Average ± SD	P-value
Thoracic volume (dm^3)	7.6 ± 2.7	8.1 ± 2.0	0.48
Thoracic perimeter (cm)	64.1 ± 6.6	66.0 ± 6.1	0.46
AP-diameter (cm)	16.0 ± 1.8	15.7 ± 1.9	0.32
Transversal diameter (cm)	22.9 ± 2.3	23.8 ± 2.6	0.23
T1-T12 length (cm)	24.7 ± 2.4	23.4 ± 2.9	0.31
Sternal length (cm)	15.8 ± 2.1	15.4 ± 2.3	0.49

Table 2. Comparison of thoracic parameters between reference and moderate scoliosis groups in girls

In moderate scoliosis and reference groups the thoracic volume increased with chronological age, as demonstrated in Figure 2. In the reference group of boys, the median thoracic volume measured 4.7 dm^3 at 4 years and it reached a maximal value of 15.8 dm^3 until the age of 16 years. In the moderate scoliosis group of boys, the thoracic volume ranged from 4.2 dm^3 to 14.1 dm^3. In girls, the thoracic volume was smaller than in boys. In the reference group of girls, the median thoracic volume measured 3.9 dm^3 at the age of 4 years. At the age of 16 years, the maximal median volume measured 13.0 dm^3. In the moderate scoliosis group of girls, the median thoracic volume ranged between 3.0 dm^3 and 12.8 dm^3. It appears that thoracic volume represents approximately 33% at the age of 4 years, at 10 years it represents 55% of its volume compared with age 16.

Thoracic volumes of 17 patients who had severe scoliosis with a Cobb angle > 65 degrees were then plotted on this diagram. Although a statistical comparison was not performed because of the small number of patients in this group of severe scoliosis, a tendency of smaller thoracic volumes in respective age sections was observed.

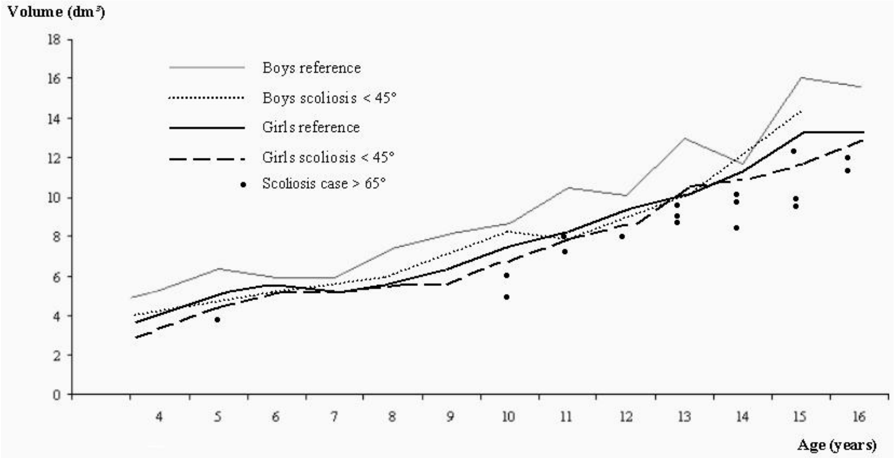

Figure 2. Median thoracic volumes related to chronological age

Thoracic volumes increased almost linearly from younger to older children, strong variations could arise within one age section. This was mainly observed in the reference group of boys during the pubertal growth spurt, after the age of 12 years. Because of possible height differences of children in one age section, we would recommend to relate thoracic volume to height measurements rather than to chronological age. Clinical growth parameters, such as sitting height, are probably more accurate than chronological age when describing trunk growth and when thoracic proportions need to be evaluated.

Relationships between 3D thoracic parameters and sitting height were observed and then verified by calculating intra-class correlation coefficients between direct thoracic measurements (cm) and percentages of sitting height measurements (cm). It appeared that the following relationships applied equally to boys and girls in reference and moderate scoliosis groups during the entire growth period:

- The transversal diameter represents approximately 30% of sitting height (r = 0.79) and corresponds to T1-T12 length (r = 0.73),
- The anterior-posterior diameter represents approximately 20% of sitting height (r = 0.78) and corresponds to sternal length (r = 0.70),
- The thoracic perimeter approximately corresponds to sitting height (r = 0.88).

In severe thoracic scoliosis with a Cobb angle > 65 degrees, strong vertebral rotation and a T4-T12 kyphosis < 15 degrees, the anterior-posterior diameter had always decreased and represented less than 20% of sitting height.

4. Discussion

The thoracic deformity caused by scoliosis is measurable with the optical ORTEN system (Lyon, France), which is normally used for brace confection [9-11]. This tool allows measuring width, depth, circumference and volume of the thorax. Dubousset et al. [2, 3] as well as Diméglio and Bonnel [8] already stressed the necessity of assessing the thoracic deformity associated with the 3D spinal deformity in patients with scoliosis. This objective method of optical trunk surface data acquisition completes the clinical examination of the thorax and trunk balance. Nevertheless, thoracic parameters should always be related to growth parameters such as sitting height rather than age because of possible height variations in one age section.

It is also interesting to notice that moderate idiopathic scoliosis < 45 degrees does not inhibit 3D and volumetric thoracic growth significantly. Severe scoliosis with primary thoracic curve > 65 degrees, strong vertebral rotation and a decreased kyphosis seem to inhibit thoracic growth.

The described thoracic proportions might be useful to describe the entire spinal and thoracic deformity, and it could help to optimize brace systems or surgical techniques in the future. Operative techniques such as expansion thoracoplasty and chest wall stabilization by a vertical expandable prosthetic titanium rib are used in younger patients with scoliosis who present a thoracic insufficiency syndrome [4, 5]. Similar techniques stabilize the immature thoracic spine of the younger child by the use of a growing spine profiler, as shown in Figure 3. These interventions treat the thoracic deformity primarily and create better conditions for pulmonary growth. Furthermore, the scoliosis is treated indirectly which allows continuous spinal growth in terms of straightening the thoracic curve in the fusionless management of the immature spine.

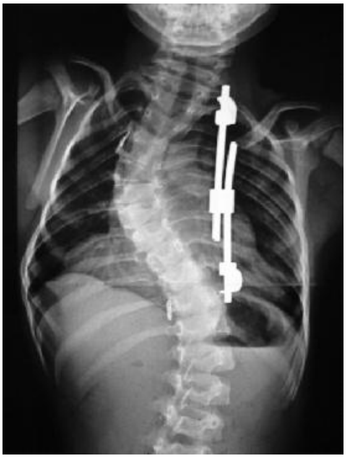

Figure 3. Treatment of the thoracic and spinal deformity with growing spine profiler

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Back trunk morphology in 3301 children aged 3-9 years old

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Abstract. The present cross sectional study reveals trunk asymmetry (TA) in "normal" Mediterranean juveniles for the first time. The scoliometer readings in both standing and sitting forward bending position (FBP) of 3301 children, (1645 boys, and 1656 girls) aged from 3 to 9 years old were studied. TA was quantified by measuring angle of trunk rotation (ATR) and children were divided in two groups. In group I the ATR was 1° to 6° degrees and in group II ≥7°. 71.25% of boys and 73.27% of girls in *standing* while 81.13% of boys and 80.74% of girls in *sitting* FBP, were symmetric (ATR = 0°). The symmetry difference at *standing* minus *sitting* FBP for boys and girls was 9.88% and 7.43% respectively. Severe asymmetry (ATR≥7°) was found in 1.74% of boys and in 1.75% of girls at the *standing* and in 1.21% and 1.22% at the *sitting* FBP respectively. Analysing ATR by age it appears that significant TA changes occur between 8 - 9 years of age for boys and between 6-7 and 8 - 9 years for girls. The amount of trunk asymmetry in children is the indicator for referral and further orthopaedic assessment. This report provides, for the first time information about the variability of back morphology in "normal" juveniles which is worth knowing when a child is examined for juvenile scoliosis.

Keywords. Juvenile idiopathic scoliosis, juveniles, back morphology, trunk asymmetry.

1. Introduction

Trunk asymmetry (TA) is considered by many authors as the clinical presentation of scoliosis [1, 2, 3]. Although the incidence of scoliosis in juveniles is much smaller than adolescents, in younger girls referred from a school-screening program there was a discrepancy between the thoracic asymmetry and the morphology of the spine [4]. Twenty five per cent of children with Angle of Trunk Rotation (ATR) ≥ 7° had either a straight spine or a curve smaller than 10° [4], which means that in juveniles, trunk asymmetry is not a sensitive clinical sign for scoliosis. As a baseline for further research on this observation, we need to know what the incidence of trunk asymmetry in a normal juvenile population is. In a previous study we reported trunk asymmetry in normal adolescents [5]. The present cross sectional study quantifies for the first time trunk asymmetry in "normal" Mediterranean juveniles.

2. Method and Material

The scoliometer readings in both standing and sitting forward bending position (FBP) of 3301 children, (1645 boys, and 1656 girls) aged from 3 to 9 years old were studied. TA was quantified by measuring angle of trunk rotation (ATR) in the thoracic, thoracolumbar and lumbar regions of the back.

Children were divided in three groups. In group 0 children were symmetric, in group 1 the ATR was 1°-6° (moderate asymmetry) and in group 2 the ATR was ≥7° (severe asymmetry). Frequency of symmetry, moderate and severe asymmetry for both boys and girls was quantified in standing and in sitting FBP for all the examined regions of the back. The difference of trunk asymmetry between standing and sitting FBP as well as differences between boys and girls in frequency of trunk asymmetry were also calculated.

3. Results

74.2 % of boys and 77% of girls were symmetric (ATR=0°) in the thoracic region in *standing* FBP, while 82.7% of boys and 84.1% of girls were symmetric in the thoracic region in *sitting* FBP. Symmetry and asymmetry in all the three examined regions of the spine in the standing FBP is shown for boys in **Table 1** and for girls in **Table 2**, while in the sitting FBP it is shown for boys in **Table 3** and for girls in **Table 4**.

		Symmetry	1	-1	2	-2	Missing	Total
Thoracic	N	**1209**	**264**	**142**	**11**	**3**	**16**	**1645**
	%	*74.22*	*16.21*	*8.72*	*0.68*	*0.18*		*100.00*
Thoraco - lumbar	N	**1155**	**275**	**168**	**22**	**9**	**16**	**1645**
	%	*70.90*	*16.88*	*10.31*	*1.35*	*0.55*		*100.00*
Lumbar	N	**1118**	**302**	**169**	**28**	**12**	**16**	**1645**
	%	*68.63*	*18.54*	*10.37*	*1.72*	*0.74*		*100.00*

Table 1: Frequency of symmetry and asymmetry in *boys*. Scoliometer readings are obtained at *standing* forward bending position. 1: mild right asymmetry (ATR 1-6°), 2: severe right asymmetry (ATR ≥7°), -1 mild left asymmetry (ATR 1-6°), -2: severe left asymmetry (ATR ≥7°).

		Symmetry	1	-1	2	-2	Missing	Total
Thoracic	N	**1262**	**221**	**139**	**8**	**9**	**17**	**1656**
	%	*77.00*	*13.48*	*8.48*	*0.49*	*0.55*		*100.00*
Thoraco - lumbar	N	**1185**	**254**	**168**	**19**	**13**	**17**	**1656**
	%	*72.30*	*15.50*	*10.25*	*1.16*	*0.79*		*100.00*
Lumbar	N	**1156**	**255**	**191**	**25**	**12**	**17**	**1656**
	%	*70.53*	*15.56*	*11.65*	*1.53*	*0.73*		*100.00*

Table 2: Frequency of symmetry and asymmetry in *girls*. Scoliometer readings are obtained at *standing* forward bending position. 1: mild right asymmetry (ATR 1-6°), 2: severe right asymmetry (ATR ≥7°), -1 mild left asymmetry (ATR 1-6°), -2: severe left asymmetry (ATR ≥7°).

		Symmetry	1	-1	2	-2	Missing	Total
Thoracic	N	**1348**	**143**	**128**	**6**	**4**	**16**	**1645**
	%	*82.75*	*8.78*	*7.86*	*0.37*	*0.25*		*100.00*
Thoraco - lumbar	N	**1335**	**144**	**129**	**13**	**8**	**16**	**1645**
	%	*81.95*	*8.84*	*7.92*	*0.80*	*0.49*		*100.00*
Lumbar	N	**1282**	**182**	**137**	**19**	**9**	**16**	**1645**
	%	*78.70*	*11.17*	*8.41*	*1.17*	*0.55*		100

Table 3: Frequency of symmetry and asymmetry in *boys*. Scoliometer readings are obtained at *sitting* forward bending position. 1: mild right asymmetry (ATR 1-6^o), 2: severe right asymmetry (ATR $\geq$7^o), -1 mild left asymmetry (ATR 1-6^o), -2: severe left asymmetry (ATR $\geq$7^o).

		Symmetry	1	-1	2	-2	Missing	Total
Thoracic	N	**1378**	**136**	**116**	**6**	**3**	**17**	**1656**
	%	*84.08*	*8.30*	*7.08*	*0.37*	*0.18*		*100.00*
Thoraco - lumbar	N	**1315**	**159**	**141**	**12**	**12**	**17**	**1656**
	%	*80.23*	*9.70*	*8.60*	*0.73*	*0.73*		*100.00*
Lumbar	N	**1277**	**179**	**156**	**17**	**10**	**17**	**1656**
	%	*77.91*	*10.92*	*9.52*	*1.04*	*0.61*		*100.00*

Table 4: Frequency of symmetry and asymmetry in *girls*. Scoliometer readings are obtained at *sitting* forward bending position. 1: mild right asymmetry (ATR 1-6^o), 2: severe right asymmetry (ATR $\geq$7^o), -1 mild left asymmetry (ATR 1-6^o), -2: severe left asymmetry (ATR $\geq$7^o).

The difference in the frequency of asymmetry between standing and sitting FBP, in all the examined regions of the spine, for boys and girls are shown in **table 5**.

	Boys			**Girls**		
	Symmetry ATR=0^o	**ATR 1^o-6^o**	**ATR $\geq$ 7^o**	**Symmetry ATR=0^o**	**ATR 1^o-6^o**	**ATR $\geq$ 7^o**
Thoracic	8,5%	8,3%	0,4%	7,1%	6,6%	0,5%
Thoracolumbar	11%	10,4%	0,6%	7,9%	7,5%	0,5%
Lumbar	10,1%	9,3%	0,7%	7,4%	6,8%	0,6%

Table 5. The difference (%) of the frequency of asymmetry between standing and sitting FBP, in the three examined regions of the spine, for both boys and girls.

4. Discussion

It is axiomatic, that any screening procedure for abnormality is based on knowledge of normality. Normal juvenile girls appear to be more symmetric than juvenile boys, a finding which is opposite in adolescents [5, 6]. Juveniles appear to have a smaller frequency of trunk asymmetry than adolescents. Furthermore, in the present study the frequency of asymmetry was detected in greater percentage in the standing than in the sitting FBP, the same as in adolescents, which implies leg length or pelvic difference in pathogenesis of trunk asymmetry.

The amount of trunk asymmetry in children is the indicator for referral and further orthopaedic assessment if a spinal curve is detected. This report provides, for the first time information about the variability of back morphology in "normal" juveniles which is worth knowing when a child is examined for juvenile scoliosis.

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The role of the intervertebral disc in correction of scoliotic curves. A theoretical model of Idiopathic Scoliosis pathogenesis

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Abstract. Wedging of the scoliotic inter-vertebral disc (IVD) was previously reported as a contributory factor for progression of idiopathic scoliotic (IS) curves. The present study introduces a theoretical model of IVD's role in IS pathogenesis and examines if, by reversing IVD wedging with conservative treatment (full- and night-time braces and exercises) or fusionless IS surgery with staples, we can correct the deformity of the immature spine. The proposed model implies the role of the diurnal variation and the asymmetric water distribution in the scoliotic IVD and the subsequent alteration of the mechanical environment of the adjacent vertebral growth plates. Modulation of the IVD by applying corrective forces on the scoliotic curve restores a close-to-normal force application on the vertebral growth plates through the Hueter-Volkmann principle and consequently prevents curve progression. The forces are now transmitted evenly to the growth plate and increase the rate of proliferation of chondrocytes at the corrected pressure side, the concave. Application of appropriately directed forces, ideally opposite to the apex of the deformity, likely leads to optimal correction. The wedging of the elastic IVD in the immature scoliotic spine could be reversed by application of corrective forces on it. Reversal of IVD wedging is thus amended into a "corrective", rather than "progressive", factor of the deformity. Through the proposed model, treatment of progressive IS with braces, exercises and fusionless surgery by anterior stapling could be effective.

Keywords. Idiopathic scoliosis, intervertebral disc, asymmetrical growth, pathogenesis of idiopathic scoliosis, conservative treatment of Idiopathic scoliosis, fusionless surgery of Idiopathic scoliosis, stapling of the spine.

1. Introduction

The rationale for management of idiopathic scoliosis (IS) during skeletal growth assumes a biomechanical mode of deformity progression, based on the Hueter-Volkmann principle [1], whereby extra axial compression decelerates growth and reduced axial compression accelerates it [2]. In treating IS conservatively, application of corrective forces does nothing more than exploiting this principle, by applying appropriately directed forces through the skin, soft tissues and ribs to the vertebral growth plates.

The role of the IVD as a contributory factor to the development of the scoliotic curve has been emphasized in a previous study [3]. 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 [4] and it is very likely that the changes in cartilagenous 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 [5].

The present study illustrates the effect of IVD modulation and its subsequent benefits in IS treatment. The proposed model is examined on conservative treatment (full- and night-time braces and exercises) and fusionless IS surgery with staples.

2. Material and Methods

A theoretical model of IVD's role in progressive IS pathogenesis is introduced. The IVD contains the aggrecans of glycosaminoglycans (GAGs) which imbibe water through the so called Gibbs-Donnan mechanism. The highest concentration of GAGs is in the nucleus pulposus (NP) where they are entrapped in a type II collagen network [6] and are exposing a convex-wise asymmetrical distribution. There is an increased collagen content in the NP of the apical IVD but also in the adjacent discs in IS, 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 [4]. Differences also exist in the collagen distribution between the concave and convex sides of the scoliotic annulus fibrosus in IS, with fewer collagen fibres in the concave compared to the convex side [7].

A diurnal variation in the water content of lumbar IVD has also been documented [8, 9], resulting in diurnal variations in loading of the vertebral growth plates, because of IVD's periodical "swelling" (during night time) and "shrinkage" (for the period of day time under the application of the body load during the upright posture) during the 24 hour period. This asymmetrical pattern of water distribution in the scoliotic IVD, combined with the diurnal variation in the water content of IVDs resulting to a sequence of "swellings" and "shrinkages", imposes asymmetrical, convex-wise, concentrated cyclical loads to the IVD and the adjacent immature vertebrae growth plates of the child during the 24 hours period [3]. The convex side of the wedged IVD sustains greater amount of cyclic (swelling) expansion than the concave side, leading to the sequelae of asymmetrical growth of adjacent vertebrae (Hueter-Volkmann's law).

Consequently, the response of bone growth to asymmetrical loading follows an asymmetrical pattern and gradually can enhance the correction of the deformity if optimal corrective forces are applied, with full time and night time braces, exercises and fusionless surgery.

3. Results

The IVD may be modulated by applying corrective forces on the curve thereby eliminating any asymmetrical accumulation of water in the apical and adjacent IVDs. This, in turn, restores a close-to-normal force application on the vertebral growth plates through the Hueter-Volkmann principle and consequently may prevent curve progression. The forces are now transmitted evenly to the growth plate increasing the rate of proliferation of chondrocytes at the corrected pressure side, the concave. All the stated treatment methods aim at alteration of the mechanical environment and modulation of the endochondral growth of the immature vertebrae. Application of appropriately directed forces, ideally opposite to the apex of the deformity, likely leads to optimal correction.

Exercises for IS are using techniques to correct and maintain the correction which has been achieved, during every day activities. By activating the appropriate muscle groups, corrective forces are transmitted on the wedged IVD and are reversing to a degree the wedging, altering the mechanical environment of the adjacent vertebral growth plates.

Full time braces, through the 3D correction and the combination of derotation together with the three point pressure principle, are exerting constant corrective forces on the wedged IVD and are restoring a close to normal force application on the vertebral growth plates. The mechanical stimulus to the concave side of the growth plate is weaker, allowing new cells to be produced in the proliferateve zone and extracellular matrix to be produced in the hypertrophic zone of the growth plate, according to Hueter – Volkmann principle. As a consequence, longitudinal growth is faster at the concave side of the curve, when a skeletally immature scoliotic child is treated with a full time brace and eventually this could stop its progression or even correct the curve, depending on child's growth potential.

The night time braces are rather overcorrecting the mild or moderate scoliotic curves, simulating gravity, acting also on the apical and adjacent wedged IVDs [10]. Their action is by reducing the previously described asymmetrically imbibed water (greater amount in the convex rather that in the concave side), but additionally they are taking advantage of the diurnal variation in the water content of IVD, which is increased during the night. Hypercorrection of the IVD with the nighttime brace results in vertebral growth under more normal conditions. Under the action of the nighttime brace, the convex side sustains no greater amount of expansion than the concave side, (ceasing the asymmetrical application of Hueter - Volkmann law), reversing the deleterious hypothesis of progression of IS curves; consequently, the growth of the apical and adjacent immature vertebrae turns more normal, within a close - to - normal biomechanical environment.

Fusionless surgery with staples, theoretically allows preservation of growth, motion, and spinal function, and perhaps has a reduced risk of adjacent segment degeneration and other spinal de-compensation problems [11]. This method has been shown to retard growth on the convex side while allowing the concave side to continue growing, enabling the abnormal curve to "self-correct" [12]. Additionally, stapling between two adjacent vertebrae at the side of curve convexity inhibits IVD expansion due to its asymmetrical water distribution and therefore, one significant factor for curve progression is eliminated. Theoretically, by stapling the growth plates, the accelerated growth on the convexity of a curve is ceased, both by inhibiting the longitudinal growth (acting directly on the convexwise vertebral end-plate cells) and by eliminating the effect of IVD asymmetrical force application on the growth plates. Perhaps growth is stimulated on the concavity of a curve, and therefore correction of the deformity can occur (Hueter-Volkmann principle). The goal of stapling is to harness the scoliosis patient's inherent abnormal spinal growth and alter it to achieve correction, rather than progression.

4. Discussion

The proposed theoretical model requires three conditions in order to be successful. First, there must be enough growth potential left; otherwise the final correction will be suboptimal. Second, the elastic properties of the IVD should allow adequate modulation and through that adequate alteration of the mechanical environment of the growth plate and third, the corrective forces should be towards the correct level, ideally perpendicular to the level of maximum deformity.

The wedging of the elastic IVD in the immature scoliotic spine could be reversed by application of corrective forces on it. Reversal of IVD wedging, by altering the mechanical environment of the adjacent growth plates, is thus amended into a "corrective", rather than "progressive", factor of the deformity. Through the proposed mechanism, treatment of progressive IS with full time and night time braces, exercises and fusionless surgery by anterior stapling could be effective.

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Ultrasound femoral anteversion (FAV) relative to tibial torsion (TT) is abnormal after school screening for adolescent idiopathic scoliosis (AIS): evaluation by two methods

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Abstract. In the scoliotic spine, torsion is generally evaluated in relation to axial rotation of the apical vertebra. In the lower limbs, the changes in torsion by age of femoral anteversion (FAV) relative to tibial torsion (TT) have been studied in dried bones, normal growing subjects and adults and subjects with osteoarthritis of the hip or the knee. This paper reports the application of real-time ultrasound to FAV and TT in normal children age 11-18 years and in scoliosis screening referrals with particular reference to how FAV relates to TT as 1) *ratios*, and 2) *tibio-femoral index* (TFI) of torsion, calculated as TT *minus* femoral FAV. The FAV/TT ratio findings show an abnormal normal relationship of FAV to TT both proximo-distally and in left-right asymmetry. These may express torsional abnormalities in femoral and/or tibial growth plates with left-right asynchrony suggesting the possibility of similar torsional abnormalities in vertebral end-plates and/or rib growth plates initiating the deformity of AIS. TFI of the right limb in the scoliosis girls is greater than in the normals that is interpreted as resulting from earlier skeletal maturation of FAV. FAV/TT ratios and TFI are unrelated to the spinal deformity (Cobb angle and apical vertebral rotation) except for boys where TFI is associated with apical vertebral rotation. FAV/TT ratios may be a more accurate method estimating the relationship of FAV to TT. than TFIs.

Key words. Idiopathic scoliosis, pathogenesis, spine, ultrasound, femoral anteversion, tibial torsion, growth plate

1. Introduction

1.1 Torsion of femur relative to tibia in bones, health and osteoarthritis at hip or knee

In dry normal adult human femora and tibiae a weak statistically significant correlation was reported between FAV/TT [1]. In healthy children [2] and healthy adults [3-5] FAV/TT did not correlate significantly and no left-right asymmetry was found.

In contrast, in adults with osteoarthritis of the hip [6] or knee [7] FAV and TT correlated significantly. Goutallier et al [8] using a *tibio-femoral index* (TT *minus*

FAV*)* in lateral or medial knee arthrosis, concluded that femoral and tibial torsions play a part in lateralized knee arthrosis together with frontal plane mechanical factors. There may be ethnic and sex differences in the relationship between torsions of the lower limbs and knee osteoarthrosis [9,10].

The above findings, considered in the perspective of torsions in the normal spine and lower limb bones (Figure 1), suggested the need to evaluate the relation of FAV to TT in girls with AIS. Two methods are used here: 1) *FAV/TT* ratio, and 2) *tibio-femoral index* [8]. No data on TFIs for normal subjects are published.

1.2. Normal postnatal changes in femoral and tibial torsion

1.2.1. Femoral anteversion (FAV), or torsion, decreases postnatally into puberty [11-14](Figure 1). This age-related change is generally attributed to muscular forces acting across the hip [15], and other mechanical forces [16], but there is a view that external torsion at the distal femoral growth plate (in the same direction as tibial external torsion) also contributes to femoral detorsion [17]. Estrogen may abet mechanical forces to drive femoral detorsion during postnatal growth [13].

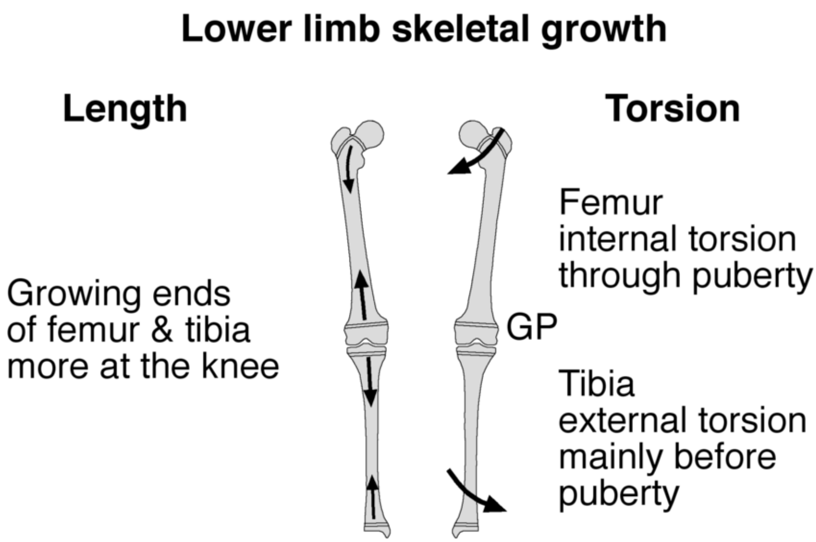

Figure 1. Diagram to show the two types of postnatal growth in femora and tibiae – growth in length mainly from growth plates at the knees, and torsion in both bones, in the femur internal torsion (detorsion) through puberty and in the tibia external torsion mainly before puberty. GP=growth plate.

1.2.2. Tibial torsion (TT) increases mainly in the first 5 years of life [18, but see 19] and mostly before puberty [13] aligning the feet in gait before the adolescent growth spurt. TT is thought to be determined at the ankle with the medial malleoli rotating forwards in relation to the lateral malleoli [18,20]. Both FAV and TT express growth-plate function influenced partly by mechanical factors and strongly by genetic control [21].

2. Femoral anteversion/tibial torsion correlations are significant, abnormal and asymmetric in the scoliosis subjects

2.1. The scoliosis referrals and normals

The scoliosis referrals, age 11-18 years, were referred to hospital by school nurses in routine prescriptive screening for the rotational back shape asymmetry of AIS using a quantitative protocol [22] during 1993-99 (girls 93, boys 35). Clinical evaluation (RGB) identified types of AIS: thoracic (30), thoracolumbar (38), lumbar (25), double (14), pelvic tilt scoliosis (16) and straight spine (5). Normal subjects, age 11-18 years were 301 (girls 157, boys 144) examined in the community by two radiographers (RKA, ASK). The spinal radiograph measurements made by one observer (RGB) included Cobb angle and apical vertebral rotation [23].

2,2. Ultrasound methods

Real-time ultrasound was used to measure femoral anteversion (FAV) and tibial torsion (TT) in the scoliosis referrals and normals by a radiographer (RKA or ASK): FAV was measured between upper end of femur and femoral condyles by the method of Zarate et al [24], and TT between upper tibial shaft and talus by the method of Kirby et al [25].

2.3. Results

A preliminary account of the findings has been published [26].

2.3.1 Reproducibility

The interobserver error (RKA and ASK, n=107, normal subjects) are for FAV: coefficient of reliability left leg 0.82, right leg 0.85 [27]: technical error of measurement left leg 3.1 degrees, right leg 3.0 degrees; intra-class correlation coefficient left leg 0.76, right leg 0.77. For TT: coefficient of reliability left leg 0.85, right leg 0.80: technical error of measurement left leg 4.3 degrees, right leg 4.8 degrees; intra-class correlation coefficient left leg 0.76, right leg 0.74. None of the FAV/TT correlation coefficients for data from normal subjects by the two radiographers are statistically significant.

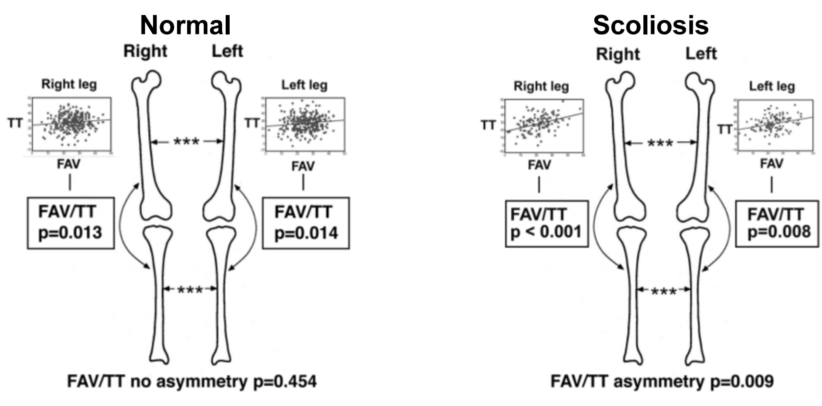

Figure 2.Diagram showing the correlations of right and left FAV to TT (FAV/TT) to be weakly significant in normals and very significant in the scoliosis subjects. p-values are shown (***=p<0.001).

2.3.2. Normal and scoliosis subjects

In the normals, FAV and TT show a weakly significant positive correlation in each leg (right p=0.013, left p=0.014) without asymmetry (p=0.454)(ANOVA after correcting for age and sex). In scoliosis referrals, FAV and TT correlate positively and significantly in each leg (p=0.001) with asymmetry (p=0.009), and very significantly different from normals (right p<0.001, left p=0.008). The FAV/TT correlation in each leg is not significantly different by scoliosis curve side or severity (ANOVA). FAV, TT, left-right differences; and FAV/TT sums are not significantly associated with spinal curve severity (Cobb angle, apical vertebral rotation).

2.4. Conclusion

In the scoliosis subjects, the abnormal FAV/TT correlations are evidently determined in femoral and/or tibial growth plates. These FAV/TT findings show an abnormality of the normal relationship of FAV to TT both proximo-distally and in left-right asymmetry. These may express torsional abnormalities in femoral and/or tibial growth plates suggesting the possibility of similar torsional abnormalities in vertebral end-plates and/or rib growth plates initiating the deformity of AIS.

3. Tibio-femoral index (TFI) of torsion in normal subjects increase with age but not in girls screened for scoliosis suggesting earlier skeletal maturation

3.1. Definition

Tibio-femoral index (TFI) of torsion, calculated as tibial torsion (TT) *minus* femoral anteversion (FAV)[8].

A preliminary account of the findings has been published [28].

3,2. Methods and subjects

The subjects, screened scoliosis and normals were the same as for the FAV evaluation. FAV and TT were measured as stated above.

3.3. Results

3.3.1 Reproducibility

The interobserver error (RKA and ASK, n=88, normal subjects) for TFI is: coefficient of reliability left leg 0.84, right leg 0.78 [26]: technical error of measurement left leg 5 degrees, right leg 6.0 degrees; intra-class correlation coefficient left leg 0.76, right leg 0.70.

3.3.2. Normal children.

Normal subjects show an increase in TFI with age (quadratic regression, <0.001, r values: girls right 0.360, left 0.471), boys right 0.515, left 0.504, while from 11-18 years, TFIs on the right increase with age (r & p values: girls right 0.174 p=0.029, left 0.098 NS; boys right r=0.249 p=0.003, left 0.108 NS). In girl scoliosis referrals, TFIs do not increase with age but do so in boys (girls right r=0.014 NS, left r=0.022 NS, boys right r=0.743, p<0.001; left r=0.341 p=0.045) with side differences in boys (p<0.002)

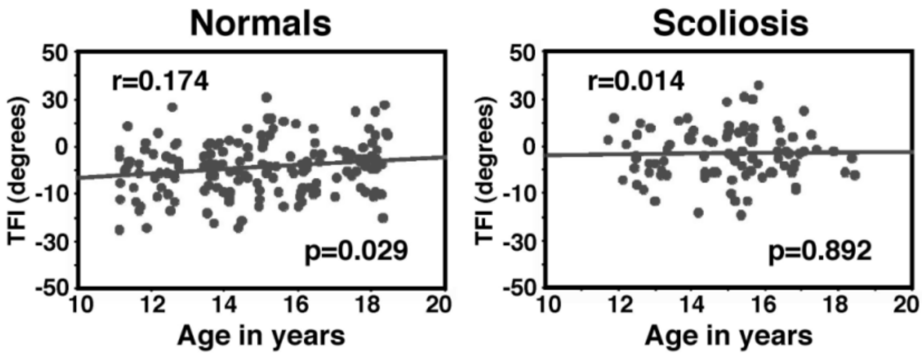

Figure 3. Right leg of normal and scoliosis girls. TFIs plotted against age. The findings for the scoliosis girls are significantly different from the normals (p=0.001) but not for the left leg TFI (p=0.107, ANOVA correcting for age).

3.3.3. Scoliosis referrals,

In girl scoliosis referrals, TFIs are 1) in the right leg are significantly different from normal (p right=0.001, left p=0.107, ANOVA corrected for age) and not significant in the boys, and 2) unrelated to curve severity but in boys are associated with apical vertebral rotation but not Cobb angle.

3,4. Conclusions

3.4.1 Normals girls and boys.

TFIs increase during growth as TT increases and FAV decreases.

3.4.2 Scoliosis girls

In the scoliosis girls, TFIs in the right leg are significantly greater than normal without detectable left-right asymmetry. The greater right TFIs is explained in the scoliosis girls by FAV being significantly less than in normals [14,29] whereas TT is not significantly different from normal [14,30]. This FAV decrease [14.29] may result from abnormally increased femoral detorsion, maturationally earlier than normals [14,29]. FAV asymmetry [14,29] detected by both FAV and FAV/TT ratios is not evident in the TFIs, perhaps because TFI has a greater measurement error than that of FAVs. FAV/TT ratios may be a more accurate method for estimating the relationship of FAV to TT than are TFIs.

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Risser sign: the value of the lateral spinal radiograph to assess the excursion of the iliac apophysis

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Abstract. The course of the ossification of the iliac apophysis is considered in adolescent patients with idiopathic scoliosis, under the name of the Risser sign, to determine the remaining spinal growth. Although the iliac crest develops in the three-dimensional space as a complex structure, the iliac apophysis ossification has been assessed only on a one plane frontal spinal radiograph. This study points out the usefulness of the lateral radiograph for the visualization of the whole iliac crest, especially the posterior region which otherwise cannot be observed. Two young female pelvis specimen were examined with anatomical measurements and radiography. Lateral spinal radiographs of 201 girls were analyzed for the iliac apophysis excursion.
The measures of the width of the iliac bone beneath the iliac crest revealed one anterior and one posterior thick regions, coupled with an intermediate thin region. The regions of the maximal thickness corresponded to the earliest appearance of the apophysis ossification (Risser 1), while the thin part of the iliac bone corresponded to late appearance of the apophysis ossification (Risser 3-4). The ossification of the posterior part of the crest was best visualized with the lateral radiograph, which was exclusive in showing the posterior superior iliac spine region. On the frontal spinal radiograph the end of the course of the apophysis (Risser 3-4) is usually searched at the level of the sacroiliac joint, while in reality this point was found to be situated more caudal, and accessible for observation on the lateral radiograph.

1. Introduction

The cranio-caudal growth of the human spine is not linear; the main phases of the most intensive growth concern the first two years of age as well as the early puberty (usually 11-13 years in girls). Increase of the structural scoliotic curvature occurs during this rapid growth phase [1, 2]. The growth potential running out, the evolution of a spinal deviation loses in its dynamics. Thus, the knowledge of the developmental stage of an adolescent with scoliosis is crucial for making therapeutic decisions: planning of surgery, brace treatment or brace weaning. In adolescence the biological age does not always correspond to the chronological age. That is why a number of indices has been developed to assess the bone age with radiography. The Risser sign [3] is one of the most popular.

The determination of the Risser sign value (from zero to five) reposes on the assessment of the excursion of the secondary ossification center of the iliac crest (iliac apophysis). In is believed that the ossification starts at the superior anterior iliac spine (SAIS), continues along the iliac crest from anterior to posterior and completes at the posterior superior iliac spine (PSIS). Minor asymmetries of the left-right apophysis ossification have been described [4]. The assessment of the Risser sign value is performed after an antero-posterior (AP) or a postero-anterior (PA) spinal radiograph comprising the pelvis. The assessment after the lateral spinal radiograph has not been reported.

The complex shape of the female pelvis reflects the function of the osseous pelvic girdle providing stability for transmitting the trunk load to the lower limbs throughout the pelvic ring. The most upper part of the left and right iliac bones, namely the iliac crests develop their shape in the three dimensional (3-D) space. Starting from the ASIS the iliac crest continues in the superior and posterior direction, then posterior, then progressively more medial to the L5 level and finally rapidly down and posterior up to the PSIS. As any 3-D structure cannot be seen on one plane radiograph, it is admitted in orthopedic surgery to systematically visualize bony structures using two perpendicular projections: a frontal one and a lateral (or axial) one. However, only the frontal one has been used so far to evaluate the iliac apophysis excursion for the Risser sign value.

The aim of the study was to investigate the size, shape, width and the spatial orientation of the iliac crest using two anatomic specimen and to assess the development of the iliac apophysis using lateral radiography.

Fig. 1. The pelvic specimen (bottom) and its radiography (top), both seen in the frontal (left), transverse (middle) and lateral (right) plane. ASIS – anterior superior iliac spine. PSIS – posterior superior iliac spine. aPSIS – apparent PSIS – the point commonly considered to be the PSIS, which is actually situated at the junction of the 70% anterior and the 30% posterior of the total length of the iliac crest. This posterior part can be seen on the lateral radiograph exclusively.

2. Material and Methods

Two young female pelvic specimen were examined with frontal and lateral radiography, attaching metal markers along the iliac crest (Fig. 1). The thickness of the iliac bone was measured just beneath the iliac crest, along the whole distance from the ASIS to the PSIS at 1cm intervals. Moreover lateral radiographs of 201 girls with idiopathic scoliosis, aged 10.2 to 20.0 years, mean 14.6 ± 2.2 years, were examined to reveal the excursion of the apophysis. The X-rays were taken from the charts of the patients, and not ordered because of this study. The position of the PSIS was studied and related to the vertebral level (to the vertebral body level or the intervertebral disc level).

3. Results

The length of the iliac crest of was 23.5cm for the first specimen, and 21.5cm for the second one. The iliac bone was the thickest in two regions, one adjacent to the ASIS and another one to the PSIS. In the ASIS region the width of the iliac bone varied from 10.7mm to 17.3mm, mean 13.7mm (the first specimen), and from 11.2mm to 14.9mm, mean 13.1mm (the second specimen). In the region of the PSIS the width of the iliac bone varied from 10.4mm to 15.7mm, mean 12.8mm (the first specimen), and from 11.4mm to 17.6mm, mean 15.5mm (the second one). The iliac bone was thin in between the two above mentioned regions. In the first specimen the width of the thin region varied from 5.8mm to 7.4mm, mean 6.5mm, while in the second specimen the width varied from 8.1mm to 10.1mm, mean 9.6mm. The radiography of the pelvic specimen revealed that the regions of the maximal width of the iliac bone corresponded to the regions of the first appearance of the ossification of the iliac crest.

The analysis of the position of the PSIS revealed the level of L5 in 3 cases, the disc L5/S1 in 4 cases, the S1 in 96 cases, the disc S1/S2 in 52 cases and S2 in 35 cases. The ossification of the iliac apophysis was clearly seen on the lateral radiograph. Various stages of the ossification were observed: (1) no ossification, (2) short and thin shadows of the beginning ossification, (3) full length excursion or (4) fusion of the apophysis with the iliac crest (Fig. 2.). Thus, the lateral radiograph excursion of the iliac apophysis was proposed to be quantified in four grades [paper submitted for publication].

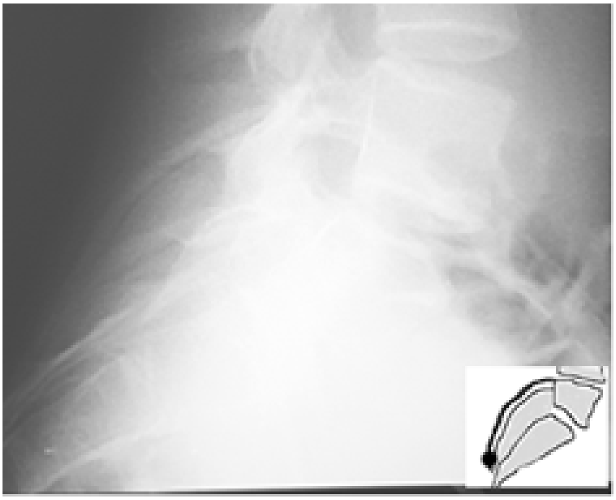

Fig. 2. Lateral radiograph showing the full excursion of the iliac apophysis up to the posterior superior iliac spine. The most posterior and inferior portion of the iliac crest is not visible on the frontal plane radiograph, however it can be observed on the lateral one.

4. Discussion

This study confirmed what is already known from anatomical studies, that the value of the width of the iliac bone can present important variations, and that the regions of maximal or minimal width are distributed in the systematic way: the anterior maximum, the middle minimum, the posterior maximum. The knowledge of the size of the iliac bone is useful in clinical practice: both the anterior and the posterior thick regions are the preferable sources to harvest the bone graft in orthopedic surgery.

It was interesting to notice that the regions of the iliac bone which revealed the maximal width corresponded to the regions of the first appearance of the apophysis ossification (Risser 1). The amount of the underlining bone would be the main reason for early appearance of the ossification in particular regions of the iliac crest. Also, the sequence typical for the Risser sign development may be explained by the sequence of ossification beginning at the large bony regions and followed by the progressive ossification of the thinner regions. It worth mentioning that the region of the posterior maximum thickness of the iliac bone cannot be seen on the frontal pelvic radiograph. On the other hand, it is well seen on the lateral radiograph.

When studying the representations of the Risser sign which are reproduced in the manuals of orthopedics, one can easily notice that the excursion of the posterior apophysis is designed as stopping at the level of L5 vertebra, lateral and superior to the sacroiliac joint. In this study the PSIS was found to be situated much lower, at the level of S1 to S2 vertebra. These findings strongly support the thesis that there exists a posterior part of the iliac crest which cannot be observed on the frontal radiograph, however it can be seen on the lateral one.

5. Conclusions

The complex 3-D shape of the iliac bone bordered with the iliac crest cannot be accurately studied from the one plane frontal radiograph. The additional use of the lateral radiograph allows detecting of the ossification of the posterior part of the iliac crest. The thickness of the iliac bone represents two maxima joined with a thin region in the middle. The thick regions correspond to the radiographic early appearance of the ossification of the iliac apophysis (Risser 1) while the thin regions correspond to the late ossification (Risser 3-4).

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Stature and growth compensation for spinal curvature

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Abstract: Spinal curvatures alter measured stature and may influence the evaluation of skeletal maturity and growth based on stature measurements. Methods: A dataset of calibrated measurements of vertebral positions of 407 radiographs in the frontal plane, together with clinically measured Cobb angles was used to determine the difference between spinal length and spinal height ('height loss') as a function of Cobb angles for radiographs indicating both single (N=182) and double (N=225) curves. Results: An apparently quadratic relationship: Height loss (mm) = 1.0 + 0.066*Cobb + 0.0084*Cobb*Cobb was found between height loss and each patient's mean Cobb angle for double curves. There was close agreement of the regression coefficients for single and double curves, and the present findings were very similar to the relationship reported by Ylikoski (Eur Spine J, 2003, 12:288-291). The relationships differed substantially from those proposed by Bjure (Clin Orthop, 1973 93:44-52) and by Brookenthal (SRS Exhibit 15, 2002). Discussion and Conclusions: The findings of the present study indicate that height loss (in mm) occurring with a 10 degrees increase in mean Cobb angle (for two curves) would be 1.1 + 0.16 times the mean Cobb angle (in degrees). For example, for a Cobb angle change from 30 to 40 degrees, the expected height loss would be 1.1 + 35*0.16 mm = 6.7 mm. This assumes that height loss occurs only as a result of altered curvature, without alteration in disc height associated with an increase in scoliosis.

Keywords: Stature; Height loss; Skeletal maturity; Spinal length; Radiography

1. Introduction

A spine of a given length will have a lesser vertical height when curved - hence scoliosis is associated with loss of stature ('height loss'). This height loss may be of concern to patients with scoliosis. Also, it may confound evaluation of growth and maturity that involve standing or sitting height measurements. In principle, if the shape of the spine with scoliosis is known, the relationship between spinal height and curvature can be evaluated geometrically. Such an analysis must assume that the total length of the spine is unaltered by the curvature - that is the height of vertebrae and discs at their centers is unaffected. A simplified analysis of this kind was reported by Brookenthal [3], assuming a circular geometry of the scoliosis curve. Other previous studies have been empirical, employing measurements of patients with scoliosis [1,2]. The present study sought to confirm the previously reports of height loss, and to determine whether the relationship of height loss to Cobb angle differed for single and double curves.

2. Methods

A dataset of measurement of 407 calibrated stereo-radiographs or patients with a diagnosis of idiopathic adolescent or juvenile idiopathic scoliosis was used to analyze the relationship between Cobb angle, spinal length and spinal height. Data were included in the present study for patients between 9 and 20 years old, before any surgery, but some patients were listed in the database as undergoing brace treatment. The radiographs were made between the years 1981–1986 in a study of three-dimensional spinal shape. [4]. The Cobb angle had been recorded in the database from measurements made by a scoliosis surgeon, and in each case measurements were identified as from single, double or triple curve deformities. Only single (N=182 radiographs) and double curve (N=205 radiographs) data were analyzed here.

The database included the three-dimensional coordinates of landmarks on each the vertebrae from T1 to L5. The height of each vertebra and disc was determined as the Pythagorean distance between the 3-D coordinates of the corresponding endplate centers. All vertebral landmarks from T1 to L5 had been measured, but the vertebrae and discs above T5 were omitted from this study because they were frequently unclear on the original films as a result of exposure or projectional problems. Spinal length was defined as the sum of the heights of all vertebrae and discs from T5 to L5 in the frontal plane. The spinal height was defined as the vertical distance from T5 to L5 in the frontal plane. Height loss was defined as the difference between spinal length and spinal height.

The patients had been radiographed in a controlled standing posture, with supports contacting the anterior superior iliac spines and clavicles, with arms to the sides, to minimize patient motion during radiography. There were 2 radiographic projections made with a 3 m film-to-focus distance, using 36-in (914 mm) cassettes, with low-dose intensifying screen and film combinations. Posteroanterior and oblique views were made. The oblique view used an x-ray tube either at 20° on the patient's right side or 15° above the horizontal. For each stereo reconstruction of the spine, vertebral landmarks (vertebral endplates and bases of pedicles) had been previously identified, marked, and digitized from each radiograph according to the methods described [4] to obtain the 3-D coordinates of each landmark.

The relationship between height loss and Cobb angle was determined by regression analysis, separately for single and double curves. In the case of double curves, the spinal deformity was quantified by the average of the two Cobb angles.

3. Results

The relationship between height loss and Cobb angle was observed to be non-linear (Figure 1). Quadratic regression analysis of the supposed relationship between height loss and the mean Cobb angle in the form

Height loss = C + B*Cobb + A*Cobb^2 was employed, generating parameter values listed in Table 1. A similar analysis was employed by Ylikoski [1], which generated a relationship similar to that found for double curves in the present study (Figure 1).

	C	B	A
Patients with single curves	1.55	-0.0471	0.009
Patients with double curves	1.0	0.066	0.0084
Ylikoski	0	0.012	0.0096

Table 1: Parameter values in quadratic regression analysis curve fit to the observed relationships between height loss and mean Cobb Angle.

Note: Ylikoski gives values for total Cobb angle (of two curves), here divided by two (i.e. corresponding to average Cobb angle).

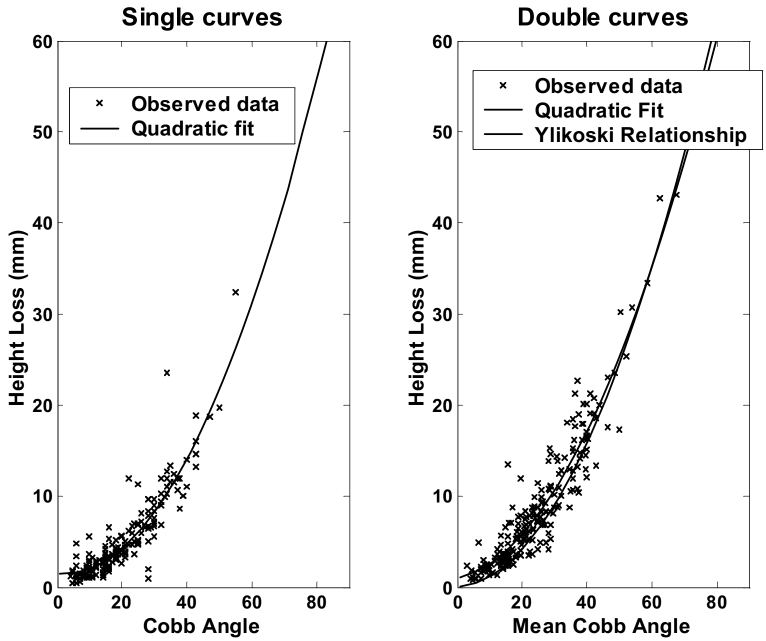

Figure 1: (Left): Observed relationship between Height loss and Cobb angle for single curves. (Right): Observed relationship between Height loss and mean (of two) Cobb angles for double curves. The relationship given by Ylikoski [1] is also plotted in the right panel graph.

4. Discussion and Conclusions

There was close agreement of the regression coefficients for single and double curves and with the relationship reported by Ylikoski [1],. The relationships differed substantially from those proposed by Bjure and Nachemson [2] and by Brookenthal [3].

Based on the findings for double curves in the present study, the height loss for an increment of Cobb angle can be estimated by taking the first derivative of the quadratic relationship - i.e. increase in height loss per increase in Cobb angle = 0.066 + 2*0.0084*Cobb. Thus for example, for a ten-degree Cobb angle change from 30 to 40 degrees, the expected additional height loss would be 0.66+ 35*0.168 mm = 6.5 mm. Annual spinal growth was reported to be about 15 mm per year at age 11 years, and about 5 mm per year at age 16 years [5], hence a progressive scoliosis can confound measurements of the rate of spinal growth.

The relationships found between height loss and Cobb angle differed substantially from those proposed by Bjure and Nachemson [2] (who assumed a logarithmic relationship) and by Brookenthal [3] (who assumed a circular geometry of the scoliosis curve). The Bjure and Nachemson relationship would predict a height loss of about 8 mm in the absence of scoliosis and would over-estimate the height loss for small curves. The Brookenthal relationship indicated height loss about 60% of that observed in the present study.

The findings in this study were very similar to those of Ylikoski [1] who reported height loss in 130 radiographs. Ylikoski considered that all patients had two curves, and reported the relationship between height loss and the total of the two Cobb angles. The present study (that analyzed single and double curves separately) indicated a lesser height loss in patients with single curves. This is probably a result of the height loss in compensatory curves that had not been included in the analysis, thus a more accurate indication of the height loss would be obtained by averaging the Cobb angle of both curves, whether or not both were considered structural.

This study examined measurements of radiographs of patients having differing degrees of scoliosis with some patients recorded more than once (combined longitudinal and cross-sectional database, but analyzed as if each observation was independent). No longitudinal studies of height loss were found through a search of the literature.

This study was two-dimensional, in that all measurements of spinal height and length were made in a frontal plane projection of the spine, despite the original data being three-dimensional. This was because only the scoliosis (lateral curvature) deformity was included, and the possible contributions of differing kyphosis or lordosis were not included. Ylikoski reported a linear relationship between kyphosis and height loss (about 15 mm loss for a 50 degrees kyphosis).

The present study assumes that spinal height loss occurs only as a result of altered curvature, without alteration in disc height associated with an increase in scoliosis. A longitudinal study would have advantages over this cross sectional study, since it could take into account any loss of discs height occurring in progressive scoliosis. In addition, only spinal height loss was considered, while the relationship between total height (stature) of a patient and the sitting height may differ during the course of adolescent growth [6].

Acknowledgements: NIH R01 AR 053132. This study originated from a suggestion by Lori Dolan (University of Iowa).

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Clinical detectable tension in the growing body: new and revisited signs in clinical examination in children with postural problems and spinal deformities

Restoration of lordosis on the thoracolumbar junction can correct sagittal and coronal plane deformity; a new (revisited) linked approach on the treatment and etiology of adolescent spinal deformities

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Abstract: Unclear etiology in scoliotic and kyphotic deformities of the spine is responsible for uncertainty in treatment options. Normal all-day factors can be of importance. Newly developed or revisited clinical examination of sitting and supine children and consequent testing of neuro-muscular tightness shows to be useful in understanding the different spinal deformations and postural problems during growth and point to neuromuscular tension in growth. The goal is: -Better understanding of the role and individual characteristics of the central nervous system, especially the cord and roots in proper and improper growth of the human spine.- Clarifying that preservation of lordosis and good function at the thoracolumbar junction at the end of growth can be of value for normal configuration and function of the spine in adult life.- Present obvious important and consistent clinical observations in children in sitting and supine position with early and advanced adolescent deformities, by photographic studies and video fragments.

--Use of work on growth and deformation of the spine by Milan Roth on uncoupled neuro-osseous growth and other historical literature. -Relate these clinical findings and background literature with common knowledge about adolescent spinal deformities and mechanical laws on tensile and compressive forces in structures. Overview of relevant clinical tests in the growing child presented with deformities show possible correlation with the proposed internal balancing problem (uncoupled neuro- osseous growth) researched by Roth. Concomitant radiological and MRI signs are shown. Around 1900 most orthopaedic surgeons and anatomists saw relationship between the new habitude of children to sit for prolonged periods in schools and spinal deformities. A physiological explanation as adaptations needed by the total neuromuscular system ("the growing system") was widely postulated (Hueter-Volkmannprinciple) and subject in research but a concise theory was not achieved. By recognising positive effects of creating lordosis at the thoracolumbar junction of the spine and consistent clinical findings in early deformations scientific support was found by earlier experimental work of Roth. With a leading role of the central nervous system in growth of the spine of standing and sitting vertebrates by steering a tension based system, deformation can be understand as adaptations. Consequences for new preventive measures and therapeutic strategies in deformities seems possible

Keywords: scoliosis, kyphosis, spinal tension, biomechanics, thoracolumbar spine, osteoneural growth, historic studies

1. Introduction

If scoliosis and other deformities are assumed to be the visible results (using X-rays as the gold standard for diagnosis) of a mismatch in the speed and control of growth between the different systems of the body and tensile forces which contribute to these differences, it is important to know if these tensile forces (or tensions) are detectable is growing children. If so, new tools in assessment, screening and treatment can be developed. Tension is always present in the musculo-skeletal system. No posture or movement is possible without a certain amount of this tension developing. Roth's spring models of deformities (Fig. 1 and 2) are ways of understanding the links between these physical forces relating to the complex spine/cord relationships.

This paper reviews aspects of the work of Roth in this area, developed in conjunction with his practice devoted to examining children, and highlighting his contribution to scoliosis research, with the object of stimulating debate on his ideas and contributions [1-6].

In 1927, Lambrinudi's work on scoliosis noted the importance of assessing muscular tightness in the legs in relationship to a progressing spinal deformity [7, 8].

In recent years, I have revisited and incorporated several tests on neuromuscular tightness and the assessing of functional properties of the spine into the clinical investigation of children. Photographs and video-fragments will be used in the lecture to demonstrate this.

The tests for tensile forces give clues on factors leading to progression of deformities. These are:

1.) The use of the Adam's bending test from the posterior (torsion) and the lateral positions; the type of kyphotic curvature present and the likelihood of achieving a horizontal lumbar spine;

2.) A "scoop" test on thoracolumbar extension pattern, using the head coming up first from the bending test with the neck grasped by both hands. A normal spine firstly creates a "scoop" or lordosis at the TL area before the hips extend. Early deformities present as a kyphosis while the hips are extended.

3) A straight leg sitting test on spinal mobility: with tense neuromuscular structures, children without visible deformation in the standing position will sit more on their sacrum than on the ischial tuberosities and will thus not be able to stretch or even lordose their spines. Sitting the subject on the edge of an examination couch gives space for the long lever-arms of the upper legs and restores opportunities for stretching and lordosing the spine.

4.) The Unilateral Straight Leg Raising test in supine children: assessment of the leg-couch angle and/or femorotibial angle: This is widely used in Scheuermann's disease [9] and is often found different between the left and right sides in scoliosis. In the early progressing phase of scoliosis some real tightness will sometimes be detected.

5.) Bilateral Straight Leg Raising test: tightness will be found when raising the feet in a fixed stretched position of the hips and knees, followed by lifting of the buttocks off the couch, extending up into the whole spine as far as the shoulders. (This is referred to "Brettsteiff" in German ie as stiff as a board).

6.) A 'Jack in the box' reflex test: assessment of the protecting tightness while lowering the lifted legs back onto the couch after bilateral straight leg raising. In children with a tense trunk, they lift their head or involuntary assume a more than complete sitting position.

The variability found in all these tests is assumed to be dependant on multiple factors like age, gender, joint mobility, familiar predisposition, “stiffness” in gymnastics, phase of growth spurts, results of bodily exercises, good compliance in bracing etc. It makes scientific, reproducible measurements less reliable than the gold standard used for measurements on X-rays and has had to be interpreted on an individual basis. An important issue is the visualisation and recognition of the children and their parents of the sometimes unusual findings in these tests. Their subsequent disappearence as a result of good exercise or brace compliance offers a positive psychological effect in normally long-term treatment.

Where do these tests fits in the neurovertebral and osteoneural growth relations? As discussed elsewhere in this volume in the context of the contributions of Milan Roth to understanding scoliosis, his views on the causation of scoliosis state that:
“*Idiopathic scoliosis may be interpreted as an adaptive morphogenetic reaction of the vertebral column upon the growth insufficiency of the intraspinal nervous structures: The growth process of the vertebral column, though continuing undisturbed at the cellular level, is adapted at the organ level by “waves” to the growth-insufficient cord-nerve complex with the musculature as the force delivering organ. Morphological features of the scoliotic vertebra together with the typical position of the spinal cord within the spinal canal speak in favour of the suggested vertebro-neural concept which offers a plausible explanation of the congenital and experimental scoliosis as well*”.

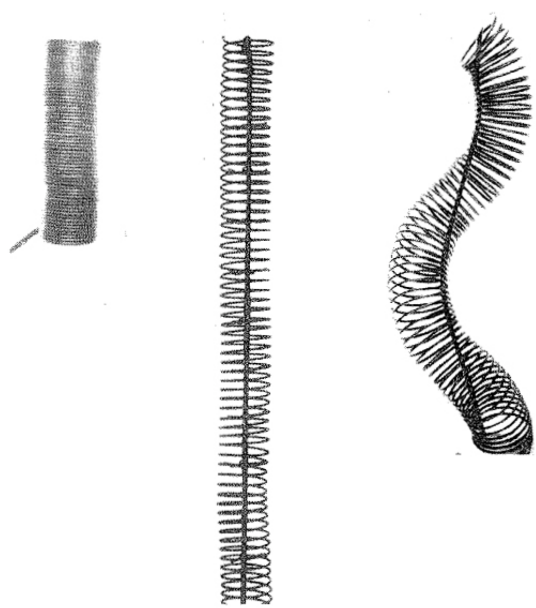

Abb. 4
Das Sprungfedermodell der Skoliosenentstehung

Рис. 4
Пружинная модель возникновения сколиоза

Figure1 *Roth’s simple model using a spring and a thread to represent a scoliotic deformity demonstrate where tensile and compressive forces are located.*

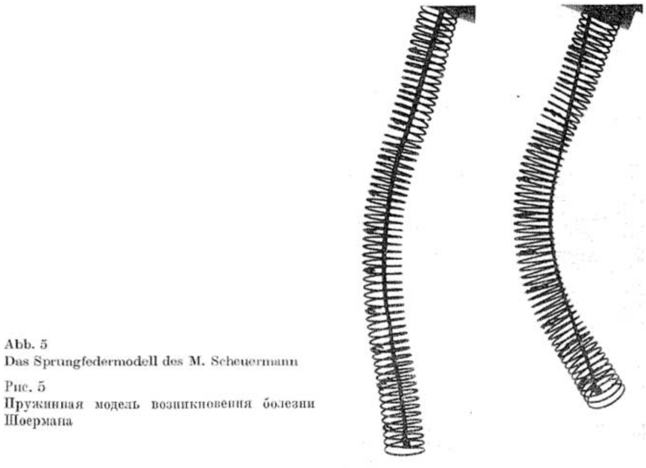

Figure 2 *Roth's simple model using a spring and a thread to represent a kyphotic deformity demonstrate where tensile and compressive forces are located. As in figure 1 changing terms as lordosis or scoliosis into unilateral compression and contra lateral distraction or shortening and lengthening helps in understanding the role of tension as a present force.*

Roth is equally clear about what happens in adjusting growing forces, and the therapeutic implications this might have:
"*Adjustment or rectification of the deformed structure like a scoliotic spine is not accompanied by lengthening, notwithstanding the fact that the scoliotic trunk is elongated; the curved spine is adjusted, not lengthened. The adjustment involves a contraction or reduction of the convexe side of the discs. Consequently in adjusting– paradoxally but irrefutably- the spinal canal is rather shortened*".

In our opinion he considered that the natural actions embodied within the Hueter-Volkmann principle could be reversed by an elastic (tensile) deforming force.

The question is now posed relating to how we can achieve modifying the position and curvature of the spine so that these tensile forces and their producing muscles can be addressed. It should be noted that providing the answer to this question was not the principle object of Roth's research.

However, some clues, which might lead to an answer to the problem, can be found elsewhere in Roth's work. Here, he stated that a lordotic form of the lumbar and thoracolumbar spine is of great importance for proper function of this complex and mobile region of the spine in childhood. This would then facilitate an improved function within the lower thoracic ribs cage, which are elevated by muscular forces and also retro-pulsed themselves. The bellows-like function of the diaphragm is also optimised by these actions. The practical outcomes of this hypothesis will be discussed later.

2. Disproportionate growth

Roth paved the way to develop a new framework of neurovertebral and osteoneural growth relations, which would allow research into these concepts of etiology of scoliosis. By introducing the research community to the work of previous generations of scientists, like Roth, there is hope to stimulate debate and new directions of research with modern-time possibilities[10-13].

For us, Roth's findings on disproportionate growth mean that an elegant incorporation of his concepts into modern research becomes possible. By developing these concepts, a new coherent system of interdependent hypotheses for the explanation of growth, and the (mal) functioning of the spine and the cord may be advanced. If form always follows function and no (muscular) function is without purpose, osteoneural growth relations are controlled. In turn, this could give us clues for formulating further research on proper treatment or prevention.

How did we get to this statement? The published work of Roth had to be reconciled with other studies of natural behaviour:

1 the very interesting work of Gracovetsky and Farfan on the optimum spine or where nature is heading for;

2 with developments in the last ten years in biomechanics or how does nature do things in order to copy this (robotology, prosthesiology),

3 with own clinical observations on tension related features or how nature shows itself

For me, the most elegant feature of these three concepts is that of the connecting element or type of forces that connects all of these three concept lines This is tension in its different manifestations and this, natural, element that is able to withstand gravity should be incorporated into orthopaedic biomechanical knowledge

3. The elements of the new concepts

The formulation of the main elements of this system of concepts fall into three parts.

3.1 Roth's concept of disproportionate growth of the cord vs. the skeleton.

Roth's concept of neurovertebral and osteoneural growth relations of the cord vs. the skeleton(and joints and discs) implies that there should be a clear and challenging domain for what triggers the manifestation of several spinal deformities. It means that research in this field can then be directed from nowadays interest in bone growth and hormonal pathways towards the causes of differences in the quality of cord stretching and the intrinsic role of growth spurts in that type of growth. While this is not the normal domain for orthopaedic surgeons, it does set a clear agenda for co-operation with geneticists, neurologists, neurosurgeons and paediatricians to research these concepts further. The way disproportionate growth manifests itself in a (de) formation of the spine however is another separate subject and field of research. There clinical tests and practical possibilities to intervene (exercises, bracing) to stop progression or correct already present deformities come into the practice of orthopaedics.

From this presumed cause of conflicting elements in two types of growth in one body that works out in the actual formation of the spine then divides in two different concepts.

3.2 How normal movements and posture create the shape of the spine.

In this area, we feel very comfortable with the progress in biomechanics that has been made in the last ten years. New ideas and concepts have been developed particularly by Gracovetsky and Farfan [14, 15]. In their work on the optimum spine, but also by several other authors [16, 17]. Movement is necessary for proper development of a child's body. The issue what could be suggested or added in those research lines is getting improved knowledge of characteristics of the thoracolumbar area in a good functioning spine as in pre-adolescents and the role of always present tensile forces in a living body.

3.3 How moulding and shape of the bony elements of the spine occurs.

Given the concepts embodied in ideas 1 and 2, how does moulding (in embryologic and postnatal growth) of the bony elements of the spine occur? We consider that, for proper understanding, a "multi-component mortar" concept is required.

Bone tissue grows by normal cell divisions as a part of the normal cell cycle. Every bony element is a result of generation (osteoblasts) and degeneration (osteoclasts) of cells where the pace of cell division creates the shape as we see it. It is also known that the resultant pace of growth is different throughout all bony structures. In the concept of "multi component mortar", tension as an underestimated natural force forms the activating component that then triggers the other biochemical components of the "mortar" to format certain dimensions. This is very well researched in trees with applications in engeneering[18, 19]

4. Conclusion: the application of the concepts.

In practice and through recent research, I have concentrated on applying the concepts under 1 and 2 on how to restore spinal deformities following the principles as stated by Roth.

My conclusion is that restoring lordosis through the thoracolumbar joint appears to be the key to achieving the appropriate adjustments to the total, inter-connected components of the spine. The thoracolumbar joint function in what should, or can, be seen as a three-dimensional hinge in a complex, connected inverted pendulum, the spine, strives to maintain an equilibrium state. Where form follows function, the coordinated neuro-muscular tension of the dynamic tension cables, the musculature, directs the positioning and form of the bony structures in order to create an intrinsically well-balanced system.

In our recent article in Spine 2008 we presented what might be called a controlled test of the principle of the working of lordotic intervention [20]. We tested the hypothesis that correction of scoliosis may benefit from a lordotic fulcrum force in the sagittal plane on the thoracolumbar spine. The results were statistically significant.

Additionally, during the last five years we have developed a spinal correction method based on this principle called thoracolumbar lordotic intervention (TLI). As a matter of fact not yet published on the neuromechanic but only biomechanic results I consequently experienced in the performance of pedicle subtraction osteotomies at the thoracolumbar spine in deformities a impressive tension releasing feature [21].

In TLI-bracing we do not put corrective force on the bone structures, but more logically, onto the tension cables, namely the muscles. Rearrangement of tensile forces is required because of a complete chance in the postural balance. Instead of a slight or clear flexed trunk position, we restore antero-posterior curvatures, and thus, this rearrangement of masses and muscle forces needed to control balance will end in a corrected three-dimensional posture. Then the presence or need of "tight hamstrings" disappears. We gently force the child's growing body to auto correct the deformity while we focus on intervening only in the sagittal plane. Shoulders and buttocks regain their relative posterior position, while the thoracolumbar area is passively and actively placed at a more anterior position.

The first results in this type of “conservative” treatment were presented at the SOSORT-Athens 2008 meeting giving strong support to the incorporation of Roth’s work in further therapeutic directions.

To revisit older or almost forgotten work of earlier scientists, not only in orthopaedics but other fields, allows the possibilities of linking such concepts and ideas together leading to an innovative path for a range of medical and scientific disciplines.

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Chapter 3

Biomechanics, Surface Topography and Imaging

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Quantification of intervertebral efforts during walking: comparison between a healthy and a scoliotic subject

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Abstract. The accurate quantification of internal efforts in the human body is still a challenge in biomechanics. The aim of this study is to quantify the intervertebral efforts along the spine during walking, in order to compare the dynamical behaviours between a healthy and a scoliotic subject. Practically, one healthy subject, one scoliotic patient before an instrumentation surgery (Cobb 41°) and after this instrumentation (Cobb 7.5°) walked on a treadmill at 4 km/h. The acquisition system included optokinetic sensors, recording the 3D-joint coordinates, a treadmill equipped with strain gauges, measuring the external forces independently applied to both feet, and bi-planar radiographs, enabling the 3D reconstruction of the spine from C7 to L5, using a free form interpolation technique. The intervertebral efforts were computed using an inverse dynamical model of the human body in 3D. As results, significant differences of the spine kinematics were recorded which lead to different internal effort behaviour in magnitude, shift, coordination and pattern when normalized to the subject mass. Particularly, the normalized antero-posterior intervertebral torques are less uniform for the scoliotic patient (from min -2.5 to max 1.9 Nm/kg) than the healthy subject (from -1.5 to 1.5 Nm/kg). This disequilibrium in the left-right balance of the scoliotic patient is a bit rectified after surgery (from -1.3 to 1.1 Nm/kg).

Keywords. Idiopathic scoliosis, gait, intervertebral efforts, multibody dynamics, spine modeling, dual kriging

1. Introduction

The in vivo accurate quantification of internal efforts in the human body is still a challenge in biomechanics. This quantification could enhance rehabilitation tools for patients with motion-linked pathologies. The purpose of this study is the quantification of intervertebral efforts along the spine during walking, in order to compare the dynamical behaviour between a healthy and a scoliotic subject.

2. Methods

One healthy subject and one scoliotic patient (before and six months after an instrumentation surgery) walked on a treadmill at 4 km/h. Three cases were analysed:

1. The healthy subject (69 kg) ;
2. The scoliotic patient (50 kg) before an instrumentation surgery, presenting a maximal Cobb angle equal to 41° between L2 and T10, and a maximal torsion equal to 30° at T12 ;
3. This scoliotic patient (50 kg) six months after an instrumentation surgery that rectified the spine curvature and joined the T9 to T12 together. The maximal Cobb angle decreased to 7.5° and the maximal torsion decreased to 5°.

The acquisition system included:

1. Optokinetic sensors (Elite-BTS), recording the 3D-joint coordinates [1];
2. A treadmill equipped with strain gauges, measuring the 3D external forces independently applied to both feet [2];
3. Bi-planar radiographs of the spine, enabling the 3D reconstruction of the spine from C7 to L5, using a free form (dual kriging) interpolation technique [3].

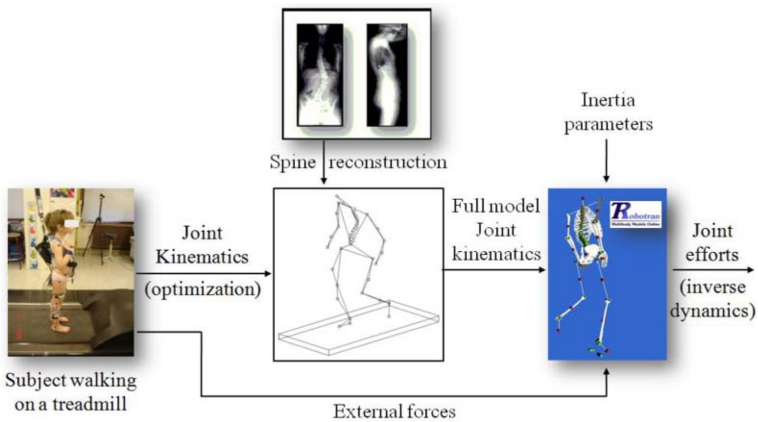

Figure 1. General principle of this method to quantify the intervertebral efforts during gait.

Using these data, a 3D multibody model of the human body [1] provides the intervertebral forces and torques, via these three consecutive steps (Figure 1):

1. The joint kinematic optimization: the joint coordinates q, velocities $\dot{q}$ and accelerations $\ddot{q}$ are numerically determined by an optimization process that estimates the joint coordinates of the multibody model that best fit the experimental joint positions [1].
2. The full model joint kinematics: the kinematics of the spine is completed by the 3D reconstruction of the spine from C7 to L5 (dual kriging) on the basis of the bi-planar radiographs of the spine [3].
3. The inverse dynamics: using a recursive Newton-Euler formalism [4], a 3D multibody model provides the vector Q of joint forces and torques during gait as follows :

$$Q = f(q, \dot{q}, \ddot{q}, F_{ext}, M_{ext}, g),$$

where f is a function of $q, \dot{q}$ *and* $\ddot{q}$ and represents the inverse dynamical model of the human body, on the basis of the external forces *Fext* and torques *Mext* applied to the system, and also gravity.

Let us note that these equations were symbolically generated by the *Robotran* software [4], developed at the CEREM – UCL, which allows us to straightforwardly interface these equations with any numerical process, such as the optimization process presented above and the time simulation of the trials.

3. Results

Significant differences of the spine kinematics were recorded, which lead to different internal effort behaviour in magnitude, shift, coordination and pattern when normalized to the subject mass.

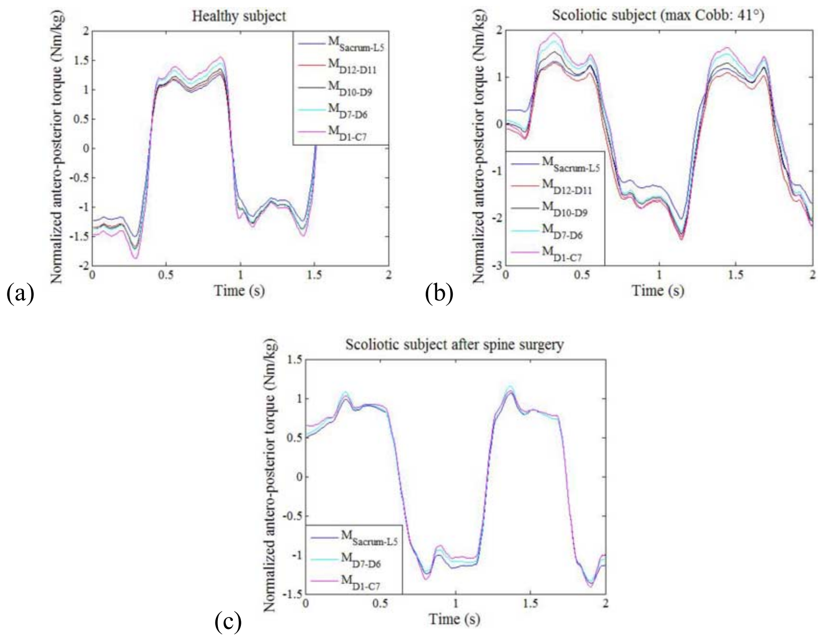

Figure 2. For (a) the healthy subject, (b) the scoliotic patient before instrumentation surgery and (b) this scoliotic patient after surgery, all walking at 4km/h on a treadmill: comparison between antero-posterior intervertebral torques corresponding to the spine extremities ($M_{sacrum\text{-}L5}$ and $M_{D1\text{-}C7}$), the apices ($M_{D7\text{-}D6}$ and $M_{D12\text{-}D11}$) and the maximal lateral inflexion ($M_{D10\text{-}D9}$) of the scoliotic patient.

Figure 2 shows significant differences between the three cases:

- The maximal absolute magnitude of the normalized antero-posterior torques (NAPT) is higher for the scoliotic patient before surgery (2.5 Nm/kg) than this patient after surgery (1.3 Nm/kg) and the healthy subject (1.5 Nm/kg);
- The NAPT maxima and minima are rather symmetrical for the healthy subject (-1.5 and 1.5 Nm/kg, resp.), while the scoliotic patient before surgery presents a

significant NAPT shift of NAPT maxima and minima (-2.5 and 1.9 Nm/kg, resp.) that represents a disequilibrium in the left-right balance of vertical forces between vertebrae; this shift is a bit rectified for the scoliotic subject after surgery (-1.3 and 1.1 Nm/kg, resp.);

- The NAPT general patterns present clear «crenel-type» left-right swings for the healthy subject, a more perturbed and more «ramp-type» behaviour for the scoliotic patient before surgery, and finally a rather «crenel-type» swing and smoother gait for the scoliotic patient after surgery;
- For the scoliotic patient before surgery, the NAPT are significantly different between each vertebra, while these efforts are rather similar for each vertebra concerning the scoliotic patient after surgery and the healthy subject.

4. Discussion and conclusions

Different dynamical behaviour was found between a normal and a scoliotic patient before and after surgery, essentially due to more significant constraint effort variation between vertebrae during walking and disequilibrium in the left-right balance concerning the scoliotic patient.

From this preliminary study on three cases it is not possible to generalize these interpretations to all healthy and scoliotic subjects. Nevertheless, these observations open the perspective of a more extended use of the quantified information provided by the internal effort measurements. Further, when completely validated, the modeling approach could be useful to compute joint loads, develop rehabilitation tools for patients with motion-linked pathologies and enhance finite element models of the spine.

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Measuring the Rib Hump in Scoliosis with ISIS2

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Abstract. The three-dimensional shape of the back of 60 patients attending a spinal deformity clinic was measured using ISIS2, a non-commercial surface topography system using digital photography and structured light. Wire-frame and contour plots were displayed, presenting quantitative information and providing a useful pictorial representation of the whole back. A numerical parameter representing the height of the rib hump was also recorded. Repeat measurements, with the patient walking around the room between photographs were carried out. The mean difference between the pairs of measurements was –0.08 mm (sd 4.18 mm) and the 95% tolerance limits were –9.82 mm to 9.66 mm. Changes of greater than ±10 mm are therefore necessary as indicative of clinical change.

Keywords. ISIS2, scoliosis, rib hump, visualisation

1. Introduction

The gold standard method of assessing back deformity in scoliosis is the Cobb angle. However, patients are generally more concerned about their rib humps and there is not necessarily a direct relationship between Cobb angle and the magnitude of the hump. A method of assessing the hump would therefore be useful to spinal surgeons and patients alike, especially if it was non-invasive.

2. Methods

The three-dimensional shape of a patient's back is measured using digital photography and structured light using ISIS2 [1], a non-commercial surface topography system. The height of the surface is calculated using Fourier transform profilometry with an accuracy of ±1 mm. The surface is related to body axes using the locations of certain bony landmarks which have been marked with small coloured stickers prior to photographing. The x-axis is horizontal and lies parallel to the line between the two lumbar dimples in the transverse plane. The y-axis runs vertically in the coronal plane. In the sagittal plane the y-axis may be at a small angle to the vertical if there is extension or flexion in the stance of the patient. The h-axis is normal to the x-y plane and positive outwards from the back. The $h = 0$ plane includes both the vertebra prominens and the sacrum. The surface is plotted as a wire-frame model and a contour plot. The wire-frame plot gives an impression of the three-dimensional shape of the back, viewed from below to exaggerate any rib humps. In the contour plot, the height is indicated both by contour lines plotted at 5 mm intervals and by colour (see Figure 1). The colours relate to the height of the surface above the zero plane and this relationship is retained in subsequent measurements. Two plots can be compared directly even if taken at different times. The maximum height of the rib hump on the sections a distance of a tenth of the back length (vertebra prominens to sacrum) to either side of the spinal line is also recorded as a numerical parameter in ISIS2.

The inherent variability in back shape caused by positioning, breathing and muscle tension was investigated by repeat measurements on 60 patients. Two photographs were taken of each patient with the patient walking around the room between them. The contour plots were compared and Bland-Altman [2] analysis was carried out on the rib hump measurements.

3. Results

Two examples of rib humps are shown in Figure 1. The upper images show a wire-frame plot and a contour plot of a patient with a low spinal curve (ISIS2 lateral asymmetry (Cobb angle equivalent) 19º R in the thoracic region and 13º L in the lumbar region) with a large hump. The lower figures are for a patient with a higher spinal curve (lateral asymmetry of 30º R in the thoracic region and 19º L in the lumbar region) but with very little hump. Figure 2 shows the difference plotted against mean of the pairs of measurements (Bland-Altman plot). There is no evidence of bias. The mean difference in hump height between pairs of measurements on 60 patients was found to be –0.08 mm, (sd=4.18) and the 95% tolerance limits covering 95% of the population [3] were –9.82 to 9.66 mm.

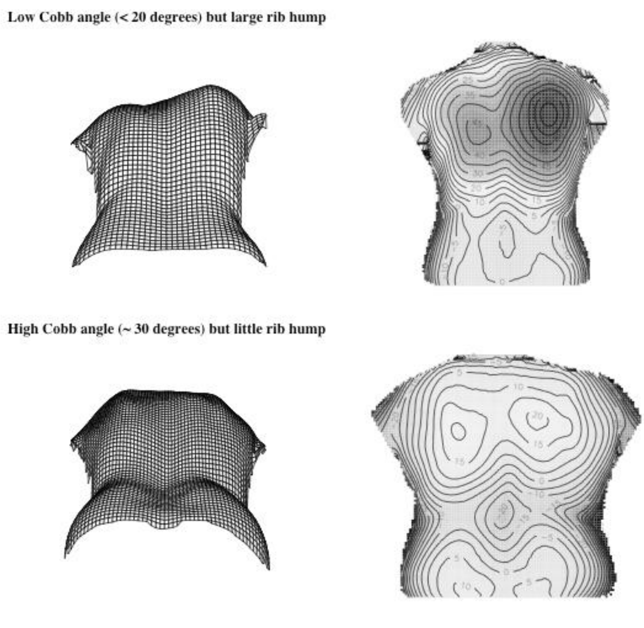

Figure 1. Example of wire-frame and contour plots

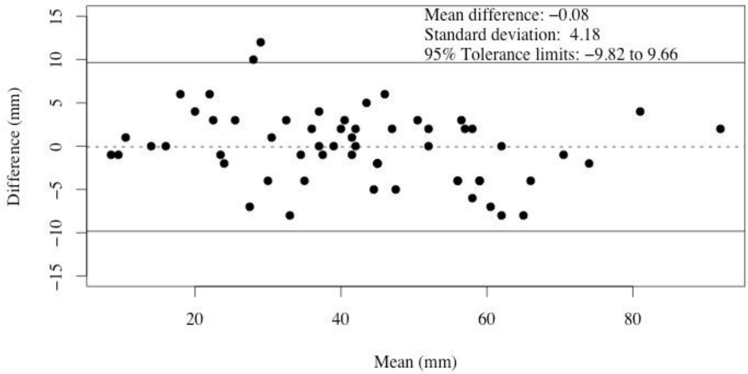

Figure 2. Bland-Altman plot for rib hump measured with ISIS2

4. Discussion and conclusion

Traditionally, patients with scoliosis are assessed by measuring their spinal curvature in the coronal plane using radiography [4]. However, radiography provides no information about the size of any rib hump that is present. Patients tend to be more interested in their back shape – what their back looks like and how their clothes hang. Cosmetic factors such as size of rib hump play a large part in the requirement for treatment [5]. Surface topography can provide this extra information. The wire-frame and contour plots produced by ISIS2 present quantitative information on back shape and provide a useful pictorial representation of the whole back, providing the surgeon and patient with an additional objective tool for assessing back shape.

The paired testing showed that the variation in hump height between measurements is relatively high, 95%, confidence limits being just under ±10 mm. Changes in hump height of less than 10 mm in ISIS2 can therefore not be regarded as indicative of clinical change. This variation reflects the natural changes in the surface shape caused by stance, breathing and muscle tension. No previous measurements of variability in such a parameter can be found in the literature for comparison.

Representing the shape of the back in a single numerical parameter remains a difficult problem and our research continues to try to improve the correlation of parameters obtained from non-invasive surface topography with the opinions of the patient and surgeon.

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Thoracic Kyphosis Angle Measurements with ISIS2

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Abstract. Thoracic kyphosis angle measurements using surface topography with ISIS2 were carried out to estimate the inherent variability in the parameter caused by natural change in the patient's stance, breathing and muscle tension. A mean kyphosis angle of 33.8º (sd 13.4º, range 6º-66º) was measured from repeat tests on 61 patients. The mean difference between the pairs of measurements was –0.02º (sd 3.18º) and the 95% tolerance limits were –7.41º to 7.38º. This variability is lower than the clinically significant change in kyphosis angle reported in the literature. Thus kyphosis angle in ISIS2 is suitable for monitoring progress in kyphotic deformities.

Keywords. ISIS2, kyphosis

1. Introduction

The increasing awareness of the risks of radiation in repeated radiographical assessment of patients with spinal deformities has lead to the development of ISIS2, a non-commercial surface topography system which measures the three-dimensional shape of the back using digital photography and structured light [1]. Markers are placed on bony landmarks prior to photography so that the surface can be related to body axes. Clinical parameters are then calculated from the surface data.

In recent years interest has grown in assessing sagittal alignment of the spine. Kyphosis and lordosis angles are readily available from ISIS2 and these parameters allow sagittal alignment to be assessed without adding to the radiation exposure of the patient. Back shape may vary, however, with patient stance, breathing and muscle tension. It is therefore important to assess the inherent variation in parameters measured with the system. The purpose of this work was to examine the range and variability in kyphosis angles measured with ISIS2 and assess the parameter's suitability for detecting clinically significant change in patients with kyphotic deformities.

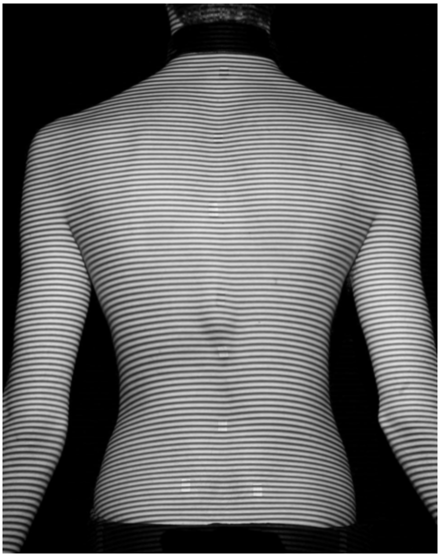

Figure 1. Example of patient image

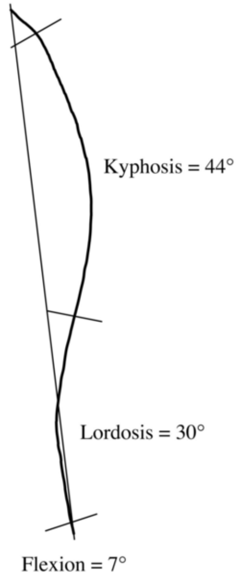

Figure 2. Kyphosis angle measurement

2. Methods

Small turquoise stickers were placed on the patient's back, on the vertebra prominens, the lumbar dimples and a number of spinous processes. The patient was then asked to stand in the patient stand in a relaxed normal pose; the feet were placed just outside the blocks on the footplate, the abdomen rested lightly against the abdominal bar and the arms were supported away from the sides of the body by the arm rests. Two photographs of each patient were taken, with the patient walking around the room between them. Figure 1 shows an example of a patient photograph.

The three-dimensional shape of the back was calculated from each photograph. The locations of the stickers were detected using image processing techniques and used to apply a correction for stance (pelvic rotation and flexion/extension) so that the surface data were related to body axes. An estimate of the three-dimensional location of the spine was then made by fitting a polynomial through the spinous process markers. Kyphosis angle, calculated by a modified Cobb technique, was then derived automatically from a polynomial curve fitted to the projection of the spinal line in the sagittal plane. Selection of the ends of the curve for the angle measurement was done automatically. The top limit is taken to be 5% of the back length down from the vertebra prominens and the lower limit is the point of inflection in the fitted polynomial. Figure 2 shows a typical sagittal profile with the perpendiculars to the tangents used to calculate the angle.

3. Results

Sequential patients attending the scoliosis clinic where the surgeon requested surface topography were asked if they would take part in the project and those who agreed had the additional photograph taken. The pairs of photographs were acquired over a period of five months for a total of 61 patients. The mean age was 16.4 (sd 6.7, range 5.9 – 47.4) years. The mean kyphosis angle measured over all photographs was 33.8º (sd 13.4º, range 6º – 66º). Bland-Altman analysis [2] was carried out on the paired data. The differences between the pairs of measurements were calculated and the mean, standard deviation and limits of agreement computed. The differences were plotted against the means of the pairs and are shown in Figure 3, where no evidence of bias can be seen. The mean difference between pairs of measurements on the 61 patients was –0.02º, (sd 3.18º) and the 95% tolerance limits covering 95% of the population [3] were –7.41º to 7.38º.

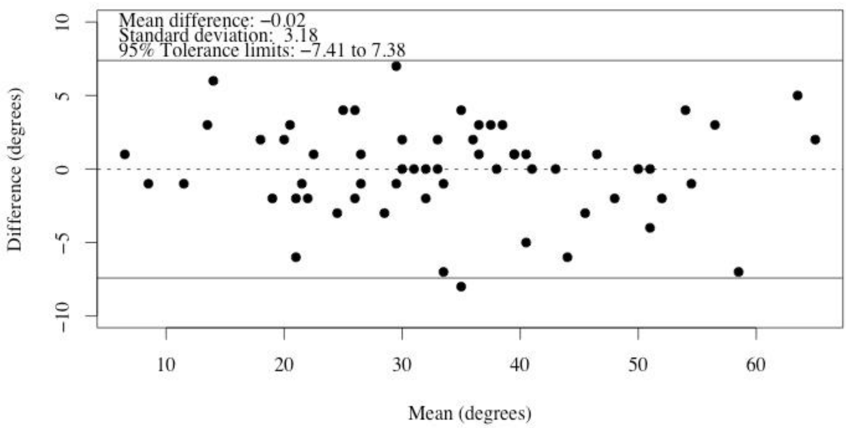

Figure 3. Bland-Altman plot for kyphosis angle measured with ISIS2

4. Discussion and conclusion

The kyphosis angle measured in ISIS2 is a global angle extending from approximately T1/T2 to the inflection in the curve of the spine which varies in height depending on the type of curve present. Many authors have reported on kyphosis angles in normal and scoliotic subjects measured radiographically but the range of vertebrae included in the measurements varies widely, T1-T12 [4,5], T3-T11 [4], T4-T12 [6], T5-T12 [7,8] T4-T9 [9] and others allow free choice of the end vertebrae [10]. This makes it difficult to compare kyphosis angles in the literature with the measurements from ISIS2. Mean values range from 27º to 45º [4-7]. The mean value of 33.8º measured in this test falls in this range.

If ISIS2 kyphosis angle is to be used for monitoring the progression of deformity then its variability must be less than the significant clinical changes that are being sought. Carman et al. [10] investigated the intra-rater variability in kyphosis radiographs and found that a change in kyphosis of 11º was necessary for 95% confidence limits covering 95% of the population. Alanay et al. [11] have reported intra-rater confidence intervals of up to ±9.3º. Clinically significant change in thoracic kyphosis angle is also reported elsewhere in the literature as greater than 10º [12]. As the variability in ISIS2 thoracic kyphosis angle is less than 10º, it can be used as a parameter to monitor progress of kyphotic deformities.

Monitoring by surface topography parameters will reduce the exposure of patients to radiation.

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Sagittal alignment correction of the thoracolumbar junction in idiopathic scoliosis by in situ bending technique

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Abstract. A long thoracolumbar sagittal rectitude is sometimes present in adolescent idiopathic scoliosis. The purpose of this study was to identify typical patterns, by comparing frontal plane deformities and vertebral rotation leading to this rectitude. Surgical thoracolumbar alignment correction by three-dimensional in situ bending of rods was then analyzed. Pre- and postoperative radiographs of 24 patients with scoliosis (36-104 degrees) were reviewed using Spineview software. Frontal curves and levels of sagittal rectitude were determined. Thoracic kyphosis, lumbar lordosis, sacral slope, pelvic incidence, pelvic tilt, T9 and T1 tilt were measured. Vertebral rotation was measured by computed tomography, Perdriolle's, Nash and Moe's methods. The intervertebral mobility of the rectitude was analyzed on side bending radiographs. Three patterns leading to sagittal rectitude were identified: 11 main thoracic curves (Lenke 1, King 3) with cranial prolongation of the physiological thoracolumbar junction (T7-T12) and maximal vertebral rotation above this zone, 13 double major or thoracolumbar curves (Lenke 3 or 5, King 1 or 2) with cranial and caudal prolongation (T9-L3) and maximal rotation above and below, 1 lumbar curve (Lenke 5) with caudal rectitude (T12-L4) and maximal rotation at L1. There was no relationship between intervertebral mobility and rectitude. Postoperatively, this zone of rectitude disappeared in 17 out of 24 patients after anterior release followed by posterior instrumentation using the in situ bending technique. In situ bending realizes a stepwise correction of the three-dimensional deformity at different levels. An accurate preoperative analysis is mandatory to achieve an adequate sagittal balance, frontal curve correction and vertebral derotation simultaneously. The determined patterns of thoracolumbar rectitude are helpful to plan surgical correction accurately.

Keywords. Idiopathic scoliosis, Sagittal deformity patterns, Thoracolumbar junction, In situ bending

1. Introduction

Adolescent idiopathic scoliosis represents a three-dimensional (3D) spinal deformity which can lead to a sagittal misalignment between thoracic kyphosis and lordosis. A long rectitude is sometimes present at the thoracolumbar junction. Kotwicki [1] described a local hypokyphosis between T9 and T12 and an adjacent hyperkyphosis between T5 and T9 in thoracic scoliosis which correspond to one sagittal pattern of thoracolumbar imbalance as a part of the 3D vertebral deformity. Furthermore, the author stressed the importance to differentiate global thoracic kyphosis measurements which may cover hyper- and hypokyphotic zones.

A detailed knowledge of segmental deformity of the spine is mandatory to perform an adequate surgical thoracolumbar alignment correction by in situ bending of rods [2]. This posterior instrumentation technique consists of a stepwise correction of each vertebra by means of alternate medialization in the frontal plane and increase of kyphosis and lordosis in the sagittal plane while derotation is maintained manually.

The purpose of this study was to identify typical patterns, by comparing frontal plane deformities and vertebral rotation leading to a sagittal rectitude at the thoracolumbar junction. The relevance of this particular deformity for surgical correction by in situ bending and postoperative thoracolumbar alignment were then analyzed.

2. Materials and Methods

For this retrospective radiographic study, the charts of all patients, who were admitted to our department for scoliosis surgery from 2002 to 2006, were reviewed. Patients, who presented an evident zone of rectitude of the thoracolumbar junction on preoperative lateral standing spine radiographs, were included in the study. This radiographic configuration was only apparent in adolescents with idiopathic scoliosis and adults who had adolescent idiopathic scoliosis that progressed with time. Patients with degenerative, congenital or neuromuscular scoliosis were excluded from the study. Twenty-four patients met the criteria for inclusion. There were 4 males and 20 females. The average age at the time of surgery was 25 years (12 to 59 years) and average postoperative follow-up was 3.5 years (1.2 to 6.1 years). Seventeen out of 24 patients had an anterior release prior to posterior instrumentation using the in situ bending technique.

Curve patterns were determined on preoperative posteroanterior and lateral spine radiographs as well as side bending radiographs, using the classifications of King et al. [3] and Lenke et al. [4]. Cobb angles of primary (structural, major) and secondary curves, T4-T12 kyphosis, L1-L5 lordosis, sacral slope, pelvic incidence, pelvic tilt, T9 and T1 tilt were measured using Spineview® software preoperatively and postoperatively at last follow-up. Furthermore, the levels of sagittal rectitude were determined. Preoperative vertebral rotation of each thoracic and lumbar vertebra was measured by computed tomography, which represents the gold standard for accuracy in supine position [5]. The techniques of Perdriolle [6] and Nash and Moe [7] were used to assess vertebral rotation in standing position. The intervertebral mobility was analyzed on preoperative side bending radiographs to differentiate structural and nonstructural levels within the zone of sagittal rectitude.

The global surgical correction of the spinal deformity was evaluated in frontal and sagittal planes: Cobb angles of primary and secondary curves as well as sagittal parameters were compared pre- and postoperatively using the Student t test. Vertebral rotation measurements were only assessed preoperatively because pedicle screws and hooks would prevent accurate measurements on postoperative radiographs. The preoperative levels of rectitude were compared to the curve pattern, the level and the degree of the most rotated vertebra. The significance of these relationships was analyzed using the χ^2 test. A detailed pre- and postoperative analysis of the thoracolumbar junction was performed by comparing the number of levels that disappeared from the zone of rectitude after in situ bending maneuvers and the number of levels that remained in this zone. The significance level in this study was set at $p < 0.05$.

3. Results

Pre- and postoperative average values and standard deviations of Cobb angles, thoracic kyphosis, lumbar lordosis, T9 and T1 tilt, pelvic tilt, pelvic incidence and sacral slope are compared in Table 1. Cobb angles of primary curves ranged between 36 and 104 degrees preoperatively, between 4 and 70 degrees postoperatively. Cobb angle of secondary curves ranged between 28 and 88 degrees preoperatively, between 2 and 53 degrees postoperatively. The surgical correction of these parameters in the frontal plane was highly significant. Although the reduction of the spinal deformity was 3D, global sagittal parameters as well as positional and anatomical spinopelvic measurements were not clearly influenced by surgery.

Parameter	**Preoperative Average ± SD**	**Postoperative Average ± SD**	**P-value**
Cobb primary curve	64.3 ± 16.5	23.7 ± 16.8	0.0001
Cobb secondary curve	58.8 ± 19.2	29.3 ± 16.5	0.0001
T4-T12 kyphosis	29.5 ± 15.7	25.5 ± 11.9	0.048
L1-L5 lordosis	42.4 ± 13.8	42.1 ± 12.1	0.715
T9 tilt	6.2 ± 4.5	6.4 ± 2.9	0.808
T1 tilt	2.7 ± 2.1	3.7 ± 2.7	0.048
Pelvic tilt	10.2 ± 6.6	12.1 ± 7.3	0.069
Pelvic incidence	52.6 ± 11.0	53.0 ± 11.6	0.740
Sacral slope	40.1 ± 7.3	39.6 ± 8.2	0.717

Table 1. Pre- and postoperative radiographic measurements (degrees) of Cobb angles and sagittal parameters

The determination of curve patterns showed the following distribution: 11 main thoracic curves (Lenke 1, King 3), 9 double major curves (Lenke 3, King 2), and 4 thoracolumbar / lumbar curves (Lenke 5, classified as King 1 only in 2 of these cases).

The analysis of vertebral rotation showed that the maximally rotated vertebra was always located between T6 and L2. Its level corresponded to the apex of the primary curve in 19 out of 24 cases. Maximal rotation occurred most often at the levels T8 or T9 (14 out of 24 cases) in main thoracic and double major curves. Average maximal rotation and standard deviation were 24.5 ± 9.7 degrees with the Perdriolle method in standing position and 20.0 ± 12.5 degrees when using computed tomography in supine position. These vertebral rotations were classified as Nash and Moe grade 2 in 18 cases, grade 3 in 5 cases and grade 4 in 1 case.

The levels of the sagittal zone of rectitude varied, depending on the curve patterns. Nevertheless, this zone was always found between T7 and L4. The number of vertebrae included in the zone of rectitude was 5 in 12 cases, 6 in 11 cases and 7 in 1 case. The analysis of segmental range of motion on side bending radiographs evidenced that this zone is always included in a part of the primary (and secondary) curve and that it remains relatively structural.

When comparing the levels of rectitude, maximally rotated vertebrae and the previously determined curve patterns, it appeared that the zone of rectitude represented a prolongation of the physiological thoracolumbar junction around T11 to L1 on the lateral view, resulting from a geometrical projection of increasingly rotated vertebrae at the upper end, at the lower end or at both ends of the thoracolumbar junction. Three patterns of rectitude and relationships with curve patterns were identified ($p = 0.008$):

- 11 cases of cranial prolongation of the physiological thoracolumbar junction in main thoracic curves (Lenke 1, King 3). The upper end of rectitude was localized at T7 in 1 case, at T8 in 5 cases and at T9 in 5 cases. The maximal vertebral rotation was at the upper end or just above this zone (Figure 1).
- 13 cases of cranial and caudal prolongation of the thoracolumbar junction in double major or thoracolumbar curves (Lenke 3 or 5, King 1 or 2). The upper end of rectitude was localized at T9 in 6 cases and at T10 in 7 cases. The lower end of rectitude was localized at L2 in 8 cases and at L3 in 5 cases. Maximal rotations of primary and of secondary curves were respectively at upper and lowers ends or adjacent to the zone of rectitude (Figure 2).
- 1 case of caudal prolongation of the thoracolumbar junction in a lumbar curve (Lenke 5) with a lower end of rectitude at L4 and maximal rotation at L1 (Figure 3).

In 17 out of 24 cases, the pre- and postoperative comparison of the thoracolumbar junction showed that the zone of rectitude disappeared completely and that thoracic kyphosis and lumbar lordosis were well balanced on postoperative lateral radiographs, after surgical correction by in situ bending of rods. This technique was combined with an anterior release in 14 patients. In seven patients, the zone of rectitude remained partially, but its extent decreased from 7 to 5 vertebrae in 1 case, from 6 to 5 vertebrae in 1 case and from 6 to 4 vertebrae in 5 cases.

The exact relationship between factors that could lead to a better reduction of the sagittal imbalance at the thoracolumbar junction remains difficult to analyze. Nevertheless, there seemed to be no direct relationship between preoperative intervertebral mobility on side bending radiographs and postoperative reduction of the zone of rectitude. It remains also difficult to determine the exact influence of an anterior release which might facilitate the 3D reduction of the deformity at the thoracolumbar junction.

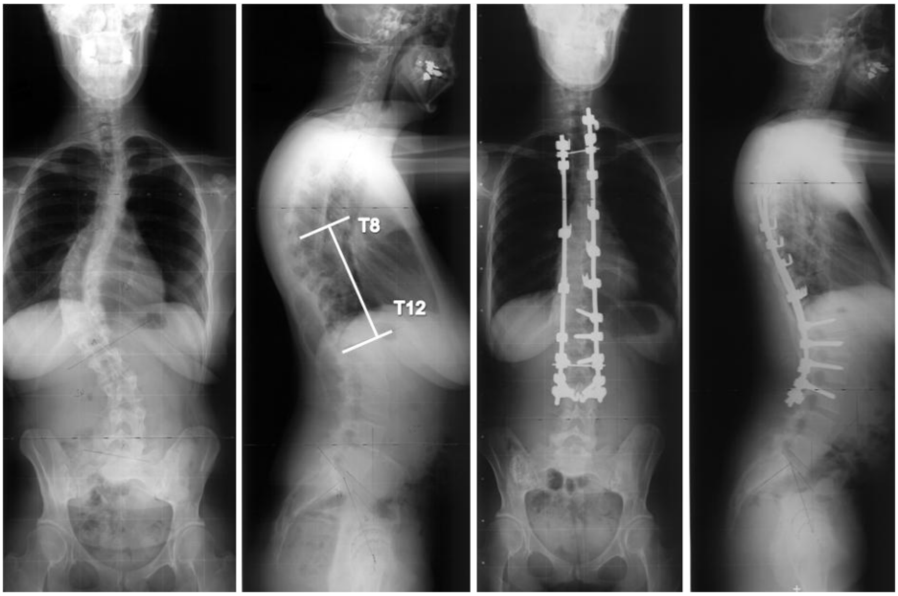

Figure 1. Cranial prolongation of rectitude in main thoracic curve and postoperative correction

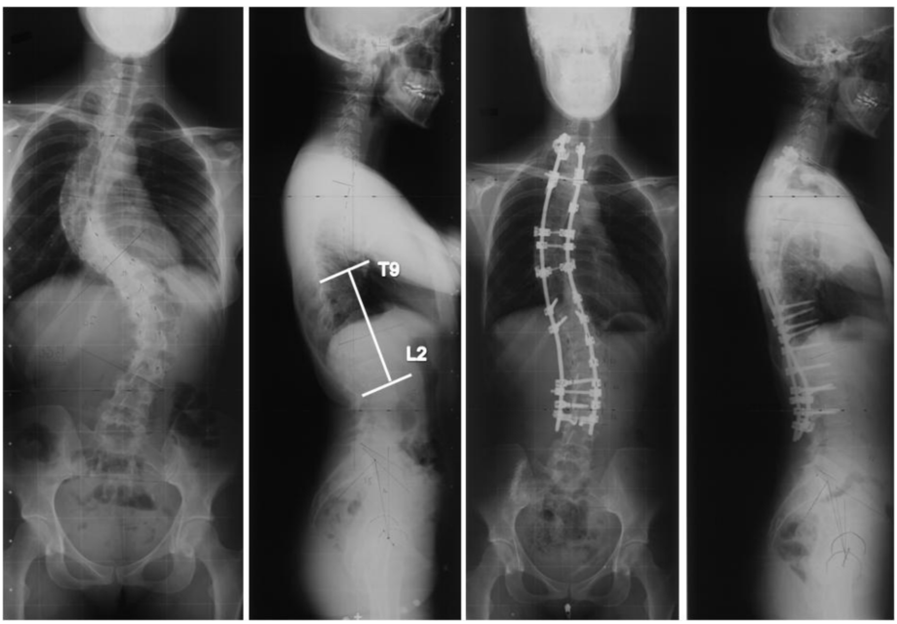

Figure 2. Cranial and caudal prolongation of rectitude in double major curve and postoperative correction

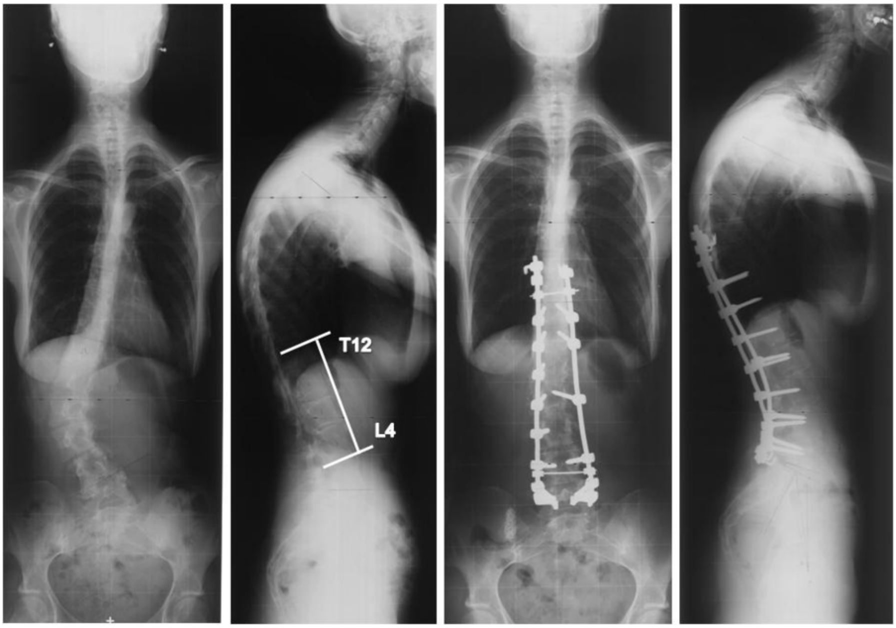

Figure 3. Caudal prolongation of rectitude in lumbar curve and postoperative correction

4. Discussion

The importance of sagittal alignment in thoracic and thoracolumbar curves in adolescent idiopathic scoliosis has been emphasized by Mac-Thiong et al. [8] and by Upasani et al. [9]. Although average values describing the balance between spine and pelvis kept relatively normal in our study, these authors found an increased pelvic incidence in thoracic and thoracolumbar curves compared to healthy adolescents. An abnormal anatomical pelvic configuration may influence the entire sagittal balance of the spine [10] and subsequently play a role in the pathogenesis of adolescent idiopathic scoliosis. Primary thoracic curves are often associated with a thoracic hypokyphosis [8, 9] which may be the result of relative anterior vertebral overgrowth but also a part of the 3D spinal deformity with increased vertebral rotation in this region.

Kotwicki [1] outlined that global thoracic kyphosis measurements could cover hyper- and hypokyphotic zones and suggests differentiating an upper and lower kyphosis. A local hypokyphosis between T9 and T12 and an adjacent hyperkyphosis between T5 and T9 was reported in thoracic scoliosis by the author. This corresponds to the pattern illustrated in Figure 1 in our study. For instance, the apical vertebra of the thoracic curve follows a circular way to the front with increasing deformity which leads to a lower hypokyphosis on the lateral view of the thoracic spine [11]. The same phenomenon applies to lumbar curves, where the apical vertebra follows a circular way to the back which decreases the upper lumbar lordosis. Increased vertebral rotation above or below the thoracolumbar junction leads to a prolongation of the physiological straight zone around T11 to L1.

The three patterns of sagittal rectitude of the thoracolumbar junction that we described are closely related to a frontal curve configuration and to vertebral rotation. These patterns correspond to a geometrical projection of the 3D deformity in the sagittal plane, appearing as a prolongation and zone of rectitude of the physiological thoracolumbar junction: cranially in thoracic curves, caudally in lumbar curves, cranially and caudally in double major or thoracolumbar curves.

In situ bending realizes a stepwise correction of the 3D deformity at different levels by means of alternate medialization in the frontal plane and increase of kyphosis or lordosis in the sagittal plane while derotation is maintained manually [2, 11]. An accurate preoperative analysis and understanding of the spinal deformity at several levels is mandatory to achieve an adequate sagittal balance, frontal curve correction and vertebral derotation simultaneously. The patterns of thoracolumbar rectitude are helpful to analyze the segmental deformity in a more precise manner and to plan surgical correction accurately. The sagittal configuration of the spine determines exact levels, directions and amount of correction using a working rod. The concave working rod is bent progressively in a posterior and medial direction to restore kyphosis, whereas the convex working rod is bent progressively in an anterior and medial direction to restore lordosis.

The thoracolumbar zone of rectitude should be taken into account for a better understanding and the treatment of idiopathic scoliosis. The maximal rotation is localized at the upper end of this straight zone for thoracic curves and at the caudal end for lumbar curves. This zone of rectitude indicates the side of the working rod for surgical reduction by in situ bending, but also for other techniques of posterior spinal deformity correction.

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A 3-D Skeleton Model & SEMG Approach For Integrated Neck And Low Back Pain Analysis Test Batteries

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Abstract. Since several years our group is working on a project to merge into a full 3D reliable and detailed human skeleton representation various segmental biomechanical models presented in literature. The obtained 3D skeleton model is fully parametric and can be fitted to each subject anthropometric characteristics. 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. A special focus has been devoted to identify and model the spine with a correct degree of accuracy and reliability. In spine pain related pathologies is of major importance the evaluation of functional limitations associated. This requires to integrate morphological characteristics with information deriving from other measurements devices as force platform data, surface EMG, foot pressure maps. The aim of this study is to present a multi-factorial approach which integrates rachis morphological characteristics with full skeleton kinematic, dynamic and SEMG measurements to quantify spine function and mobility in particular for neck and low back pain. A set of clinical-biomechanical tests have been implemented. Static posture characteristics are first evaluated. After that, patient is asked to perform specific motion test batteries in order to fully measure the whole ROMs (spine angles ranges and spine shape modifications) for Axial rotations, forward-backward flexion-extension, lateral bendings per each spine functional units (Skull and neck, thoracic and lumbar districts). During forward bending also a digital Schober test is performed. Such data are correlated to simultaneous SEMG muscle activities recording to investigate motor co-ordination/dysfunction as well as the presence absence of flexion-relaxation phenomena associated to pain.

1. Introduction

In spine pain related pathology is of major importance in the evaluation of functional associated limitations. Quantitative functional evaluation represents one of the main goals to achieve in this field and at the same time one of the most challenging problems to treat. Optoelectronic measurement approaches appear to be a potentially significant solution to obtain the necessary functional information. In fact, such an approach is recognized to have great potential for addressing clinical problems in orthopaedics and rehabilitation and the use of stereo-photogrammetry based movement and gait analysis, and their contribution to scientific knowledge, is increasingly being reported in the literature. What is required is a way to measure skeleton movement. The underlying assumption is that the human body can be modelled as a collection of rigid segments connected by ball or hinge joints. Subject-specific models have to be built based upon data (related to specific body landmarks) collected to assess kinematic and dynamic variables of movement. Based on these concepts, our group has undertaken a project aimed to create a complete fully 3D reliable, detailed representation of the different segmental biomechanical models previously in the literature [1,2,3]. The 3D skeleton model is fully parametric and can be fitted to each subject's anthropometric characteristics [4]. Part of the research has focussed on the identification and modelling the spine with accuracy and reliability [5,6]. In addition to kinematic measurements, forces, torques, and electro-muscular activity have to be collected in order to correlate the morphological characteristics with a full functional evaluation. In this case, a multi-factorial approach has been developed to permit simultaneous recording of kinematic data at the same time as information derived from other measurement devices, such as force platforms, surface EMG or baropodographic systems.

In order to properly quantify spinal function, a set of specific motor tasks has to be identified. Movements in the lumbar spine, including flexion and extension, are governed by a complex neuromuscular system involving both active (muscle) and passive components (vertebral bones, intervertebral disks, ligaments, tendons, and fascia) [7,8]. Common among spinal disorders are disruption to the neuromuscular balance and load sharing of the spinal tissues, ultimately resulting in pain and disability [9]. In the assessment of patients with lumbar complaints, measuring the electromyographic (EMG) activity of the trunk musculature is one objective means used by biomechanists and clinicians to assess the function of the lumbar spine. There is evidence to suggest that EMG differences exist between patients with back pain and healthy subjects during dynamic flexion tasks performed at peak flexion [10,11]. Several studies have examined the apparent myoelectric silencing of the low back extensor musculature during manoeuvres such as transition from standing to full trunk flexion or flexion-relaxation phenomenon (FRP). The electrical signal reduction or silence that occurs in healthy subjects during lumbar spine flexion has been hypothesized to represent the extensor musculature being relieved of its moment-supporting role by the passive tissues, particularly the posterior spinal ligaments [12]. Likewise, a failure of the muscles to relax in patients with back problems is indicative of heightened erector spinae resting potentials or underlying back muscle spasticity. Similar phenomena have been documented also in neck pain [13].

The aim of this study is to present a multi-factorial approach which integrates the morphological characteristics of the spine with full skeleton kinematic, dynamic and SEMG measurements, so as to quantify spinal function and mobility, particular in neck and low back pain.

2. Materials and Methods

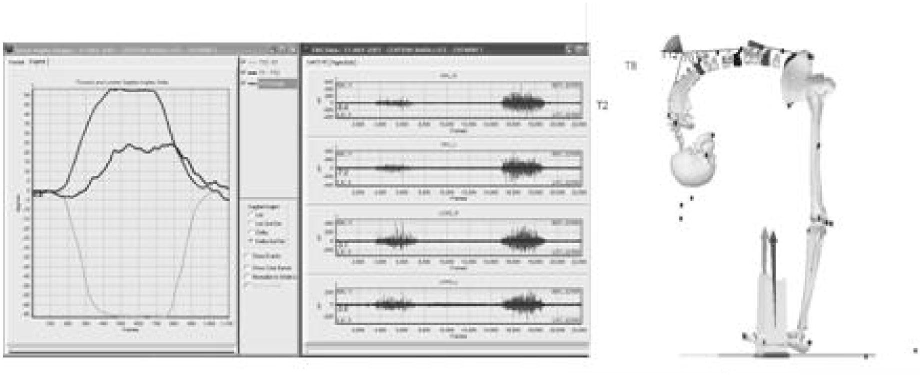
A non-ionising approach based on 3D opto-electronic measurements of body landmarks labelled by passive markers has been chosen to build the 3D parametric biomechanical skeleton model [4,5,6]. The developed model can work at different stages of complexity. That is, depending on different analysis purposes 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. The accuracy and precision of the model relies both on anatomical findings [1,2,3] reported in literature and on the approach and signal processing procedures we largely described

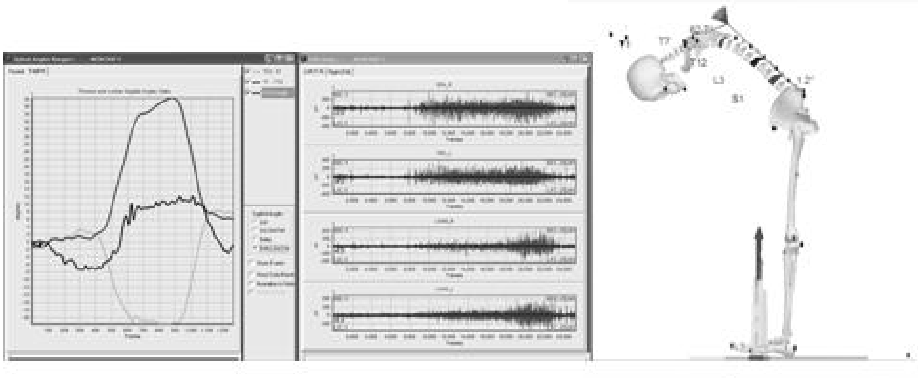
[4,5,6]. To analyse human posture and spinal related pathologies (scoliosis, back pain etc.), a 27 markers protocol has been set and tested extensively in clinical environment [4,6]. Given the focus of the current study on neck and back pain, specific test batteries have been established to evaluate the related postural and spine dysfunction. In this case a further 3 markers set placed on a head band are added to the 27 marker protocol in order to be able to reconstruct head and neck even during a forward bending test. In fact during patient's forward bending execution the three markers placed on the face (zygomatic bones and chin needed to measure the skull pose) usually disappear from TV-cameras field of view. In this case skull pose cannot be identified anymore. To overcome such problem the three added markers placed on the head band are used: during orthostatic posture acquisition, the rigid geometrical relationship occurring between the head band markers and the skull anatomical ones is established. During the forward bending the markers on the head band remain always visible to cameras, thus allowing skull and neck poses reconstruction along all the movement. In the same way also head axial rotations can be evaluated for neck pain patients. A couple of force platforms is used to record forces exerted on the floor (AMTI Inc.- USA). Surface electromyographic activity is recorded by a telemetric system (Aurion Srl - Italy). Following the SENIAM recommendations [14] four channels are used to measure low back pain patients. Multifidus activity is collected by positioning electrodes bilaterally aligned with a line from caudal tip posterior spina iliaca superior to the interspace between L1 and L2 interspace at the level of L5 spinous process (i.e. about 2 - 3 cm from the midline). While Erector Spinae- Longissimus Dorsi activity is recorded by placing electrodes bilaterally at about 2 - 3 cm lateral from the L1 spinous process [14,15]. In neck pain patients, SEMG is recorded on the upper trapezius muscles, and the electrodes are placed bilaterally at 50% on the line from the acromion to the spine on vertebra C7 [14]. If also the underfoot pressure distribution is of interest an in-shoe insole system is adopted (Novel Gmbh - Germany). For both neck and low back pain patients static posture characteristics are first evaluated. After that, patient undergoes a specific motion test batteries.

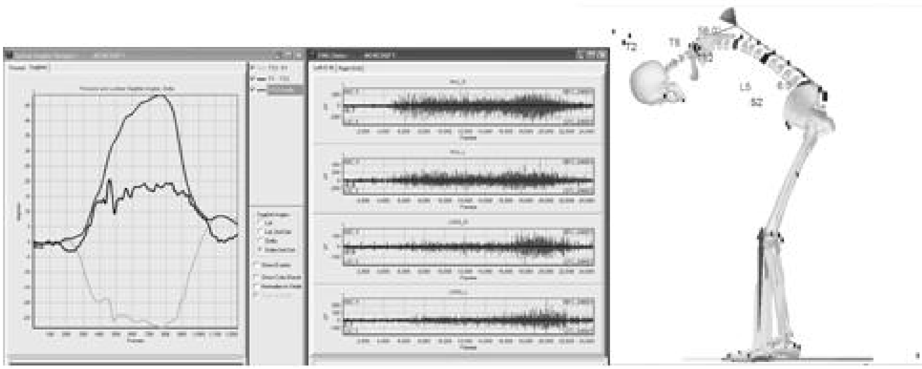
Low back pain patients are asked to perform trunk Axial rotations, forward-backward flexion-extension, lateral bendings. Neck pain patients have to perform head Axial rotations, cervical spine forward-backward flexion-extension and lateral bendings. In this way the whole ROMs (spine angles ranges and spine shape modifications) for each spine functional units (Skull and neck, thoracic and lumbar districts) are measured. During forward bending also a digital Schober test is derived from the marker calculated lumbar spine elongation. From the kinematic and platform acquired data joint net forces and torques are assessed. Such data are correlated to simultaneous SEMG muscle activities recording to investigate motor co-ordination/dysfunction as well as the presence absence of flexion-relaxation phenomena associated to pain.

3. Results

Several studies are currently being carried out by our group about spine and posture disorders with the described methodology. Given the length limit of this paper, only paradigmatic examples from the application of the proposed approach are presented.







Figures 1, 2 and 3. Forward bending results for healthy (fig. 1) and low back pain subject (figs.2 and 3). See text for explanation.

Fig. 1, 2 and 3 describe the execution of a forward bending manoeuvre both by an healthy subject and by an acute phase low-back pain patient. Starting from left to right, the 3 panels of each figure represent: a) the spinal angles ranges (variations with respect to standing posture) in the sagittal plane for the thoracic and lumbar spinal segments measured along the movement together with pelvis tilt; b) the SEMG signals graphs, showing the periods of activation/silence of the trunk muscles taken into consideration; c) the full 3D skeleton reconstruction at the frame of maximum forward flexion. Fig.1 refers to an healthy subject, while figs 2 and 3 refer to a low-back pain patient who performs the same task in two different ways. By analysing the test results, different functional behaviour can be enlightened. As can be noted, the healthy subject presents with respect to the pathological one, both a noticeably wider range of spinal angles and a different pattern showing different strategies in task execution. SEMG in the healthy subject shows clearly the presence of FRP as expected, while low back pain subject shows a full contraction of all the recorded muscles as soon as the forward bending starts, confirming the painful condition associated to this movement. Even when the patient has been let free to perform the forward bending in the less perceived painful way (i.e. with flexed knees), FRP was still absent, while the two angular patterns are only slightly different proving the difficulty in the performance of such task.

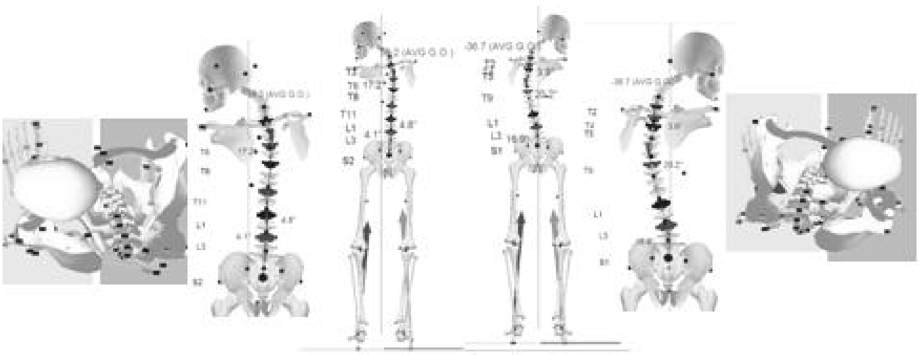


Figure 4. Head and trunk axial rotations.

Figure 4 shows the capability of the3D skeleton reconstruction to describe in a very detailed way postural and spine morphology changes together with full ranges of motion during the performance of head and trunk axial rotation. This is an example of test results in the functional evaluation of neck pain patients.

4. Discussion

From a review of the biomechanical literature relevant to the FRP [7], the presence of the FRP during trunk flexion represents myoelectric silence consistent with increased load sharing of the posterior discoligamentous passive structures of the spine to achieve equilibrium. From the research reviewed, there is clinical significance to the presence or absence of the FRP. A number of studies have shown differences in the FRP between patients with low back pain and healthy individuals, and the reliability of the assessment. Persistent activation of the lumbar erector spinae musculature among patients with back pain represents the body's attempt to stabilize injured or diseased spinal structures thereby protecting them from further injury and avoiding pain.
Our experience confirmed results from previous studies on FRP. The majority of them however concerned only SEMG analysis, while few of them took into account gross spine

segment motion by using electrogoniometers. The peculiarity of the proposed methodology is to perform a true multifactorial approach by joining the full 3D skeleton kinematics to SEMG and force measurements. The easy clinical approach of this procedure suggests its use in routinely clinical evaluation. This quantitative approach can be used in the functional assessment, as a source of information to design a rehabilitation project and as an outcome measure as well. In this way more detailed studies investigating differences into the response of different patient populations, and the effects of different rehabilitation strategies will serve to improve the body of knowledge relevant to the clinical utility of the FRP.

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Analysis of the mechanisms of idiopathic scoliosis progression using finite element simulation

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Abstract. The mechanisms of idiopathic scoliosis progression are still not fully understood. The aim of this study is to explore, using finite element simulation, effect of the combination of gravity and anterior spinal overgrowth on scoliosis progression. 14 adolescents (10 girls, 4 boys) with an average age of 10.8 years [range 9; 13] were divided in three groups: thoraco-lumbar scoliosis (TL), lumbar scoliosis (L), asymptomatic patients (A). Accurate 3D reconstructions of the spine have been built using bi-planar X-rays. A patient specific validated finite element model has been used. Simulations have been launched with simulation of the combined effect of gravity and growth. The progression during the simulation was defined by a maximal axial rotation movement greater or equal than 4° and a maximal lateral displacement greater or equal than 5 mm ("first order progression" for one criterion, "second order" for the both criteria). In the group TL, we notice an aggravation for 4 patients (Cobb angle increase at least by 4°, mean at 5.9°). Only three patients of the group L show a progression with a smaller Cobb angle increase (mean 3.9°). For the group A, no progression is found for 3 and a progression is found for 1. An anterior spinal overgrowth combined with gravity and a pre-existent curve in the spine could lead to a progression of scoliosis. It seems necessary to consider differently lumbar curves from other curves. Numerical simulation with a patient specific model appears as a useful tool to investigate mechanisms of scoliosis aggravation.

Keywords: scoliosis; progression; growth; finite element simulation

1. Introduction

Because of the number of factors involved, the mechanisms of idiopathic scoliosis progression are still not fully understood. These mechanisms are bound both to the nature of the deformation and to the growth process. Particularly the factors that induce the well known torsion phenomenon with vertebral axial rotation, lateral deviation and sagittal extension still remain obscure. The aim of this study is to explore, using finite element simulation, biomechanical mechanisms involved in the progression of scoliosis. We will focus on the combination of gravity and anterior spinal overgrowth.

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2. Materials and methods

Fourteen adolescents (10 girls, 4 boys) with an average age of 10.8 years [9; 13] were divided in three groups: thoraco-lumbar group (TL), lumbar group (L) and asymptomatic group (A) **(Table 1)**.

The group TL is composed of 4 patients (3 girls, 1 boy) who have a thoraco-lumbar scoliosis, with an average age of 10.3 years [range 9.5; 11] and a mean Cobb angle of 13.3° [range 8.8°; 17°]. The group L includes 6 patients (5 girls, 1 boy) who have a lumbar scoliosis. The patients present an average age of 11.3 years [range 9; 13] and a mean Cobb angle of 11.1°[range 3.1°; 18.8°]. The group A is composed of 4 asymptomatic patients (2 girls, 2 boys). The patients present an average age of 10.3 years [range 9; 12].

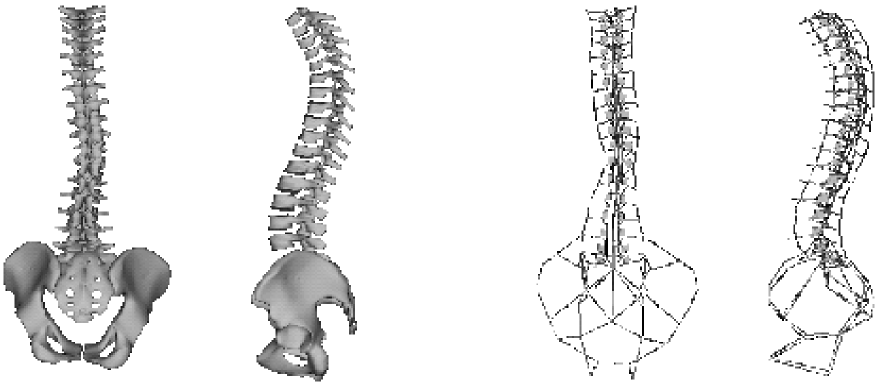
Table1. Clinical data for each patients group

Patient	Group	Age	Sex	Scoliosis		Curvature			Cobb Angle
				Zone	Convexity	UEV	Apex	LEV	(°)
013287_1	TL	11	F	TL	Left	T8	T12	L3	11,4
013489_1	TL	9,5	M	TL	Left	T9	T12	L2	16,1
013421_1	TL	10	F	TL	Right	T7	T10	L2	17,0
993365_1	TL	10,5	F	TL	Left	T7	T12	L2	8,8
020633_1	L	12	F	L	Left	T11	L1	L4	18,8
983341_1	L	12	F	L	Left	T12	L2	L4	3,1
013572_1	L	13	M	L	Left	T11	L1	L3	13,2
013683_1	L	10,5	F	L	Left	T11	L1	L3	8,2
020584_1	L	9	F	L	Left	T11	L2	L4	6,5
963902_1	L	11,5	F	L	Left	T11	L1	L3	16,6
AGT_001	A	12	F	asymptomatic					
AGT_013	A	10	M	asymptomatic					
AGT_014	A	10	F	asymptomatic					
AGT_015	A	9	M	asymptomatic					

TL: thoraco-lumbar; **L:** lumbar; **A:** asymptomatic; **M:** Male; **F:** Female; **UEV:** Upper End Vertebra; **LEV:** Lower End Vertebra

The X-Rays data used for the groups TL and L were performed within routine exams after their first visit for scoliosis. All the patients of groups TL and L present a Risser index of 0. Patients of the group A are involved in a parallel project which was led at the Laboratoire de Biomécanique (with ethics committee approval).

Using bi-planar X-rays and an accurate reconstruction method [1], accurate 3D reconstructions are obtained (Figure 1.a). A patient specific finite element model, which was described and validated in a previous study [2; 3], is built from the reconstructions (Figure 1.b). For each functional unit, a global model is considered. Vertebrae are represented using stiff elastic beams connecting attachment points for discs and ligaments. Surfaces are attached to these beams to represent joint facets, their orientation being defined according to the vertebral level. Ligaments are modelled using tension-only cable elements. The pelvis is taken into account as a quasi-rigid body represented by a set of stiff beams connecting attachment points of iliolumbar ligaments. Discs are modelled using modified beam elements: to take into account the torsional effects of the disc fibers, mechanical properties are set to differentiate behaviour in bending and torsion.



(a) (b)

Figure 1 : 3D Reconstruction (a) & patient specific finite element model (b)

All degrees of freedom of each node modelling the pelvis are blocked. The z-axis translation is free and all others degrees of freedom are blocked for T1. The gravity effect is modelled by a 400N z-axis compression force on T1 vertebral body. The anterior spinal overgrowth is modelled by a 15% z-axis lengthening of each vertebral body (i.e. on each beam modelling each vertebral body) with no specific constraints on the posterior part. For each patient a simulation has been launched with the combined effect of gravity and growth.

The progression during the simulation is defined by a maximal axial rotation movement greater or equal than 4° and a maximal lateral displacement greater or equal than 5 mm. When one criteria is observed, the progression is classified "P1" and "P2" when both criteria are observed. The observations are completed with the modification of the Cobb angle and the T5-T12 kyphosis.

3. Results

Simulations show various results for the subjects (Table 2). In the TL group, we notice a progression for 4 patients on 4.The Cobb angle increases at least by 4° (mean 5.9°). The mean maximal movement for axial rotation and lateral displacement are respectively 4.6° [range 3.0°; 7.3°] and 8.0mm [range 5.7mm; 10.0mm]. Considering the L group, 3 patients on 6 show a progression with a smaller Cobb angle increase (mean 3.9°). For these three patients, the mean maximal movement is 4.8° [range 4.7°; 5.0°] for axial rotation and 4.3mm [range 2.7mm; 5.1mm] for lateral displacement. For the other three patients, these values are 2.5° [range 2.0°; 2.5°] for axial rotation and 2.2mm [range 1.8mm; 2.6mm] for lateral displacement. For the group A, maximal movement is under 3° for the axial rotation and under 5mm for the lateral displacement (for all except one). For all the 14 patients, we notice a decrease of the thoracic kyphosis (mean -7.4°, [range -2.8°; -11.9°]). In some cases the thoracic curve became lordotic.

Table 2. Results of progression finite element simulation

Patient	Group	Maximal vertebral axial rotation movement (°)	Maximal Lateral Displacement Movement (mm)	Kyphosis evolution (°)	Cobb angle evolution (°)	Progression order
013287_1	TL	3,0	7,4	-3,9	5,0	1
013489_1	TL	5,9	8,7	-9,1	7,0	2
013421_1	TL	7,3	10,0	-7,0	7,5	2
993365_1	TL	2,1	5,7	-5,8	4,0	1
020633_1	L	4,7	2,7	-8,5	4,0	1
983341_1	L	2,0	2,6	-11,9	1,2	0
013572_1	L	2,5	1,8	-4,5	2,0	0
013683_1	L	3,0	2,0	-8,8	2,0	0
020584_1	L	4,7	5,1	-5,3	3,0	2
963902_1	L	5,0	5,0	-2,8	4,8	2
AGT_001	A	1,5	4,0	-6,6	-	0
AGT_013	A	1,0	2,5	-8,3	-	0
AGT_014	A	2,5	6,4	-10,3	-	1
AGT_015	A	2,5	4,7	-10,6	-	0

4. Discussion and conclusion

Several authors have investigated the anterior spinal overgrowth leading to scoliosis progression according to the "rotational lordosis" [4; 5].Some have developed this theory by defining the "vicious cycle" [6] based on the asymmetrical growth due to the stress distribution. On this study we focus only on the spinal anterior overgrowth without growth modulation and use finite element simulation to investigate this. Several others studies use numerical simulation to investigate scoliosis progression. Most of them support the "Hueter-Volkmann law" with integration of growth modulation [7; 8]. However some authors have already investigated the "anterior spinal overgrowth by using the finite element simulation. Azegami *et al* investigate the reaction of the spine under different buckling mode inducing by thoracic anterior spinal overgrowth [9]. Goto *et al* investigate the influence of bone modelling on the same buckling mode [10]. Both found that the second bending mode on the sagittal plane due to thoracic anterior spinal overgrowth combined with bone resorption lead to scoliosis and progression.

The results of this preliminary study support this theory. It seems that with some pre-existing deformations anterior growth can explain lateral deviation, axial rotation and Cobb angle progression. This Cobb angle increase could itself yield an asymmetric growth as a secondary effect. However this combination seems not to be an initiating factor on a normal spine, while it could aggravate a pre-existing deformation. Even if the number of subjects is too small to perform statistical tests, initial pattern plays a particular role: TL group seem more likely to progress under our hypothesis than L group. Then, the mechanisms of progression seem to be different in lumbar curves and in thoraco-lumbar ones. An investigation on a larger group of subjects will provide us a better understanding of scoliosis pattern role. Numerical simulation with a patient specific model appears as a useful tool to investigate mechanisms of scoliosis aggravation.

- An anterior spinal overgrowth combined with gravity and a pre-existent curve in the spine could lead to scoliosis progression.
- It seems necessary to consider differently lumbar curves progression mechanisms from other curves.
- Numerical simulation with a patient specific model appears as a useful tool to investigate mechanisms of scoliosis aggravation.

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The Relationship Between Hip Flexion/Extension and the Sagittal Curves of the Spine

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Abstract. The objective of this study was to develop a finite element model (FEM) in order to study the relationship between hip flexion/extension and the sagittal curves of the spine. A previously developed FEM of the spine, rib cage and pelvis personalized to the 3D reconstructed geometry of a patient using biplanar radiographs was adapted to include the lower limbs including muscles. Simulations were performed to determine: the relationship between hip flexion / extension and lumbar lordosis / thoracic kyphosis, the mechanism of transfer between hip flexion / extension and pelvic rotation, and the influence that knee bending, muscle stiffness, and muscle mass have on the degree to which sagittal spinal curves are modified due to lower limb positioning. Preliminary results showed that the model was able to accurately reproduce published results for the modulation of lumbar lordosis due to hip flexion; which proved to linearly decrease 68% at 90° of flexion. Additional simulations showed that the hamstrings and gluteal muscles were responsible for the transmission of hip flexion to pelvic rotation with the legs straight and flexed respectively, and the important influence of knee bending on lordosis modulation during lower limb positioning. The knowledge gained through this study is intended to be used to improve operative patient positioning.

Keywords: surgical positioning, lower limbs, spine, scoliosis, biomechanics, finite element modeling.

1. Introduction

Patient positioning is increasingly being recognized as an important step in spinal surgeries [1,2,3]. One of the most important desired outcomes of spinal instrumentation surgeries is preservation / restoration of sagittal balance [4], which can improve long term fusion results [5,6]. The relationship between hip flexion and lumbar lordosis has been studied by Stephen et al. [7] on the Andrews frame and Befanti et al. [8] on the Wilson frame who concluded that that hip flexion results in a loss of lumbar lordosis and that the correlation between the two is subject to inter-patient variability. As a general rule hips should not be flexed greater than 30° in order to maintain sufficient lumbar lordosis to avoid flat back symptoms. The influence of lower limb positioning on thoracic kyphosis has received little attention. The mechanism of transfer between lower limb positioning and resulting geometrical changes to the spine has not been properly defined. Stokes et al. [9] have reported on the influence of the hamstring muscles on lumbar lordosis in sitting while others have reported on the possible contribution of the gluteal muscles with knees flexed [10]. Finite element modeling (FEM) has been previously used to study the impact of patient positioning on the geometry of the vertebral column. Duke et al.[2] looked at the impact of dynamic positioning parameters on the geometry of the vertebral column using a FEM, the impact of lower limb positioning was approximated through the modulation of pelvic inclination +/- 15°.

Our overall objective is to develop a patient-specific FEM which is able to simulate the impact of lower limb positioning on the geometry of the spine. It is hypothesized that manipulation of lower limb position, hip and knee flexion/extension, can significantly impact lumbar lordosis and thoracic kyphosis. It is also hypothesized that the mechanism of transfer between lower limb positioning and pelvic angle modulation includes both the hamstring and gluteal muscles groups and is dependent on the degree of knee flexion. The specific objectives of this pilot study were to use the developed FEM to analyze the relationship between hip flexion/extension and the sagittal curves of the spine.

2. Materials and Methods

A previously developed simplified global beam FEM of the spine, rib cage and pelvis [11] which uses a biplanar reconstruction technique [12] to obtain patient specific geometry was adapted to include the lower limbs. Complementary detailed geometry of the femur, tibia, and fibula was taken from Visible Human Project (VHP) data with scaling based on anthropological equations factoring height and sex13. A total of 31 muscles per leg were modeled with origins and insertions obtained by mapping of the coordinates defined by White et al. [14]. Lower limb muscle cross-sectional data and material properties were taken from literature [15,16]. Hip and knee joints were represented as well as ligaments. In all, the model contains 1790 nodes and 1247 elements (Figure 1).

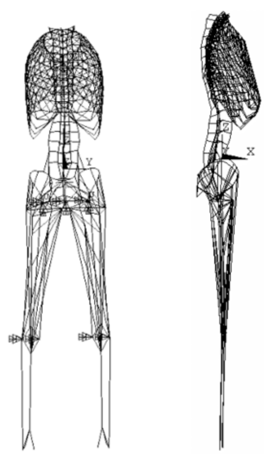

Figure 1 - Frontal and Lateral Views of the FEM developed

Simulations were performed in order to evaluate the model's ability to reproduce published results for loss of lumbar lordosis due to hip flexion [5,6]. The geometric reconstruction of a healthy young male subject taken from the databases at Sainte-Justine University Hospital measuring 150 cm with an initial L1-S1 lordosis of 44° and a T4-T12 kyphosis of 31° was used for this and subsequent simulations. Hamstring muscle initial strains were uniformly adjusted such that the percent loss of lumbar lordosis obtained through FEM simulations matched the average results obtained by Befanti et al [6] for 30° of hip flexion. These conditions were maintained and additional simulations performed for 60° and 90° hip flexion with the results compared to the averages obtained by Stephen et al.5 in similar conditions.

A sensitivity study was performed in order to determine the relative impact that hamstring muscle initial strain (representing flexibility), cross-sectional area, and elastic modulus have on the degree to which hip flexion impacts the sagittal profile of the spine. 30° hip flexion simulations were performed while varying hamstring muscle initial strain 0-10%, doubling and halving cross-sectional area baseline values, and elastic modulus +/- 50% their baseline value.

In order to evaluate the muscles responsible for transmission of lower limb positioning to pelvic rotation and the impact of knee flexion on this relationship, hip flexion / extension simulations were performed, over their respective ranges of motion [17], at intervals of 20° while maintaining the knees different degrees of flexion 0°, 30°, 60°, and 90°. In each case, the resultant impacts on lordosis, kyphosis, and lower limb muscle strains were recorded. Muscles with strains exceeding their initial strain were considered stretched and to contribute passively to the transfer of lower limb positioning to pelvic rotation.

3. Results

The results of the model validation based on published references are outlined in Table 1. They were obtained for a uniform hamstring initial strain of 4%.

	L1-S1 Lumbar Lordosis	
Hip Flexion	Simulated Results	Published values[5,6]
30°	33°	33°
60°	24°	23°
90°	14°	15°

Table 1 - Validation of the relationship between hip flexion and loss of lumbar lordosis

The sensitivity study demonstrated that the most influential factor impacting the degree to which hip flexion impacts the sagittal profile of the spine is muscle flexibility; a 5% increase in hamstring initial strain caused an additional 9% reduction of lordosis at 30° of hip flexion. The impacts of muscle cross-sectional area and elastic modulus were less important; doubling cross-sectional area and elastic modulus respectively caused an additional 4% and 6% loss of lumbar lordosis.

The muscles found to be responsible for the transmission of straight leg hip flexion to pelvic rotation were the hamstrings (semimembranosus, biceps femoris long head). Once knee flexion reached approximately 60°, the gluteals (gluteus medius) started increasingly contributing. The primary muscles responsible for the transmission of hip extension to pelvic rotation are the anterior thigh muscles (rectus femoris, satorius, vastus medialis, tensor fasciae latae) up until the maximum hip range of motion. The degree of knee flexion (0° to 90°) for 30° hip flexion simulations contributed to additional modification of lordosis of 14%.

The impact of lower limb positioning (90° of flexion to 30° of extension, while maintaining the knees at 30° of flexion) on lordosis (L) and kyphosis (K) is outlined in Figure 2.

4. Discussion

One aspect of the model, which remains to be validated, is its ability to accurately reproduce the impact of hip extension on spinal geometry. Since no literary data was available, anterior thigh muscles were given the same initial strain determined for thehamstring muscles. Due to the nature of beam FEMs not all origin and insertion coordinates coincided with an anatomical representation, specifically with regards to the un-represented ilium, and had to be translated to the nearest available element. However, this factor was assumed to negligibly impact the results as the translation distances did not exceed 4 cm. Also it is important to note that only passive contribution of the lower limb muscles was considered as once a patient is place on a surgical frame, the current position can be maintained and variations to the lower limb position can be made without inducing voluntary or involuntary muscular contractions. In addition with any spinal surgical procedures, the patient is under general anaesthesia.

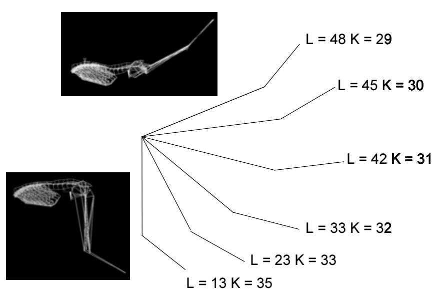

Figure 2 - Impact of Lower Limb Positioning

The results obtained for the mechanism of transfer between hip flexion and pelvic rotation is in agreement with those proposed in literature. This study was able to show which muscles of the hamstring and gluteal groups are responsible for this transmission and at what degree of knee flexion does the transmission from the hamstrings to gluteals take place.

The inter-patient variability found in literature with regards to lumbar lordosis modulation with hip flexion can be attributed to individual lower limb flexibilities. It is proposed that any attempt made to predict patient specific modulation of spinal geometry due to lower limb positioning incorporate clinical flexibility testing data into personalized FEMs.

5. Conclusion

The FEM developed has shown good agreement with published results in its ability to reproduce the impact of lower limb positioning on spinal geometry in a patient-specific manner. Its preliminary exploitation has allowed for a more detailed study of the mechanisms of transfer and influential factors between lower limb positioning and spinal geometry than has been previously reported in literature. It is believed that the use of surgical frames which allow lower limb positioning in conjunction with knowledge of how lower limb positioning impacts patient specific spinal geometry can be used in order to facilitate an improve upon current operating procedures.

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Constrained Intensity-based Image Registration: Application to Aligning Human Back Images

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Abstract. In this work, an accurate method to register multi-view images of the human torso is developed. In particular, a new framework that incorporates prior statistical knowledge about the registration is developed and tested. This framework leads to a computationally efficient procedure to accurately align images of the human torso. An intensity based image registration procedure is used to obtain the deformation fields by modelling them as both locally affine and globally smooth. Next, the estimated geometric deformation fields are analyzed in order to construct a prior deformation model. Two subspace analysis projection techniques are used to construct the subspaces of plausible deformations, namely principal component analysis (PCA) and independent component analysis (ICA). Accurate deformations are now guaranteed by projecting the locally computed geometric transformations onto the subspaces of plausible deformations. The proposed registration method was validated using high resolution images of the human torso. In order to handle the high resolution images, a multi-resolution framework was employed in the registration process. Experiments demonstrate promising performance in terms of mean square error and in the computational complexity. The main contribution of this work is the development of image registration method that uses subspace constraints to align images of the human torso. This method did not use the intra and inter image constraints used in most intensity based image registration algorithms in the literature.

Keywords: Intensity Image Registration, Independent Component Analysis, Human Torso

1. Introduction

Image registration is a key component in many computer vision applications. The aim of registration is to overlay two or more images taken from different viewpoints, at different time instances, or by different modalities [1]. In particular, the main goal of image registration is to determine the spatial deformation, i.e. the geometric transformation, which relates images to be aligned [2]. Models of mapping functions can be divided into two main categories, global and local mapping models. The global models generate warping functions which are valid for the whole image. On the other hand local models treat images as a composition of patches and compute the transformation for each patch separately [3]. Recent approaches impose smoothness constraints on the local patches to guarantee the accuracy of the registration process [4].

In this work, a method that generates smooth deformation fields based on the idea of subspace representation is developed. The subspaces of plausible deformation fields are generated using either principal component analysis (PCA) or independent component analysis (ICA). The final deformation field is approximated using a linear combination of the bases of either subspace. The subspace constraints proposed in this paper will replace the intra and inter image constraints used in image registration. the developed method is tested on images of the human torso.

2. Methods

The proposed method can be intuitively subdivided into three steps. First, an optical flow based image registration is used due to its potential to match featureless smooth objects. Second, statistical prior knowledge about the deformation is constructed using subspace learning approaches. Third, the constructed prior knowledge is embedded into the registration process in order to guarantee the smoothness and accuracy of the deformation fields.

2.1. Optical flow based image registration

The goal of image registration is to determine an optimal warping function that maps image pixels in the source image onto their equivalents in the target image. In optical flow based image registration, a differential framework is used to match the source and target images [5]. The following quadratic error function is minimized in order to get an accurate alignment.

$$E(\bar{u}) = \sum_{x \in v} \left(f_t(\bar{x}) - f_s(\bar{u}^T \bar{x}) \right)^2 \tag{1}$$

Where f_s and f_t are the pair of images to be registered, $\bar{u}$ is the deformation field computed in local image neighborhood v. This function could be slightly modified to handle brightness and contrast variations in the images to be registered. Moreover, the minimization process is simplified by using a first order truncated Taylor serious expansion. This will lead to a close form solution to the local deformation estimation. The error resulting after using Taylor approximation could be minimized by adopting a multiresolution framework. The estimated deformation at the coarsest resolution level is used to initialize the warps at the next finer levels. The constraints used in [4] ensure smoothness by minimizing the absolute gradient of the deformation flows.

Unfortunately, these smoothness constraints will yield to poor flow estimation at edges and object boundaries. Moreover, it will result in nonanalytical minimization procedures, and thus intensify the computational complexity of the registration process [2].

2.2. Construction of prior deformation knowledge using subspace learning

Constructing a statistical model for a class of deformations requires a training set of transformation fields. Since training is an offline process, the computationally expensive and robust elastic image registration technique proposed by Periaswamy [4] will be used to generate a training set of deformation fields. These fields will then be used to generate the training ensembles D_h and D_v, for the horizontal and vertical components of the deformation map respectively. Each column in D_h will be obtained by scanning the horizontal components of the deformation field in a lexicographic order. Practically the mean deformation is subtracted from the columns of D_h. The same process will be done for the vertical components D_v. In order to construct the subspaces of plausible deformations two methods for deformation representation will be used principal component analysis (PCA) and independent component analysis (ICA).

2.2.1. Deformation representation using Principal component analysis

In the first approach, principal component analysis (PCA) [6] will be used to compute a lower dimensional subspace of smooth deformation fields. The goal of PCA is to find a set of orthonormal bases pointing to the direction of maximum covariance in the data. These bases are the eigenvectors of the covariance matrix. This approach is not feasible due to the high dimensionality of the deformation field. Another approach is done by computing the singular value decomposition (SVD) of D in order to obtain the principle deformations as shown in equation 2.

$$D = B \Sigma H^T \tag{2}$$

Where B is an $s \; X \; n$ matrix (s is the size of the deformation image and n is the number of deformation maps used in the training) whose columns are the orthonormal deformation bases, and Σ is an nXn diagonal matrix that contains the singular values, sorted in a decreasing order. H^T is an nXn orthogonal matrix [7]. These deformation bases will be referred to as the EigenWarps.

2.2.2. Deformation representation using independent component analysis

The second approach to generate the deformation basis is to use independent component analysis (ICA). ICA was originally proposed in blind source separation applications to recover M source signals, $s_1 \ldots s_M$, after linearly mixed into $x_1 \ldots x_M$ using the relation in equation 3. Minimum amount of information about the sources and the mixing matrix A should be used to solve equation 3 [8].

$$X = AS \tag{3}$$

In order to define an independent component representation of the transformation warps, a statistical model will be formulated where the fields are considered as observations and the value of the deformation at each pixel as random variables. The target is to generate a factorial code representation consisted of the independent coefficients U for the linear combination of basis warps. The objective of ICA training is to find the de-mixing matrix $W=A^{-1}$ that makes the coefficients U, where $U=WX$, as independent as possible [9].

In this work, the used approach for independent component analysis is based on finding the vectors which maximize the nongaussianity of the mixture [10]. Approximations of the negentropy are used to measure the nongaussianity.

2.3. Smoothing using subspace approximation

After generating the basis functions, smooth thus accurate deformation fields will be generated by approximating the fields as linear combinations of the predefined deformation basis. These deformation bases are either the EigenWarps, which is based on PCA or the factorial codes which is based on the ICA. The correspondence of the Principal component- EigenWarps with the Independent factorial codes is direct. While the principal component coefficients constitute an uncorrelated deformation code, the independent component coefficients constitute an independent code. Moreover, since the constraint of orthogonality is released in independent component analysis, it has the ability to pick both local and global features in the images.

3. Experiments and results

For our experiments, images from volunteers from university of Alberta in addition to images captured for cast model for the human torso were taken. The training set contains 25 image pairs. The testing was done using a set containing 12 image pairs. Different pairs were used for testing. Figure 1 shows samples of the images used in the experiments.

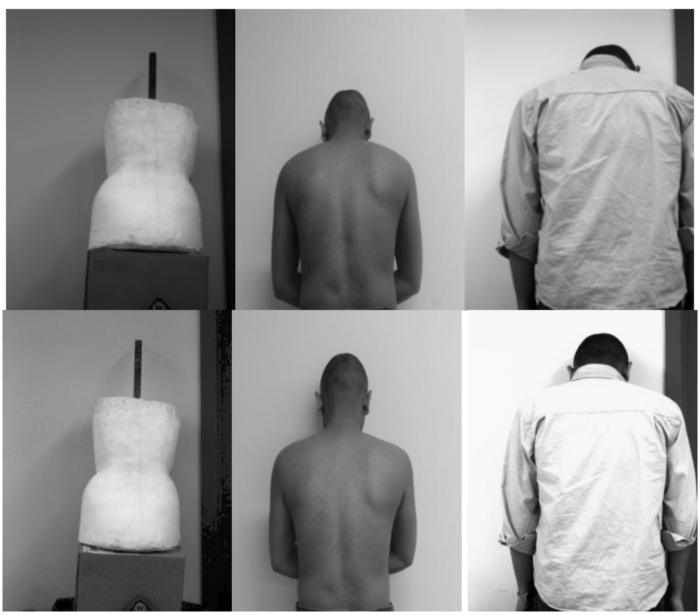

Figure 1. Sample of the multiview pairs used in the experiments

In the training phase, transformation maps D are obtained using the elastic image registration proposed by Periaswamy et al in [4]. Next, subspaces of allowable geometric transformation are obtained using either PCA or ICA. The basis warps are separately calculated for the horizontal and vertical fields then merged to calculate the final deformation field.

Figure 2 depicts a block diagram of the proposed constrained image registration framework. To register a new pair of images, first a three level Gaussian pyramid is built for both the source and target images. The image pair at the coarsest level is then aligned to obtain an initial estimate for the deformation field. This is used to pre-align the image pair at the next finer level. And at each scale the deformation is estimated locally using the procedure explained in section 2.3, then projected onto the subspace of allowable warps to impose smoothness in the estimated flows.

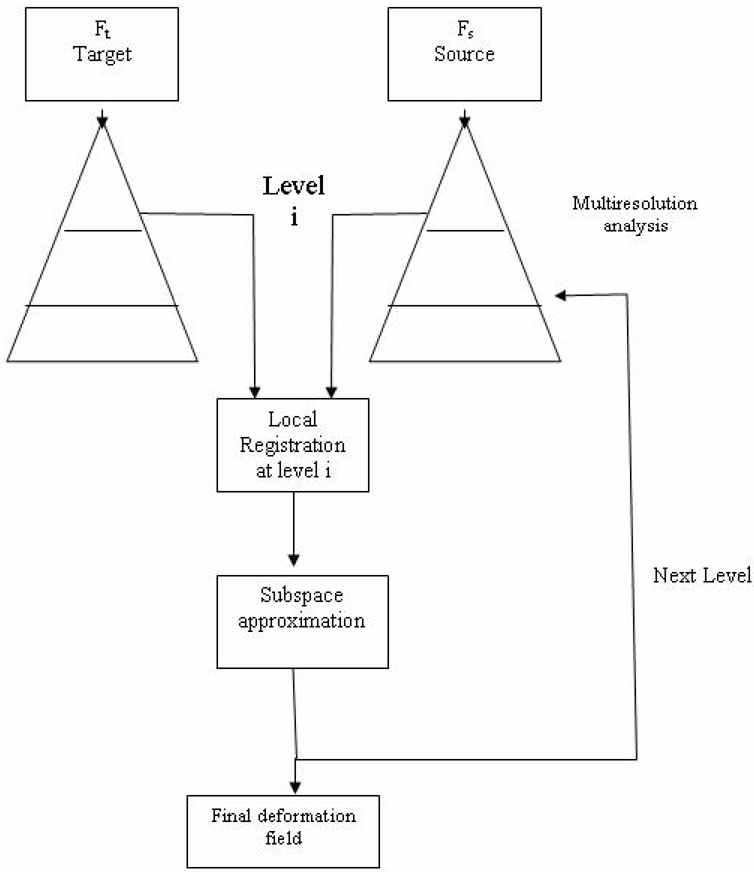

Figure 2. Block diagram for the proposed image registration framework

The performance of the proposed frameworks, in-terms of root mean square error (RMSE), for the used database is shown in figure 3. The results show reduction in the root mean square error when compared to the elastic registration algorithm presented in [4]. Moreover, the reduction of the computational complexity is measured using the improvement in the CPU time, i.e. the amount of time used by a computer program in processing central processing unit (CPU) instructions. Figure 4 shows an average of 62% reduction of the computational time when using the prior knowledge to replace the inter-image smoothness constraints used in most intensity based image registration.

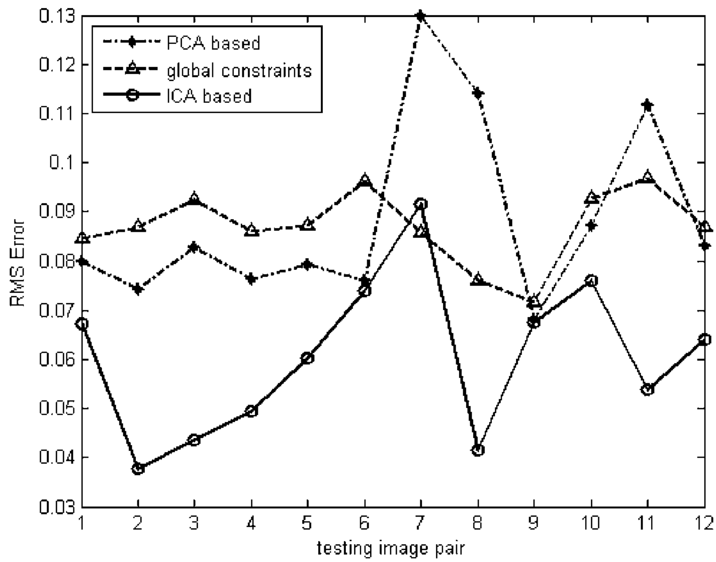

Figure 3. RMSE for the proposed framework and the global constraints system.

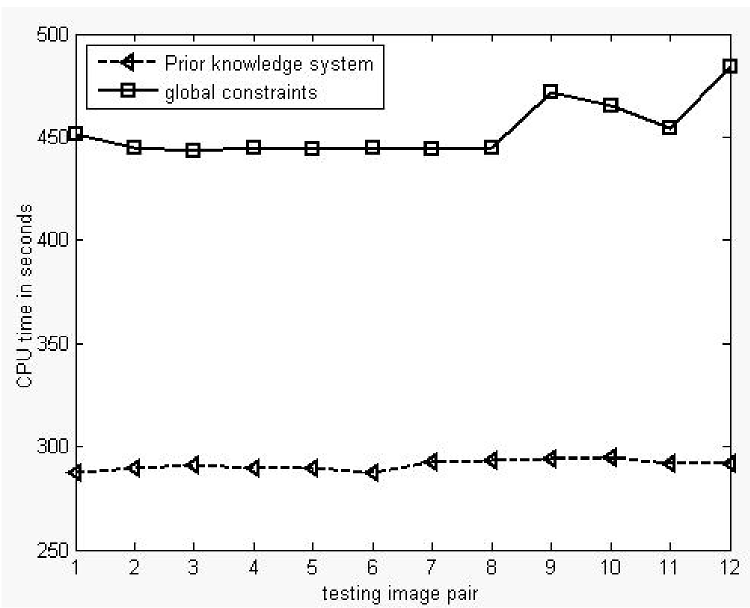

Figure 4. CPU time for the proposed and the global constraints system.

4. Conclusion

A new framework that incorporates prior deformation knowledge in the registration process has been developed and tested. A smooth deformation is now guaranteed by approximating the locally calculated deformation using a combination of the bases of allowed deformations. One advantage of the proposed approach is in its ability to guarantee smoothness without the need for lengthy regularization procedures. The new algorithms were validated using images high resolution images for the human torso.

Two subspace analysis methods have been tested. Comparisons of the proposed framework with a recent, accurate algorithm in literature show reduction in the root mean square error. Moreover, experiments show that using independent components outperform orthogonal components in approximating the deformation warps; this was due to their ability to efficiently capture both global and local deformations. The experiments also show reduction in the computational time.

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Ergonomically designed kneeling chairs are they worth it? : Comparison of sagittal lumbar curvature in two different seating postures

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Abstract. General agreement among researchers suggests that poor seating posture may predispose individuals to developing low back pain. A variety of methods such as ergonomically designed chairs have been developed to assist people to maintain good posture and preserve the 'natural' lumbar curve. The aim of this study was to compare lumbar curvature on an ergonomically designed kneeling chair (EKC) with that on a standard computer chair (SCC), with reference to the standing lumbar curvature. The study used a repeated measures, within-subjects design. A convenience sample of twenty participants was recruited aged 18-35 (9 male and 11 female). Lumbar curvature was measured using the 'Middlesbrough Integrated Assessment System' (MIDAS) postural assessment tool in three different postures; sitting on a SCC, sitting on an EKC set at $+20^0$ inclination and standing as the reference measurement. Results were analysed by a repeated measures one-way ANOVA (1 factor) with 3 levels followed by the Bonferroni post hoc test. The results showed a statistically significant difference between standing lumbar curvature and lumbar curvature produced by both of the chairs ($p<0.05$). There was also a statistically significant difference between the two seated positions ($p<0.05$). This study suggests that ergonomically designed kneeling chairs set at $+20^0$ inclination do maintain standing lumbar curvature to a greater extent than sitting on a standard computer chair with an overall mean difference of 7.633^0. Further research with a greater number of subjects and on different chair designs is warranted.

Keywords. Posture, Lumbar Lordosis, Ergonomics, Physiotherapy

1. Background

Back pain is one of the most common pain complaints in modern society [1]. Lifetime prevalence ranges from 60 - 90% [2]. Throughout the course of one year it is estimated that 40% of the population will experience an incident of low back pain and between 15 - 20% are experiencing some form of back pain at any given time. According to Drezner [2], low back pain is second only to the common cold as a cause for primary care visits and direct medical costs increase year after year [3]. Gray and Maniadakis, estimated that in 1998 alone the direct health care costs of low back pain totaled £1,632 million [3].

Sitting is a posture in which the body's weight is transferred through the ischial tuberosities and surrounding soft tissues of the buttocks and the thighs to the seat of a chair. A flexed seated posture is one that reverses an individuals (normally lordotic) lumbar curve into a kyphotic position [4]. An extended sitting posture encourages or maintains the lumbar curve close to that of an individual's lordotic standing posture [5].

SCCs typically produce a trunk-thigh angle of 90° or less [5]. When moving from standing to unsupported sitting, the lumbar lordosis decreases by on average 38° [3] or up to 85% [6]. Design of the EKC encourages good posture by sliding the hips forward and aligning the back, shoulders and neck. The chair has a forward slanting seat that leads to a more 'natural' position for the spine [7][8]. A previous study by Frey and Tecklins [8] concluded that the BMC (Westnofa Balans® Multi-Chair), set at +20°, maintained lumbar curvature to a greater extent than the SCC. If the EKC can be shown to correct poor posture (increase lumbar lordosis) then physical therapists could recommend it to improve posture and decrease the incidence of low back pain.

2. Methodology

2.1. Participants

The sample population consisted of a convenience sample of twenty University of Teesside physiotherapy Students. (9 males and 11 females). The age of the participants ranged from 20 – 27 years of age. Participants were excluded from the study if they had a history of recurring back pain or if they had a known allergy to the self-adhesive stickers used for surface marking.

2.2. Equipment

The low-cost, portable 3-D mechanical digitizer Microscribe 3DX, Immersion Corp Ltd, also referred to as the 'MIDAS System' – i.e. 'Middlesbrough Integrated Assessment System' [9][10] was used to assess lumbar curvature.

Figure 1. Standard computer chair (SCC) backrest removed.

Figure 2. Ergonomic kneeling chair (EKC).

2.3. Procedure

Anatomical landmarks on the participant's backs were palpated and identified with self-adhesive stickers. The Posterior Superior Iliac Crest (P.S.I.S) was palpated followed by all the lumbar spinous processes. The curvature of the lumbar spine was measured on each participant in three different positions; 1) when standing, 2) when sitting on a SCC, with the back rest removed, and 3) when sat on an EKC. The backrest was removed from the SCC to allow the researcher to easily touch the surface markings with the stylus tip of the MIDAS system. The EKC was adjusted so that the seat was inclined at +20°, the SCC seat was adjusted to be of an equivalent height from the ground. Data was collected by touching the MIDAS stylus tip on each of the marked points, in the following order L1, L2, L3, L4, and L5, left P.S.I.S and finally right P.S.I.S for each of the three postures. All measurements were taken during one session to reduce the probability of variations in posture.

3. Results

The data was analysed using SPSS (Statistical Package for Social Sciences) version 13.0 for Windows. The minimum, maximum and mean lumbar curvature for the three postures are shown in table 1.0. A repeated measures one way ANOVA (1 factor) with 3 levels followed by a post-hoc Bonferroni test was used to determine whether the results were statistically significant. A large mean difference in the lumbar curvature was found between standing and sitting on the SCC (24.232°) and standing and sitting on the EKC (16.599°) (See table 2.0). Comparison of the subject's lumbar curvature in each chair revealed a mean difference of 7.633° (See table 2.0).

Posture	N	Min (Degree)	Max (Degree)	Mean (Degree)	Std Dev
STOOD	20	-77.49	16.98	-21.5882	23.90013
SCC	20	-8.39	16.82	2.6438	6.09663
EKC	20	-18.11	4.17	-4.9893	7.13743

Table 1.0 Minimum, Maximum and Mean lumbar curvature for the three postures.

Postures			Mean Diff (Degree)	Std. Error	p value
STOOD	vs	SCC	-24.232	5.595	0.000
SCC	vs	EKC	7.633	1.409	0.000
EKC	vs	STOOD	-16.599	5.253	0.005

Table 2.0 Mean difference and p values for the three postures.

4 Conclusion

The aim of this study was to determine if there was a statistically significant difference in the lumbar curve produced by sitting on two different chairs (ergonomic kneeling chair, set at +20° inclination, and standard computer chair, with the back rest removed) when compared to standing. Analysis of the data showed a statistically significant difference between standing and the two seated positions (STOOD/SCC $p = 0.000$ and STOOD/EKC $p = 0.005$), and there was a statistically significant difference between the two seated positions themselves (SCC/EKC $p = 0.000$).

The mean lumbar curvature for the standard computer chair was 2.6438°, whilst the mean curvature for the EKC was -4.9893°. Although the EKC lumbar curvature did more closely approximate to that observed in standing (-21.5882°) the angular difference between the two seated postures whilst statistically significant different was fairly small and it is unclear whether this is sufficiently large enough to produce any tangible benefits.

Future research is required to expand, and attempt to understand, the topic fully. The current research found a slightly closer approximation to the standing lumbar curvature when sitting on an EKC, with the seat inclined to +20°, than when sitting on a SCC.

It is suggested that investigating the effect of increasing the inclination of the seat on the EKC to +25° could expand this research.

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Faulty Posture and Style of Life in Young Adults

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Abstract. Study was aimed to determine the incidence of postural faults, level of physical activity and their possible relationship in young adults. Material included 100 subjects recruited randomly among students of Medical University of Silesia (54F aged 20-28, mean=22.9, SD=2.11 and 46M aged 20-29, mean=25.1, SD=1.86). Posture was examined according to modified Klapp protocol. For thoracic kyphosis and lumbar lordosis, values of 30°±2 were considered as normal. ATR exceeding 5° was considered as scoliosis. Physical activity was evaluated with a questionnaire, admitting 1 point for each hour of physical labour and 2 points for each hour of sport activity per week. Statistical analysis was based on the one-way ANOVA test. Postural faults were widespread in assessed group. Most common was lumbar hypolordosis (71.0%, 48.1%F and 97.8%M) and thoracic hyperkyphosis (58.0%, 53.7%F and 63.0%M). Scoliosis was observed in 54.0% (50%F and 58.7%M). Physical activity in assessed group was high, with 71% of cases (76%F and 62.5%M) within range of mean value ± 1SD. Level of activity in men was significantly higher than women (mean 20.25 vs. 6.28 points, $p<0.05$). Significant dependence of postural faults and physical activity was not observed. Conclusions: Young adults prefer active way of life. Postural faults are widespread among young adults. Correlation between level of physical activity and postural faults was not observed.

Keywords: faulty posture, physical activity, style of life

1. Introduction

Good posture reflects health and harmony in the body build. Posturogenesis – the course of development of the posture – proceeds throughout the entire times of ontogenesis, with critical periods at school age and puberty. Posturogenesis envelops growth of the chest, shaping of sagittal curvatures of the vertebral column, development of the pelvis and limbs. Also mature individuals come under postural changes till the wane of life. The end of pubertal period comes together with setting of a definite frame of a posture for individual subject. Such a condition, when the posture remains stable, should last for next over a dozen years. Again, in the middle of a fourth decade, posture can change. Involutional changes supervene especially in sagittal plane, regarding predominantly increase of sagittal curvatures of the spine [1,2,3,4].

The posture is determined both by inborn and acquired factors. Considerable effect on posture exerts general condition of health, welfare, nature of occupational activity and the style of life. Physical activity is considered to cause favourable changes in all body systems of organs, including in particular musculo-skeletal system. Physical training improves elementary motor attributes like strength, speed, flexibility and resilience. Methodical motor activity results in straight, slim shape, better musculature, resilient gait, better physical efficiency and general wellness [2,3,5,6,7].

2. Aim of the study

Study was aimed at the incidence of postural faults, level of physical activity and their possible relationship in young adults.

3. Material and methods

Study included 100 subjects recruited randomly among students of Medical University of Silesia (54F aged 20-28, mean=22.9, SD=2.11 and 46M aged 20-29, mean=25.1, SD=1.86).

Posture was examined according to modified Klapp protocol. Sagittal curvatures were measured by Rippstein plurimeter. For thoracic kyphosis and lumbar lordosis, values of 30°±2 were considered as normal. Angle of trunk rotation (ATR) was measured by Bunnel scoliometer during forward bend test. ATR exceeding 5° was considered as scoliosis. Physical activity was evaluated with a proprietary questionnaire, admitting 1 point for each hour of physical labour and 2 points for each hour of sport activity per week. Statistical analysis was based on the one-way ANOVA test.

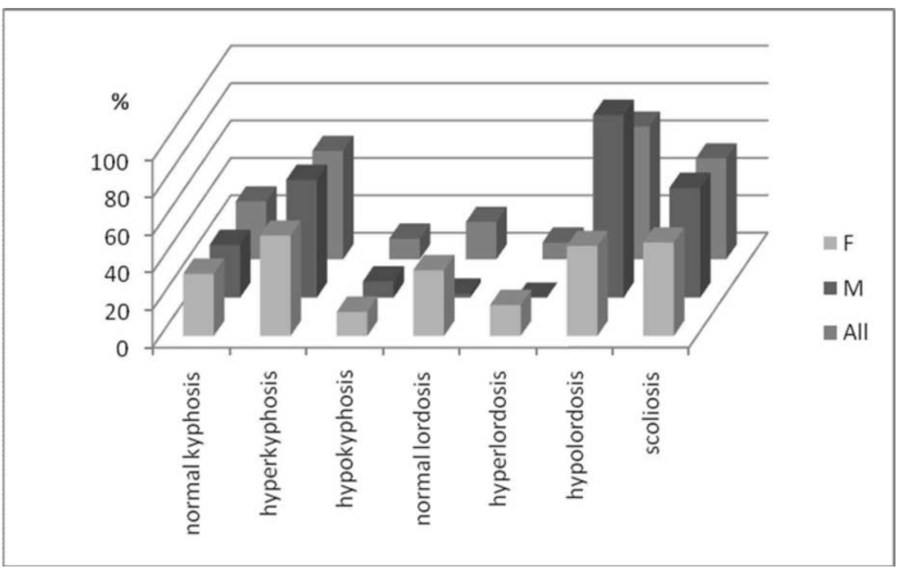

Figure 1. The incidence of postural faults and scoliosis in assessed group.

4. Results

Physical activity in assessed group should be described as high. 71% of subjects (76%F and 62.5%M) fall within range of calculated mean value ± 1SD. Average level of physical activity in men at 20.25 points was significantly higher than that of women at only 6.28 points ($p<0.05$).

Postural faults were widespread in assessed group. Most common was lumbar hypolordosis (71.0%, 48.1%F and 97.8%M) and thoracic hyperkyphosis (58.0%, 53.7%F and 63.0%M).

Scoliosis was observed in 54.0% of subjects (50%F and 58.7%M). The incidence of postural faults and scoliosis is presented on Figure 1.

Significant dependence of postural faults and physical activity was not observed.

5. Discussion

Review of the literature did not reveal similar surveys conveyed on comparable group. Current study shows that, apart from very high average physical activity in men, entire assessed group presented prevalently mediocre to high physical activity.

Postural faults were very common in examined group. Most faults were related to sagittal plane of the vertebral column. This finding may prompt to reconsider the norms for angle values for sagittal curvatures. However, scoliosis was found in little less percentage, exceeding 50% as well. Such an observation may testify the statement of common occurrence of postural faults in observed young adults.

Significant dependence between postural faults and level of physical activity was not observed in assessed group. Review of the literature shows disparate observations regarding sport training and its influence on the posture, but usually indicates some kind of relationship, rather than total lack of correlation [8,9,10,11].

The negative outcome of present study may have several reasons. Assessed group could be inconsistent and too small. The level of physical activity was determined on the basis of subjective and arbitrary method. The difference between the level of physical activity of men and women was substantial and could also affect observations. Perfect condition for such a study would be a prospective survey of abundant group in subsequent stages of development, from early childhood throughout the period of puberty till the adulthood, considering all significant changes in posture and objective methods of parallel measurement of physical activity.

6. Conclusions

1. Young adults prefer active way of life.
2. Postural faults are widespread among young adults.
3. Correlation between level of physical activity and postural faults was not observed.

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Finite element modeling of vertebral body stapling applied for the correction of idiopathic scoliosis: preliminary results

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Abstract. Endoscopic vertebral body stapling is an innovative technique intended to treat adolescent idiopathic scoliosis, but the optimal instrumentation design is not yet established. The objective was to simulate the immediate correction obtained from two stapling configurations. A parametric finite element model of a typical right thoracic scoliotic spine (Cobb 21°) was developed using geometrical and mechanical data from the literature. Staple insertion and closing were modeled. The intra-operative lateral decubitus and standing positions were taken into account. Two implant configurations, varying the number of staples per vertebra, were simulated. The major correction (9°) came by simulating the intra-operative posture. The immediate Cobb angle correction due to the staples alone was less then 1° for both configurations. However, the staples helped maintain the correction obtained by the intra-operative posture when the post-operative standing position was simulated. Next steps are to validate the model using surgical cases, implement growth modulation modeling, improve lateral decubitus modeling, and analyze different vertebral stapling strategies for different scoliotic curves.

Keywords. Scoliosis, staple, surgery, finite element model, implant configuration

1. Introduction

Scoliosis is a complex three-dimensional deformity that can be treated with braces, for the less severe cases, or by surgical instrumentation with vertebral fusion for the most severe curves. Each technique presents limits or potential hazards. There is growing interest in the fusionless technique of vertebral stapling for the correction of adolescent idiopathic scoliosis, which is the only one to date applied as a treatment. This technique presents less surgical risks and complications than the traditional fusion surgery, and preserves spinal growth, motion, and function. Initial clinical studies indicate that this technique mainly stabilizes the deformities [1]-[6]. Betz et al. [1] obtained curve stabilization in 6 out of 10 patients (defined by a progression less than 6°) but curve progression in the four others. In a subsequent study, Betz et al. [2] reported 87% coronal curve stabilization (defined by a progression less than 10°) in 39 patients at a minimum 1 year follow-up. In investigations with goats, Braun et al. first obtained a 6.9° reduction in Cobb angle with Nitinol staples [3]-[4], but in a latter study [5]-[6], the staples did not stop the progression of scoliosis. Perhaps the large difference in the initial scoliosis between the two studies might explain the differing results: 57° in the former compared to 77° in the latter. These previous investigations on vertebral body stapling show promising results. Recommendations [1]-[7] have been made, such as using appropriate staple accordingly to the size of each vertebra, implanting 2-3 staples per level, instrumenting the different Cobb levels, and selecting patients with immature skeleton and curves between 20-45°. However, the optimal instrumentation design still needs to be established. The objective of this project was to model by finite elements the immediate correction obtained from two stapling configurations.

2. Methods

A simplified non-linear parametric finite element model of a right thoracic scoliotic spine (21° Cobb angle, Lenke type 1) was generated based on a 3D reconstruction [8] obtained from the postero-anterior and lateral x-rays of a scoliotic patient. The posterior elements of the vertebrae were neglected, and only the vertebral bodies and discs were modelled. The four reconstructed corners (posterior, anterior, left, right) of each endplate (referred here as the growth plate in adolescents) were used to generate the top and bottom contours of the vertebral bodies with splines (Figure 1). A parametric approach was used to generate and model the different growth plate zones inside the vertebral body. The reserve zone was modelled by shells (three-node triangular elements) and the proliferative and hypertrophic zones as solid volumes (six-node wedge elements). The growth plate was assumed to be 2 mm thick, with the proliferative and hypertrophic zones representing respectively 31% and 48% of its thickness [9]. A volume representing the junction (metaphysis) between the cancellous bone and the growth plate was also included. The contours of adjacent metaphysis were then connected to create a cylindrical volume (four-node solid tetrahedrons) representing the cancellous bone, which was surrounded by a cortical shell (three-node triangular elements). The remaining space between two adjacent vertebral bodies modeled the disc (annulus and nucleus) based on the previously defined growth plate contours. The annulus and nucleus were meshed with eight-node solid hexahedral elements and six-node solid wedge elements respectively. There were approximately 3700 elements per vertebra and 1200 per disc. Mechanical properties of bone and other tissues, which were assumed homogenous and isotropic, were taken from Goel et al. [10].

Studies have shown that spinal deformity can decrease by 9-10° between standing and supine positions [11]-[12]. Before implementing the staples, a simplified lateral decubitus position, as seen in surgery, was simulated by a traction load in the cranial direction accordingly to Schultz's law expressed in Villemure et al. [13] and by applying lateral forces corresponding to the weight of the thorax's cross sections (11N). Four staple sizes (prong spacing of 6, 8, 10, 12 mm; Medtronic Sofamor Danek) used in surgery were then modelled with four-node tetrahedrons. Staples were inserted into the vertebral bodies, and the prongs' volumes were subtracted from the cancellous volume and cortical shell. Contacts were made between the prongs and the vertebral body. Staples were inserted between T6-T11, with the following configurations: 1- one staple per vertebra on the convex side, 2- two staples per vertebra on the convex side. The smallest staple applicable without penetrating the metaphysis was used for each level. Due to software constraints, staple were closed all at the same time. Once the staples were closed, a compression force representing the gravity was applied downwards at each vertebra according to Schultz's law to simulate the post-operative standing position. To avoid free-body motion, boundary conditions were applied at L5, as well as T1 in the transverse plane only.

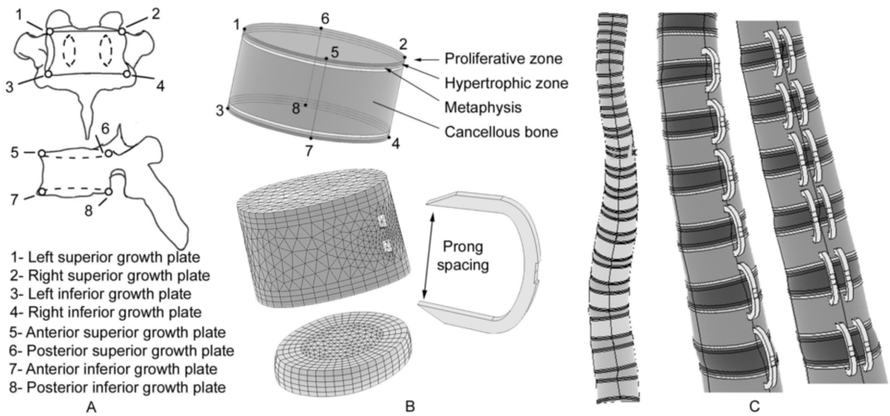

Figure 1. A- anatomical landmarks, B- simplified vertebral body geometry and staple modelling, and C- total spine modelling and staple insertion

3. Results

Results showed that simulating the patient lying down reduced the Cobb angle by 9°. The implantation of the staples, regardless of the configuration used, had little supplementary correction (reduction of the Cobb angles less than 1°). However, the staples helped maintain the initial correction obtained during surgery by the decubitus position when returning to the standing position (less that 1° of curve modification). Therefore, the final correction was about 9°. Figure 2a shows the simulated pre- and post-operative geometries that were obtained. On the other hand, using two staples increased the maximum stress in the proliferative zone by 33%. The maximum stresses in the staples inserted between T6-T7 and the stresses in the lower proliferative zone of T6 are also in Figure 2b.

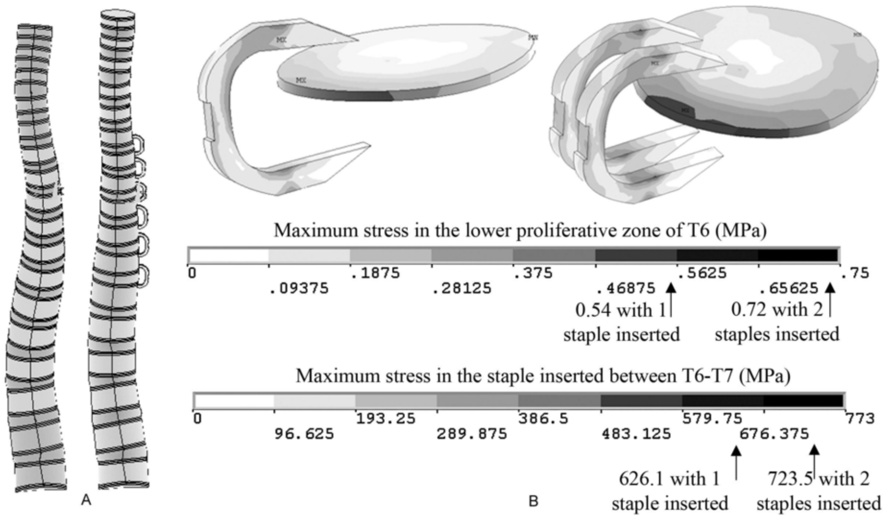

Figure 2. A- pre- and post-operative geometries, B- Stresses in the lower proliferative zone of the T6 growth plate and staples for both configurations inserted between T6-T7

4. Discussion and Conclusion

Preliminary results show that the simulated staple surgery reduced in total the Cobb angle by 9^o, which is similar to the results obtained by Braun et al. [3], who found a reduction of 7^o immediately after the treatment. With the present model, staples alone had little impact on the immediate intra-op changes. However, they helped maintain the correction brought by the intra-operative posture changes when the standing position was modelled by modifying the direction of the gravity in this preliminary study. Adequate positioning during surgery should be obtained prior to staple insertion. However, the intra-operative posture for this type of surgery has not yet been issued in the literature, and could play a key role in the staple efficacy. Delorme et al. [14] and Duke et al. [15] showed that intra-operative changes due to positioning and anaesthesia, which relaxes the muscles and reduces the spine stiffness, should be taken into account for supine surgical instrumentation. A study on the postural changes due to the lateral decubitus position is currently under investigation and results will be added to the model. Different spine stiffness and the representation of postural control by the muscles should also be taken into account.

Slight differences between the two stapling configurations were seen on the immediate intra-op correction or in the standing position. Other stapling configurations, not simulated in this study, may also affect the results. Different sizes of staples, with shorter prongs, were used by Braun et al. Longer prongs, or staples inserted too far in, generate compressive forces directed centrally along the vertebral body instead of the desirable effect of intervertebral tilt. Also, the dynamic forces of every day to day activity were not simulated, and a configuration with two staples would better sustain these stresses. The two staples configuration applies more compression stresses on the growth plates, thus possibly allowing more growth restriction on the convex side according to the Hueter-Volkman principle [16], which could result in a long-term reduction of the Cobb angle [17]. More staple configurations should be tested to optimize the growth modulation effect.

The model is currently under validation with data from surgical cases, thus the results should be considered as preliminary. Final step will be oriented towards the analysis of vertebral stapling strategies for different scoliotic curves and personalizing material properties.

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Influence of correction objectives on the optimal scoliosis instrumentation strategy: A preliminary study

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Abstract. In three recent studies we have shown how different correction objectives from a group of experienced spine surgeons add to the variability in AIS instrumentation strategies. This study examined the effect of correction objectives of three surgeons on the optimal instrumentation strategy. An optimization method using six instrumentation design parameters (e.g. limits of the instrumented segment, number, type and location of implants and rod shape) that were manipulated in a uniform experimental design framework was linked to a patient-specific biomechanical model to analyze the effects of a specific instrumentation configuration. The optimization cost function was formulated to maximize correction in the three anatomic planes and with minimal number of instrumented levels. Three surgeons from the Spinal Deformity Study Group provided their respective correction objectives for a single patient (56° thoracic and 38º lumbar Cobb angle). For each surgeon, 702 surgical configurations were iteratively simulated using a biomechanical model. The influence of the three different correction objectives on the optimal surgical strategy was evaluated. The resulting optimal fusion levels were T2-L4, T4-L2, and T4-L1. A Wilcoxon non parametric test analysis showed that fusion levels and the location of implants significantly were influenced by the correction objectives strategies ($p< 0.05$). The optimal number of implants although different (12 vs.11 vs.10) was not statistically significant ($p>0.1$). Thus different surgeon-specified correction objectives produced different optimal instrumentation strategies for the same patient.

Keywords: Adolescent idiopathic scoliosis, scoliosis surgery, surgery simulator, biomechanics, experimental design, optimization, 3-D correction.

1. Introduction

In severe cases of adolescent idiopathic scoliosis, surgical instrumentation is necessary to correct the deformity and preserve spinal mobility[1]. Recent instrumentation designs and new preoperative techniques are more complex and require detailed planning. However, the choice of the instrumentation system and fusion levels is still very controversial. In the same context, three recent studies have documented a large variability in AIS instrumentation strategies, and in the correction objectives on a significant group of experienced spine surgeons[2, 3, 4]. This variability reinforces the need to find a clear consensus on an appropriate optimal surgical strategy. To address this problem, we recently developed an optimization method to determine the most favourable surgical instrumentation strategy for a specific patient[5]. This method was personalized to the specific correction objectives of a given surgeon. The aim of this study was to evaluate the influence of correction objectives on the optimal instrumentation strategy.

2. Materials and Methods

One female (16 year) candidate for surgical treatment of AIS with Lenke curve type 3A (56° thoracic Cobb angle, 38 ° lumbar Cobb angle) was selected (Figure1).

Figure1. Pre-operative radiographs of the patient

The global spinal correction was quantified by an objective function φ that included 12 different geometric parameters describing the 3D spinal deformities and was oriented to minimize the number of instrumented levels (mobility). The parameters were taken from the SDSG Radiographic Measurement Manual[6]. The objective function φ was calculated as the weighted sum of the square of the ratio of these descriptors over their initial values with an additional mobility factor defined by the ratio of the number of unfused vertebrae (F) over the maximum number of unfused vertebrae in all the strategies (F^0).
Each term in the objective function was multiplied by a weighting factor that was specified by three experienced spine surgeons that are Fellows of the Scoliosis Research Society (SRS) and also members of the Spinal Deformity Study Group (SDSG), according to their importance for an optimal 3-D correction (Table1).

$$\begin{aligned}\phi = & W_1 \cdot [a_1 \cdot (\frac{\theta_{PT}}{\theta^0_{PT}})^2 + a_2 \cdot (\frac{\theta_{MT}}{\theta^0_{MT}})^2 + a_3 \cdot (\frac{\theta_{TL/L}}{\theta^0_{TL/L}})^2 + a_4 \cdot (\frac{X_{AVT}}{X^0_{AVT}})^2] \\ & + W_2 \cdot [b_1 \cdot (\frac{\theta_{TK} - \theta^n_{TK}}{\theta^0_{TK} - \theta^n_{TK}})^2 + b_2 \cdot (\frac{\theta_{LL} - \theta^n_{LL}}{\theta^0_{LL} - \theta^n_{LL}})^2] \\ & + W_3 \cdot [d_1 \cdot (\frac{\theta_{PT-OPMD}}{\theta^0_{PT-OPMD}})^2 + d_2 \cdot (\frac{\theta_{MT-OPMD}}{\theta^0_{MT-OPMD}})^2 + d_3 \cdot (\frac{\theta_{TL/L-OPMD}}{\theta^0_{TL/L-OPMD}})^2 + d_4 \cdot (\frac{\theta_{PT-AVR}}{\theta^0_{PT-AVR}})^2 + d_5 \cdot (\frac{\theta_{MT-AVR}}{\theta^0_{MT-AVR}})^2 \\ & \quad + d_6 \cdot (\frac{\theta_{TL/L-AVR}}{\theta^0_{TL/L-AVR}})^2] \\ & + W_4 \cdot [(\frac{F}{F^0})^2]\end{aligned}$$

Angle θ^0 was defined as the preoperative angle. The 'normal' thoracic kyphosis (θ^n_{Tk}) and lumbar lordosis ($\theta^n_{LL.}$) were arbitrarily defined as 35° and 40° respectively[7, 8]. $F^0$was defended as the maximum number of unfused vertebrae in all the strategies.

Table1: Weights assigned to the terms of the objective function for objective of geometric correction

Lenke 3 (Double major)			Surgeon1	Surgeon2	Surgeon3
Correction in the Coronal plane		W1	40%	30%	20%
Correction in the Sagittal plane		W2	40%	30%	15%
Correction in the Transverse plane		W3	10%	10%	15%
Mobility (Nb of unfused/saved vertebrae)		W4	10%	30%	50%
Specific weights assigned to of the Coronal Plane					
Cobb PT	θPT	a1	10%	10%	30%
Cobb MT	θMT	a2	35%	30%	30%
Cobb TL/L	θTL/L	a3	35%	30%	30%
Apical Vertebra Translation	XAVT	a4	20%	30%	10%
Specific weights assigned to of the Sagittal Plane					
Thoracic Kyphosis	θTK	b1	50%	20%	50%
Lumbar Lordosis	θLL	b2	50%	80%	50%
Specific weights assigned to of the Transverse Plane					
Apical Vertebral Rotation (PT curve)	θAVR-PT	d1	15%	5%	16.66%
Apical Vertebral Rotation (MT curve)	θAVR-MT	d2	35%	15%	16.66%
Apical Vertebral Rotation (TL/L curve)	θAVR-TT/L	d3	35%	45%	16.66%
Orientation – plane of max. curvature (PT)	θOPMD-PT	d4	5%	5%	16.66%
Orientation – plane of max. curvature (MT)	θOPMD-MT	d5	5%	15%	16.66%
Orientation – plane of max. curvature (TL/L)	θOPMD-TL/L	d6	5%	15%	16.66%

In order to evaluate the effect of the correction objectives on the instrumentation strategy, we used an optimization approach to minimize three cost functions (maximize the spine correction), one for each surgeon participating in this study. Details of optimization approach have been presented in Majdouline *et al.* (2008)[5]. This optimization method used six instrumentation design parameters: the upper instrumented vertebra (UIV), the lowest instrumented vertebra (LIV), number, type and location of implants and rod shape. These instrumentation parameters were manipulated in a uniform experimental design (U-type)[9,10] framework which was linked to a patient-specific biomechanical model implemented in a spine surgery simulator (S3).[11] The simulator allowed analyzing the effects of each instrumentation configuration. The biomechanical model contains the thoracic and lumbar vertebrae (from T1 to pelvis) connected by intervertebral structures that were modelled using flexible elements. The implants (screws, hooks) were modelled as rigid bodies while the implant-vertebra links were modeled as a generalized stiffness element that restrained mobility in rotation and in translation. Boundary conditions were imposed to represent the state of the patient on the surgical table. All degrees of freedom, except sagittal plane rotation, were fixed at the pelvis. At T1, the vertebra was allowed to translate and rotate freely in the frontal plane. For each surgeon, 702 surgical configurations were iteratively simulated using S3 and for each configuration 12 geometric parameters were measured. Eleven equations were built from the linear regression coefficients. These equations were obtained and used to make a simplified model representing the 12 geometric measurements as a function of the six instrumentation parameters. These equations were entered into the objective function $\varphi(x)$. Once the approximation model describing the relationship between design variables and the objective function was obtained, the minimum was found using

the Matlab Optimization Toolbox (MathWorks, USA). To solve the non-linear optimization problems, the function "*fmincon*"[12] was used.
Using this optimization approach, the optimal strategies for each surgeon were obtained, thus the influence of the different correction objectives on the optimal surgical strategy was evaluated. Analyses were conducted using Statistica software (StatSoft, USA). The influence of the three different correction objectives on the optimal surgical strategy was evaluated using a Wilcoxon non parametric test and a level of significance set at 0.05.

3. Results

The results of the optimal strategies for each surgeon are summarized in Table 2 and Figure 2. Overall, there is a significant influence ($p< 0.05$) of the objectives correction on the optimal strategy. The resulting optimal fusion levels were T2-L4, T4-L2 and T4-L1. A Wilcoxon non parametric test analysis showed that fusion levels and the location of implants significantly were influenced by the correction objective strategies ($p< 0.05$).The optimal number of implants was different (12 vs.11 vs.10) but not statistically significant ($p>0.1$). The shape of the rod was different according to the surgeon correction objectives. For example, Table 1 shows that the correction objectives for the number of instrumented levels (mobility) were different between three surgeons (10% vs. 30% vs. 50%). This difference produced different number of instrumented levels (15 vs. 10 vs. 9).

Table2: Optimization parameters of instrumentation results

Optimal Strategy		Surgeon1	Surgeon2	Surgeon3
Type of Implans		Screw	Screw	Screw
Number of Implants		12	11	10
Number of fusion leveles		15	10	9
UIV		T2	T4	T4
LIV		L4	L2	L1
Shape of the rod	Thoracic curve	20°	30°	20°
	Lumbar curve	30°	30°	45°

4. Discussion and conclusion

Our study evaluated the effect of the objectives correction on the optimal instrumentation strategy for a specific patient. Based on our results, different surgeon-specified correction objectives produced different optimal instrumentation strategies for the same patient. In fact, the optimal instrumentation design parameters (LIV, UIV, number, type and location of implants and rod shape) were different according to the different surgeon's objectives correction.
Several publications have revealed variability in the choice of instrumentation strategy on a significant group of experienced spine surgeons [2, 3].The preliminary results obtained with this study demonstrate that this variability can be attributed to the objectives of surgical correction. Further investigation with more surgeons would be needed to validate this influence between the correction objectives on optimal instrumentation strategies.

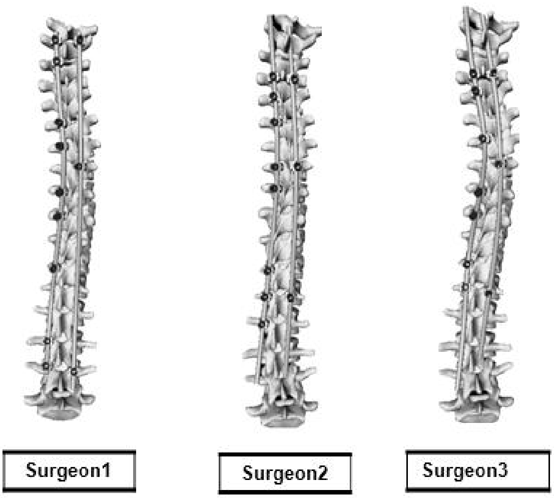

Figure2: The simulation of the three optimal surgery using S3

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Development of an Apparatus to Evaluate Adolescent Idiopathic Scoliosis by Dynamic Surface Topography

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Abstract. For cases of Adolescent Idiopathic Scoliosis (AIS), commonly the first indicator is a change in the surface shape of the back over time. A proportion of patients so diagnosed require surgical intervention to prevent further progression and to improve cosmesis. The results of a preliminary literature survey have revealed that significant work has already been published on the static acquisition and analysis of back surface shape. There is new interest in establishing correlations between breathing, posture, the underlying spinal deformity and changes in the surface topography of the back during clinical sessions together with an increased focus on the impact of the cosmetic defect on the patient and in the measurement of pre and post-operative dynamic capability.

The continuing development of an apparatus based on established optical motion capture technologies, that generates a sequence of tri-dimensional images and provides measurements derived from changes in the position of anatomical reference landmarks and of the surface topography of the back will be presented. If, using the same landmarks, the trunk range of motion could be captured concurrently, it is hoped that the resulting data would form the basis of a useful clinical study.

1. Introduction

Between 1984 and 1988, the author was involved with the development and introduction of the commercial version of the Integrated Shape Imaging System (I.S.I.S.) [1] based on the previous work of Turner-Smith and Houghton [2, 3]. For the past twenty years he has concentrated on the development and application of optical motion capture technologies to the fields of clinical gait analysis, rehabilitation, sports biomechanics and ergonomics. Within the last decade, the same technology has been widely applied to the creation of animated background characters used in the crowd scenes of many major film productions including Titanic, Troy, Gladiator, Star Wars II and III. In recent years the technology has advanced to a degree where it is now being used to capture the subtleties of characteristic whole body motion and facial expressions of well known actors as the main characters in feature films such as *The Polar Express* and *Beowulf*. The aim of the study was to investigate how it might be possible to apply similar technologies and experience to synchronously capture video images to quantify, in three dimensions, the changes in the position of surface anatomical landmarks and back surface shape during clinical presentations.

Earlier work by many researchers concentrated on attempting to reduce the radiographic exposure to AIS patients by investigating if there was a reliable correlation between the progression of an underlying spinal deformity and changes in back surface topology over time [4,5,6]. The techniques applied and the relational algorithms developed were found to be prone to error by postural and non-spinal artifacts and were in-sufficiently robust to accommodate all cases so limiting their measurement sensitivity, specificity and usefulness as general clinical tools.

A recent paper [7] focussed on the need to quantify the cosmetic defect of spinal deformity and work has been published on the evaluation of tri-planar spine range of motion following spinal fusion [8], implying a need still exists for apparatus [9] that can dynamically acquire the location of pre-defined anatomical surface landmarks and back topology to within clinically acceptable accuracies.

2. Materials and Methods

Previous work using optical motion capture technology has been published. Rotelli and Santambrogio [10] placed an array of passive detectable markers across the surface of the back and captured the resulting tri-dimensional positions. Aliverti et al. [11] used a laser scanning mechanism to apply a moving point of light to the surface synchronized to each acquisition of the apparatus optical sensors. Rotelli and Santambrogio's method had the advantage of presenting an absolute measure of the location of all markers during each acquisition but would not be a feasible option for routine clinical sessions due to the time needed to apply sufficient markers before each measurement. The approach by Aliverti et al. would have been prone to errors introduced by postural and breathing artifacts, so was not considered further.

2.1. Data Acquisition

The study used an obsolete and modified 6 Camera, VICON motion capture system (Vicon Motion Systems Ltd., Oxford, U.K.) to acquire anatomical landmark positions and surface data simultaneously at a rate of 60 frames/second. Fig. 1 depicts the arrangement of two groups of three, optically isolated, cameras and a projector used to generate an array of points.

VICON systems use spherical markers coated (Fig. 2) with a material that reflects light directly back to a strobed source surrounding a camera lens. The cameras are shuttered to open only during a strobe flash and contain filters optically matched to the spectra of the light source. Only circular bright markers will be sampled by each camera sensor, independent of the rate of subject movement and ignoring skin, fabric and other objects within the field of view. The centre of markers are calculated as positions within the two dimensional image illuminating the sensor during a given frame by analyzing the relative intensities of light impinging onto groups of adjacent pixels. Before each capture session, calibration objects with markers attached at known positions are used to establish the global coordinate system of the measurement volume; the physical position and orientation of each camera and the scaled relationship between the acquired coordinates and the actual positions. The optical distortion of the cameras (particularly from the lenses at the corners) is also calculated and a linearization correction applied to each subsequent frame captured. Within the measurement volume defined by the lenses chosen and the distance to the object, accuracy of marker centre reconstruction was determined by experiment to be within a mean of ± 0.1mm, S.D. 0.3mm, n = 4,500.

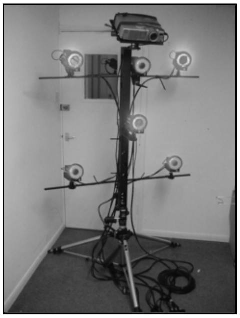

Fig. 1. Acquisition Apparatus

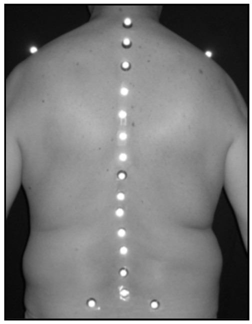

Fig. 2. Anatomical Markers

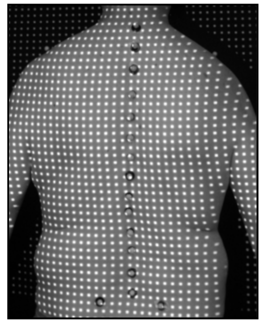

Fig. 3. Projected Point Cloud

To detect the markers, three shuttered, strobing cameras were configured to emit and detect light in the visible red spectral region (660 nm). Three further passive cameras were fitted with optical, short-pass filters to exclude light in the red spectra but to allow passage of the image of the projected surface point cloud (Fig. 3) to the camera sensors. The centres of the points were determined in the same way as for the markers.

Providing a minimum of two calibrated cameras see a marker or a point anywhere within the measurement volume, the third dimension can be calculated in exactly the same way as humans estimate distance with two offset eyes viewing a common object [12]. The presence of a third or more cameras further improves the reliability of point and marker re-construction.

2.2. Surface Data Processing

Figures 4 and 5 depict the presentation of anatomical marker (Fig. 4) and surface point cloud (Fig. 5) locations in two dimensions, acquired from a single frame from cameras in each group. Supporting software has been developed to automatically separate marker and point data into two files for further processing into frames of three–dimensional coordinates.

The resulting three dimensional data were normalised to a reference plane defined by the positions in each frame of the markers placed by palpation over the vertebra prominens (C7/T1) and the left and right posterior superior iliac spines (PSIS) [1]. Two additional markers were applied to the acromion to provide a measure of shoulder droop. For pre-operative cases, 10-13 additional markers were applied to the spinous processes and a tri-planar cubic spline interpolation calculated to define the delineation between the left and right sagittal surface sections. Placement of markers in post-operative cases should follow the convention established by Jefferson et al. [13]. Boundary cubic splines were also calculated based on a proportion of the height of the spine between C7/T1 and the bisection point between the PSIS to remove data not required for further analysis such as the arms. Algorithms have been developed that automatically identify the reference markers and order spinous process markers in most expected cases within defined degrees of freedom. Table 1 lists the clinical data that are calculated and Fig. 6 depicts an example graph of changes in imbalance over 440 frames (7.3 s) captured from a normal subject.

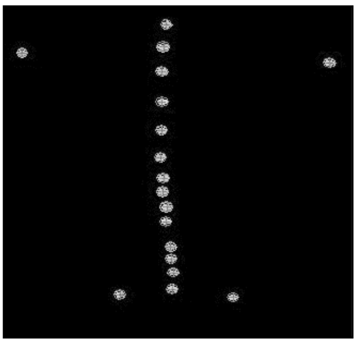

Fig. 4. Anatomical Markers

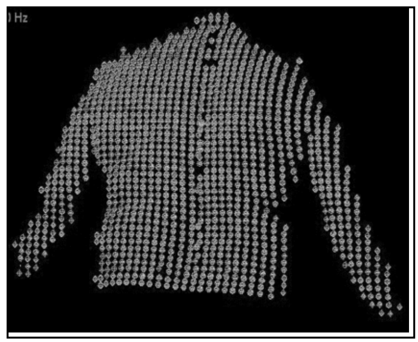

Fig. 5. Surface Cloud Points

Prior to export for display and surface data interpolation, the resulting point cloud data were automatically allocated into one of twenty transverse sections above the normalised reference plane to further amplify volumetric differences between the sagittal sections. A number of third party surface topography interpolation and display packages (Surfer 8 © and Voxler ©, Golden Software Inc.) are currently being investigated for suitability. Fig. 7 depicts the resulting Voxler © output for frame 45 of a 150 frame capture of the subject's back. Further work is being undertaken to use the results obtained to develop numerical measures to describe volumetric asymmetries.

2.3 Range of Motion Data Processing

Range of motion data were captured from the same subject using common marker placements by switching off the point array projector and switching on the strobes (in the blue spectra) of the three surface capture cameras to improve the reconstruction accuracy of more rapidly moving markers within the measurement volume. Fig. 8 depicts the display of markers in three dimensional space and Fig. 9 a graphical sample of the angle subtended between C7/T1, the central spinous process marker and the marker adjacent to the PSIS over 2000 frames (33 s). The impact of skin movement of the markers on results will be considered as part of the final study.

Parameter	Units
Height	mm
Tilt	degrees (+/-)
Imbalance	mm (L/R)
Pelvic Tilt	degrees (L/R)
Pelvic Obliquity	degrees (to L/R)
Shoulder Droop	mm (L/R)

Table 1. Calculated Parameters

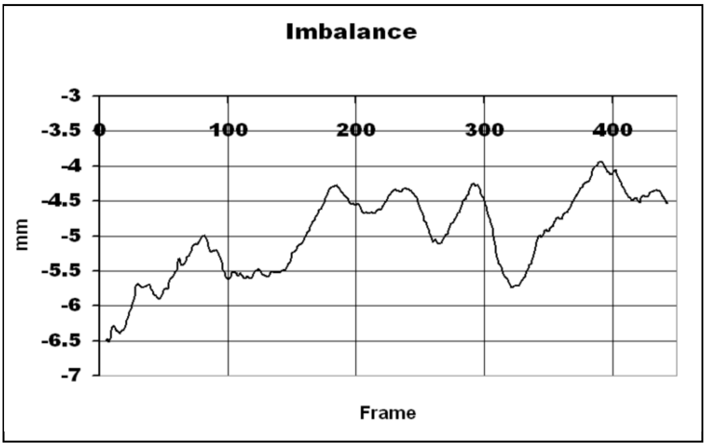

Fig. 6. Variations in Imbalance from a Normal Subject over 7.3 s

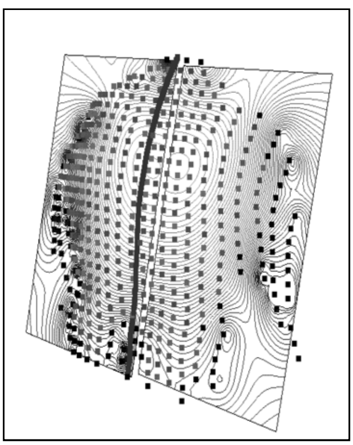

Fig 7. Voxler© Data and Contour Image - Frame 45

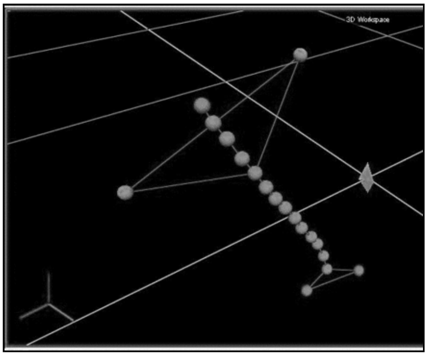

Fig. 8. Markers Single Fame

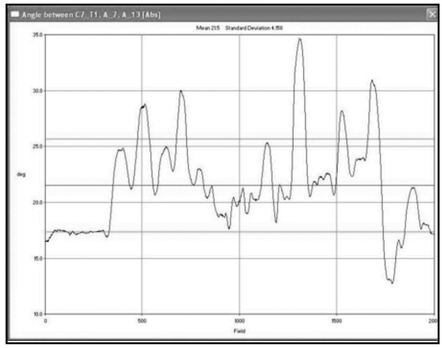

Fig. 9. Range of Motion Angles

3. Conclusion

Development of the apparatus and supporting algorithms continues with the goal of producing a tool to quantify and express changes in back surface shape and the range of motion during a clinical session. The resulting data are hoped to form the basis of a useful clinical study.

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Biomechanical Modelling of a Direct Vertebral Translation Instrumentation System: Preliminary Results

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Abstract. Many new spine instrumentation concepts were introduced in recent years, like the incremental direct vertebral translation. The objective was to develop a biomechanical model in order to analyze the biomechanics of this instrumentation system. The patient-specific spine model was built using the 3D reconstruction based on bi-planar radiographs of a scoliotic patient (thoraco-lumbar Cobb: 49°). The mechanical properties were derived from literature, experiments on cadaver spines and patient's side bending radiographs. Each screw construct was modelled by four rigid bodies connected each other by kinematic joints. The screw-vertebra flexible joint was represented by 3 experimentally derived non-linear springs, and the rods by non-linear flexible elements. The correction manoeuvres were simulated by lowering the rod, tightening the crimps (incremental segmental translation) and applying secondary correction manoeuvres (direct vertebra derotation, compression, distraction and construct tightening). The simulations showed that the system allows a good force distribution among implants. The long post pushing and pulling contributed, to a great extent, to a global correction in the coronal plane, while the crimp tightening had more important effect in the sagittal plane. The preliminary results illustrated the effectiveness of local correction by a direct vertebra translation technique. Our next step is to validate the model and compare the performance of this strategy with other spinal instrumentation systems.

Keywords: spine, instrumentation, scoliosis, biomechanical model.

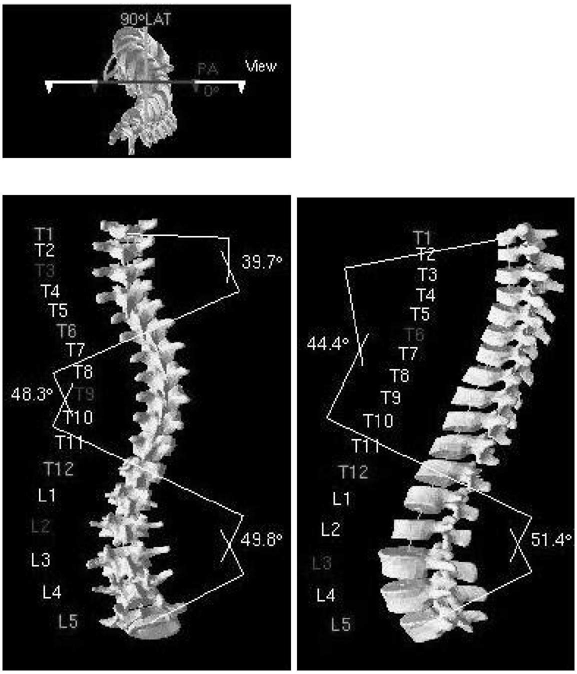
1. Introduction

Spinal instrumentation systems for scoliosis consist of different correction manoeuvres that are applied to the spine via a mechanical constructs and flexible rods usually bended to desired sagittal profile. The basic techniques of achieving the desired spine contour involve the vertebra translation, rod derotation, direct vertebra derotation, compression and distraction, and in situ rod contouring. In order to maintain the correction rods are fully seated and locked into the slot of each implant, making it difficult to fine-tune the implant-rod relative location and control the force distribution amongst the implants. A new concept (direct incremental segmental translation) was proposed to provide a better control on the vertebra location with respect to the rod [1]. The most distinguishing point of this concept is to allow each implant to be translated towards and fixed on the rod at any distance and at any angle. This is done by introducing a pivoting post and a post-rod connector. The post-rod connector is equivalent to the combination of two telescopic joints and one universal joint which become a rigid connection once the set screw is tightened.

The objective of this work was to develop a biomechanical model in order to analyze the biomechanics of this instrumentation system.

2. Biomechanical modeling

The spine 3D geometry of a 16 year old idiopathic scoliosis patient (Cobb: Thoracic 48°/ Lumbar 50°) was derived from the 3D reconstruction computed from bi-planar radiographs (Figure 1).



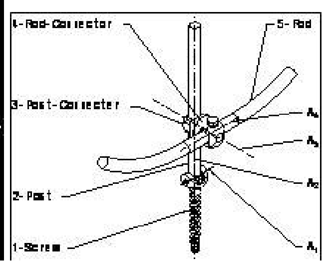


Figure 1. Patient spine model

Figure 2. Construct simplification

Since the vertebra deformation is negligible compared to its global displacement during correction manoeuvres, each vertebra body was considered as a rigid body [2,6]. The biomechanical inter-vertebra behaviour was modelled as a 6-dimension general force having a linear correlation with the 6-dimension general inter-vertebra displacement6. This linear correlation is represented by a 6-by-6 stiffness matrix whose initial values come from the in vitro experimental data reported in the literature [3, 4] and then adjusted by applying weighting factors computed from the patient's side bending Cob angles [5,6].

The instrumentation construct is composed of a pedicle screw, a post hinged to the pedicle screw, and a connector. The connector has two parts, i.e. the post connector and the rod connector having a one-degree-of-freedom (DOF) rotational relative mobility around their common axis. The post connector can rotate around and translate along the post, so can the rod connector relative to the rod. All mobility (6 DOF) from the post to the rod can be eliminated by tightening a single set screw, making the post-rod connection become rigid. The construct can be assembled above the patient and lowered into position out of the way of the paraspinal muscles. The deformation of each component and the deformation between some components being negligible compared to the global vertebra displacement, the construct was simplified to be composed of 1 flexible body (rod) and 4 rigid bodies, i.e. the pedicle screw, the post, the post connector, and the rod connector (Figure 2). Then the spine model and the construct model were integrated to form a single biomechanical system allowing the simulation of the reaction of the system under different correction manoeuvres. This was done by first placing all pedicle screws relative to their corresponding vertebrae and then creating screw-vertebra connections. The screw location was approximated using the mean pedicle axis. The screw-vertebra connection was realized by applying a 6-dimension general screw-vertebra force which has a non linear relation with the 6-dimension general screw-vertebra relative displacement. The non linear relation is modelled using in vitro experiment data.

3. Simulation data and instrumentation manoeuvres

The instrumentation specifications for the patient used in this study were derived from the real operation:

- Left side: T4, T6, T8, T10, T12, L1, L2: long post pedicle screw; 5.5mm titanium rod.
- Right side: T3: downward transverse process hook; T5, T7, T9, T11, L1, L2: long post pedicle screw; 5.5mm titanium rod.

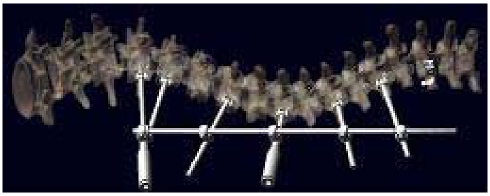


Figure 3. Construct assembly

Instrumentation manoeuvres were derived from the video of the real surgery. After the pedicle screws having been inserted and the rod bended to the desired contour, the constructs were assembled above the spine and lowered into position (Figure 3). Then the rod was anchored at the distal end by tightening the corresponding set screw to prevent it from rolling. The spine was translated towards the rod by first tightening the crimp, a special component going with each long post. Since the reaction force of the spine at the crimp being tighten can be felt by the surgeon, the crimp tightening was simulated by alternating the crimp tightening such that the reaction force of the spine at each implant is controlled under 390 N. After the crimp tightening, more correction was achieved by pushing or pulling the long posts around the rod. Compression and distraction were performed just like other instrumentation system. The vertebra rotation was reduced by tightening the crimps with different quantities on the left and the right sides.

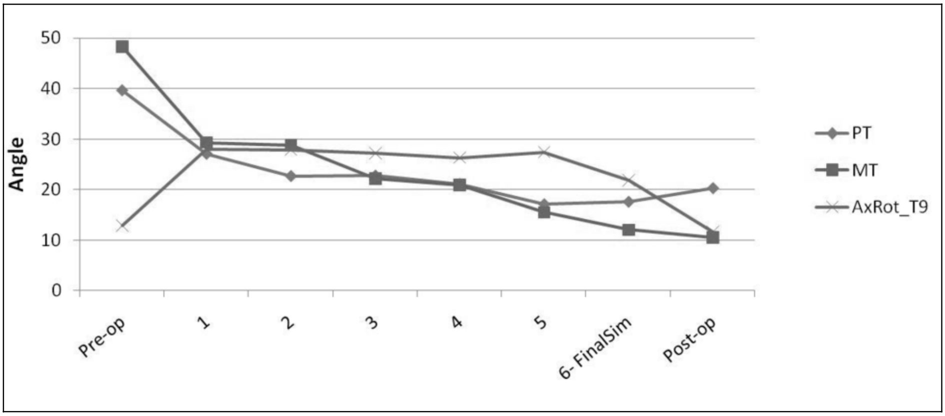


Figure 4. Corrections for each simulation step

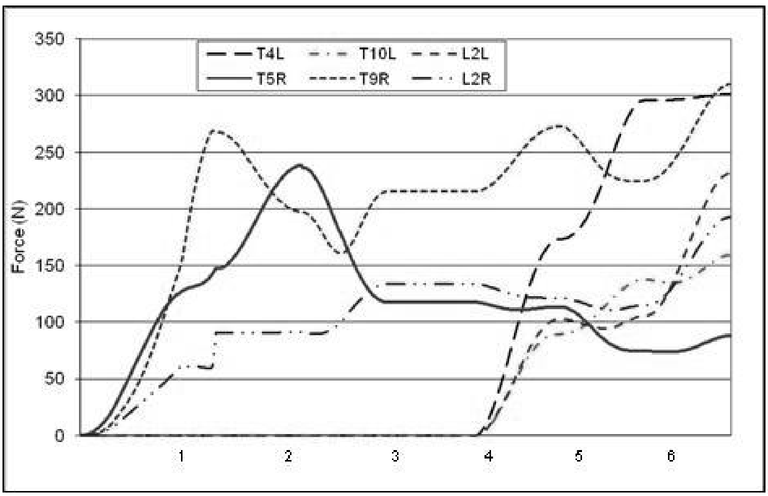


Figure 5. Force evolution during the whole simulation

4. Simulation results

For each simulation step, the implant-vertebra forces were monitored, and the Cobb angles and apical vertebra rotation angles measured. Since during the construction assembly and the left rod anchoring, slight correction and implant-vertebra force change were observed; Figures 4 and 5 show respectively the corrections and implant-vertebra force evolution for the following steps: 1-Right side rod anchoring; 2- Right side crimp tightening; 3- Right side long post pushing and pulling; 4- Left side crimp tightening; 5- Left side rod pushing and pulling; 6- Vertebra rotation reduction.

Figure 6 shows the posterior views for steps 1 to 5.

5. Discussion and Conclusion

This study is a feasibility study of biomechanical modelling of an instrumentation system based on incremental direct vertebral translation. Preliminary simulations showed that the developed model allows simulating and analyzing the general reactions of the scoliotic spine under different steps of the surgery. The simulation results should be considered as preliminary because slight modifications to both the model and the simulation parameters may make sizeable differences in the resultant forces and correction. Model validation is therefore necessary. It will be done by comparing the simulation results with patients' post-operative spine reconstruction model. When the model validation will be completed, the system can serve as a preoperative planning tool to optimize instrumentation strategies.

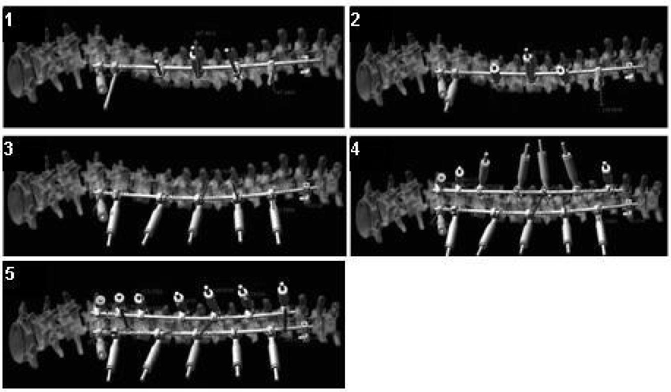


Figure 6. Posterior views for steps 1 to 5

Acknowledgements

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SpineCor vs. Natural History – Explanation of the results obtained using a simple biomechanical model

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Abstract. In the recent peer reviewed literature the SpineCor is described as an effective method of treatment for patients with scoliosis. However until recently no prospective controlled end-result study is presented comparing the results obtained with this soft brace to natural history. The objective was to determine whether the results obtained by the use of the SpineCor are better than natural history during pubertal growth spurt. The method employed prospective comparison of the survival rates of SpineCor treatment vs. natural history with respect to curve progression during pubertal growth spurt. 12 Patients with Cobb angles between 16 and 32 degrees (at average 21 degrees) during pubertal growth spurt are presented as a case series treated with the SpineCor. Survival rate of this sample is described and compared to natural history (SRS brace study 1995). All girls treated in both studies were at risk for being progressive with the first clinical signs of maturation (Tanner 2-3). During the pubertal growth spurt most of the patients (11/12) with SpineCor progressed clinically and radiologically as well (at least 5 degrees). Progression could be stopped changing SpineCor to the Chêneau brace in most of the sample described (7/10). The avarage Cobb angle at the start of treatment with the SpineCor was 21.3 degrees, after an average observation time of 21.5 months 31 degrees. At 24 months of treatment time 33% of the patients with the SpineCor where still under treatment with their original bracing concept, at 72 months follow-up time 8 % of the patients with the SpineCor survived with respect to curvature progression. Survival proportion in the SpineCor sample, though was 0.08, while in the natural history cohort it was 0.34. The SpineCor treatment during pubertal growth spurt seems to lead to a worse outcome than observation only. The use of a simple biomechanical model explains that in the brace the compression forces exceed the lateral forces used for the corrective movement. Therefore SpineCor does not seem to be indicated as a treatment during pubertal growth spurt.

Keywords. Adolescent idiopathic scoliosis, SpineCor, natural history, growth spurt

1. Introduction

In the recent peer reviewed literature the SpineCor is described as an effective method of treatment for patients with scoliosis [1,2]. However until recently no prospective controlled end-result study is presented comparing the results obtained with this soft brace to natural history. Two studies reveal data that support the hypothesis, that the use of the SpineCor brace is less successful than the use of other braces during pubertal growth spurt [3,4].

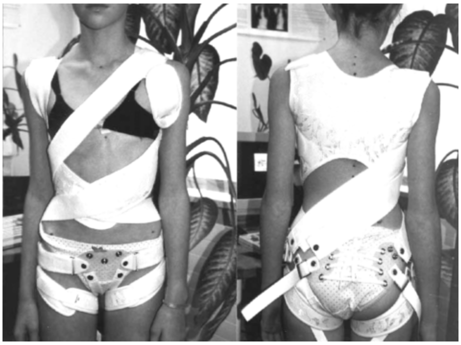

Figure 1. SpineCor as adjusted by the original authors [1,2] at our centre. No changes have been made to the original adjustments unless a clear progression has been detected.

Objectives: If the use of the SpineCor during pubertal growth spurt is less successful than the use of other braces, the question remains to be answered as to whether one can expect at least results superior to natural history using this soft brace. To determine whether the results obtained by the use of the SpineCor are better than natural history during pubertal growth spurt, this study has been undertaken.

2. Material and Methods

This is a prospective comparison of the survival rates of SpineCor treatment vs. natural history with respect to curve progression during pubertal growth spurt.

12 Patients with Cobb angles between 16 and 32 degrees during pubertal growth spurt are presented as a case series treated with the SpineCor. Survival rate of this sample is described and compared to natural history as presented in the control group of the SRS brace study [5]. All girls treated in both studies were at risk for being progressive with the first clinical signs of maturation (Tanner 2-3), the girls from the SpineCor sample all were premenarchial at the start of treatment.

3. Results

During the pubertal growth spurt most of the patients (11/12) with SpineCor progressed clinically and radiologically as well (at least 5 degrees). Progression could be stopped changing SpineCor to the Chêneau brace in most of the sample described (7/10). The avarage Cobb angle at the start of treatment with the SpineCor was 21.3 degrees, after an average observation time of 21.5 months 31 degrees. At 24 months of treatment time 33% of the patients with the SpineCor where still under treatment with their original bracing concept, at 72 months follow-up time 8 % of the patients with the SpineCor survived with respect to curvature progression. Survival proportion in the SpineCor-sample, though was 0.08, while in the Natural History cohort it was 0.34.

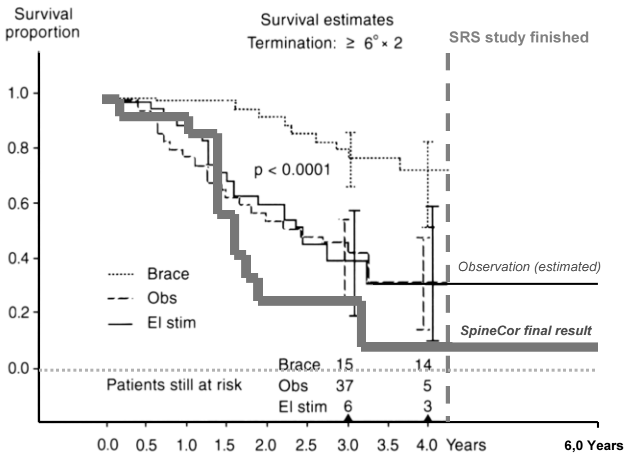

Figure 2. Survival analysis comparing natural history [modified from 5] to SpineCor treatment (fat grey line) during pubertal growth spurt clearly shows worse results for the SpineCor sample at 4 years.

4. Discussion

In this study no patients have been lost for follow-up. Therefore the results of our study can be compared to other studies with similar study design [4]. The material in the study performed by Nachemson et al. [5] however, is slightly different including also postmenarchial girls (65 premenarchial, 46 postmenarchial) with clear signs of maturation (82 with Risser 0-1, 28 with Risser 2-5).

Follow-up time is not shorter in our study compared to Nachemsons (72 vs. 48 Month) and the last remaining patient (18 years of age) in our study was no more of risk for progression at the end of the observation period.

The proportion of patients without progression (rate of success) under Boston brace treatment was 74 % (worst case 50%) whereas the Chêneau sample from our previous study did quite better with a success rate of 80% [3] (no patient lost, one patient Risser 1, the others Risser 0 in the Chêneau sample of patients).

Success rate for the SpineCor sample was 8% compared to the success rate of the natural history sample in the Nachemson study [5] of 34%. So we cannot expect the SpineCor treatment to change natural history, although we must admit the SpineCor sample to have a slightly worse prognosis (being more immature) than the controls [5].

The poor results of SpineCor treatment during pubertal growth spurt may be explained by the fact, that this soft brace leads to axial loading (Fig. 3.) with kyphosing effects to the thoracolumbar junction as shown in lateral x-rays [2], while sagittal realignment with lumbar re-lordosation has been shown to be beneficial in the treatment of patients with scoliosis [6-8] and therefore this should be implemented in actual bracing concepts.

5. Conclusions

The SpineCor treatment during pubertal growth spurt seems to lead to a worse outcome than observation only. The use of a simple biomechanical model explains that in the

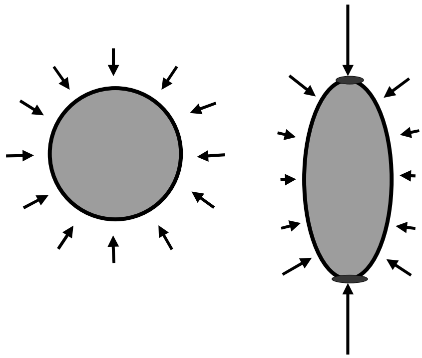

Figure 3: In a sphere wrapped into elastic material the compression forces can be estimated to be the same at every point (left). In a lengthwise oval model (right) – independently of any lateral forces applied – axial compression forces will always overweight the lateral forces leading to a junctional thoracolumbar kyphosis with the consequence of an instable segmental alignment in this area.

brace the compression forces exceed the lateral forces used for the corrective movement. Therefore SpineCor does not seem to be indicated as a treatment during pubertal growth spurt.

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Comparison of the kyphosis angle evaluated by video rasterstereography (VRS) with x-ray measurements

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Abstract. Surface topography evaluations are prone to technical errors due to postural sway of the patients measured. The technical error of lateral deviation (rms) and surface rotation (rms) may vary between 15 and 20%, while the kyphosis angle (IP-ITL) has a technical error of only 5% (2,5 degrees), which is comparable to the x-ray measurement. Purpose of this study was to investigate the hypothesis that video rasterstereography can be used for prognostication of a kyphosis patient.

Materials and Methods. 53 Patients (23 females, 30 males, average age 17 years with a range from 11 to 56 years) undergoing in-patient rehabilitation have been measured with the help of video rasterstereography (VRS) before starting the treatment program and the values for kyphosis angle have been correlated to the kyphosis angle measured on a lateral x-ray (XR) not older than 6 weeks before VRS measurement. 26 had a thoracic Scheuermann, 3 a thoracolumbar, 15 an Idiopathic Kyphosis and 9 a kyphosis of other origin.

Results. Average Kyphosis angle XR was 49 degrees (SD 17) and VRS 63 degrees (SD 13). There was a high significant Pearson correlation of 0.78 and a high significant difference of 14 degrees in the t-test (t –9,6, p<0,001).

Conclusions. The kyphosis angle VRS (Vertebra prominens – lower neutral zone of inclination) seems to allow a follow-up of individual kyphosis patients. The XR kyphosis angle according to Stagnara is measured from T4 to the lower end vertebra and therefore is lower than the VRS kyphosis angle measured from T1. The difference found between XR and VRS kyphosis angles may be explained by the angle between T1 (VRS) and T4 (XR) differently used as the upper end vertebra. Therefore the prognostication of an individual patient seems possible within certain limits.

Keywords. Kyphosis angle, videorasterstereography, VRS, radiography

1. Background

Surface topography evaluations are prone to technical errors due to postural sway of the patients measured. The technical error of lateral deviation (rms) and surface rotation (rms) may vary between 15 and 20% [1,2], while the kyphosis angle (IP-ITL) has a technical error of only 5% (2,5 degrees), which is comparable to the x-ray measurement [3]. Purpose of this study was to investigate the hypothesis that video rasterstereography can be used for prognostication of a kyphosis patient.

2. Material and Methods

53 Patients (23 females, 30 males, average age 17 years with a range from 11 to 56 years) undergoing in-patient rehabilitation have been measured with the help of video

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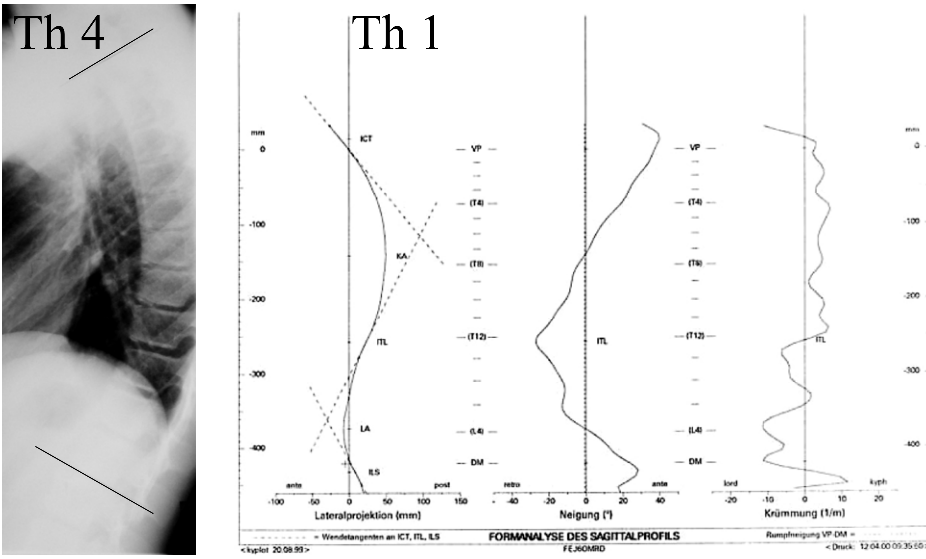

Figure 1. The XR kyphosis angle according to Stagnara is measured from T4 to the lower end vertebra and therefore is lower than the VRS kyphosis angle measured from T1.

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Average kyphosis angle XR was 49 degrees (SD 17) and VRS 63 degrees (SD 13). There was a high significant Pearson correlation of 0.78 and a high significant difference of 14 degrees in the t-test (t –9,6, p<0,001).

4. Discussion

The kyphosis angle VRS (Vertebra prominens – lower neutral zone of inclination) seems to allow a follow-up of individual kyphosis patients. The XR kyphosis angle according to Stagnara is measured from T4 to the lower end vertebra and therefore is lower than the VRS kyphosis angle measured from T1.

The difference of at average 14 degrees found between XR and VRS kyphosis angles may be explained by the angle between T1 (VRS) and T4 (XR) differently used as the upper end vertebra. Therefore the prognostication of an individual patient seems possible within certain limits using VRS.

VRS kyphosis angles therefore seem to be precise and can be used for prognostication and follow-up of kyphosis patients as well.

15 degrees should be subtracted from the VRS (VP – ITL) kyphosis measurements to estimate the XR Stagnara angle of kyphosis.

5. Conclusions

The kyphosis angle VRS (Vertebra prominens – lower neutral zone of inclination) seems to allow a follow-up of individual kyphosis patients. The XR kyphosis angle according to Stagnara is measured from T4 to the lower end vertebra and therefore is lower than the VRS kyphosis angle measured from T1. The difference found between XR and VRS kyphosis angles may be explained by the angle between T1 (VRS) and T4 (XR) differently used as the upper end vertebra. Therefore the prognostication of an individual patient seems possible within certain limits.

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Postural changes in patients with scoliosis in different postural positions revealed by surface topography

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Abstract. Claims have been made that surface topography is an objective tool, however there are significant postural influences (relatively large technical error due to postural sway) those measurements are prone to. Purpose of this study was to help estimate these influences by measuring patients with scoliosis in three standardized postural positions.

Material and Methods. We studied the surface-topography measurement in 100 in-patients with idiopathic scoliosis divided into different age-groups. First group: 7 to 12 years (n=12), second group: 13 to 16 years (n=51), the third 17 to 20 years (n=15) and the fourth > 21 years (n=22) (7 males and 93 females). The thoracic Cobb angle was 26.4 degrees, lumbar Cobb angle 25.7 degrees. We investigated the average lateral deviation (rms) and average surface rotation (rms).

Measurements were taken one day before the patients left the clinic, after a 3 or 4 week in-patient intensive rehabilitation program (SIR), in three different postures:

Normal posture: no specific instructions: standing with feet in an standardized way.

Conscious posture: The patients acquired this posture during intensive daily exercising.

Corrected posture: The most corrected posture the patients are able to achieve by using specific muscle tension and specific breathing techniques.

We compared the results between the different postures. Then we calculated the results for the different age groups.

Results. There are significant differences in both parameters tested, some of them more than 40% to 67% greater than the measurement error calculated. The best results were achieved in the second and the third group with the conscious posture, the adult group had the best valued in most corrected posture. For the youngest patients there were no significant changes with the different postures.

Conclusions. Surface measurements can be influenced by artificial postures and therefore cannot be attributed as objective. This is why the surface measurements should be made by someone independent from the treatment process in order to exclude any bias as far as possible. Surface topography may be used for postural monitoring in the rehabilitation process of patients with scoliosis.

Keywords. Videorasterstereography, VRS, rehabilitation, postural control, objectivity

1. Background

Claims have been made that surface topography is an objective measurement, however there are significant postural influences (relatively large technical error) that influence such measurements [1-3]. The purpose of this study was to help estimate these influences by measuring patients with scoliosis in three standardized postural positions.

2. Material and Methods

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We compared the results between the different postures. Then we calculated the results for the different age groups.

3. Results

There are significant differences in both parameters tested, some of them more than 40% to 67% greater than the measurement error calculated. The best corrective effects were achieved in the second and the third group with the conscious posture. The adult group had the best values in most corrected posture. For the youngest patients there were no significant changes with the different postures. The results are listed in table 1 and 2.

Group	age	NP	ADLP	CP
I	10,8 (SD 1,7)	11,1 (SD 6,7)	10,1 (SD 6,6)	10,6 (SD 5,6)
II	14,6 (SD 1,0)	11,4 (SD 6,0)	8,9 (SD 4,8)	8,3 (SD 4,4)
III	17,7 (SD 1,0)	13,8 (SD 5,3)	11,1 (SD 4,8)	11,2 (SD 4,7)
IV	39,8 (SD 12,9)	17,2 (SD 6,8)	14,9 (SD 7,5)	12,8 (SD 6,3)

Table 1. Average lateral deviation (rms) in the four different age groups in “normal” (scoliotic) posture (NP), ADL posture (ADLP) and in corrected posture (CP).

Group	age	NP	ADLP	CP
I	10,8 (SD 1,7)	5,6 (SD 2,1)	6,3 (SD 4,1)	6,2 (SD 1,9)
II	14,6 (SD 1,0)	6,8 (SD 3,0)	6,2 (SD 2,8)	7,3 (SD 4,5)
III	17,7 (SD 1,0)	7,4 (SD 2,8)	6,5 (SD 2,3)	7,9 (SD 3,6)
IV	39,8 (SD 12,9)	8,7 (SD 2,9)	7,7 (SD 2,8)	9,0 (SD 3,2)

Table 2. Surface rotation (rms) in the four different age groups in “normal” posture (NP), ADL posture (ADLP) and in corrected posture (CP). The changes achieved here are not as clear as the changes in lateral deviation.

4. Discussion

With the outcomes for the different age groups, we are able to create a more evidence based model for conservative treatment in order to improve postures that enable patients to stop the vicious cycle of scoliosis progression by a more balanced loading (unloading) of spine.

5. Conclusions

Surface measurements can be influenced by artificial postures and therefore cannot be attributed as objective. This is why the surface measurements should be made by someone independent from the treatment process in order to exclude any bias as far as possible. Surface topography may be used for postural monitoring in the rehabilitation process of patients with scoliosis [4-7]. The limitations of the use of surface topography to document the outcome of patients during conservative management have well been described [8].

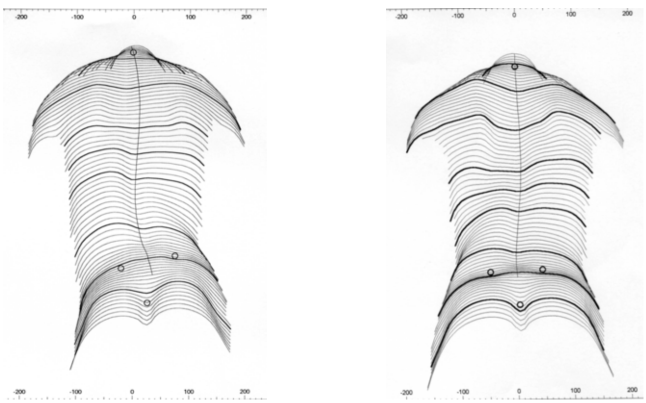

Figure 1. Surface reconstruction of a patient in her scoliotic posture (NP) on the left and corrected during an exercise to achieve best corrected posture (CP) in daily activities.

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Quantification of Localized Vertebral Deformities Using a Sparse Wavelet-based Shape Model

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Abstract: Medical experts often examine hundreds of spine x-ray images to determine existence of various pathologies. Common pathologies of interest are anterior osteophites, disc space narrowing, and wedging. By careful inspection of the outline shapes of the vertebral bodies, experts are able to identify and assess vertebral abnormalities with respect to the pathology under investigation. In this paper, we present a novel method for quantification of vertebral deformation using a sparse shape model. Using wavelets and Independent component analysis (ICA), we construct a sparse shape model that benefits from the approximation power of wavelets and the capability of ICA to capture higher order statistics in wavelet space. The new model is able to capture localized pathology-related shape deformations, hence it allows for quantification of vertebral shape variations. We investigate the capability of the model to predict localized pathology related deformations. Next, using support-vector machines, we demonstrate the diagnostic capabilities of the method through the discrimination of anterior osteophites in lumbar vertebrae. Experiments were conducted using a set of 150 contours from digital x-ray images of lumbar spine. Each vertebra is labeled as normal or abnormal. Results reported in this work focus on anterior osteophites as the pathology of interest.

1. Introduction

The spinal deformities research community is constantly concerned with enhancing the ability to distinguish between the anatomy of healthy vertebrae and others with pathology. Experts frequently examine radiographs of the spine for assessment of various vertebral pathologies. Common pathologies of interest are anterior osteophites, disc space narrowing, and wedging. These pathologies often correlate to the shape variations from space of normal shapes. By careful inspection of the outline of the shape of vertebral bodies, experts are able to identify and assess vertebral abnormalities with respect to the pathology under investigation. Computer-aided methods for quantification of vertebral deformities have been the interest of various research groups worldwide. Conventional quantification methods commonly use a six-point representation for the vertebral body. However, such representation fails to capture subtle shape changes that might be useful for diagnosis [1]

Several authors have proposed methods that make use of the entire vertebral shape rather than the six-point representation. Using the whole shape of the vertebral body is more likely to better quantify vertebral deformities. Symth et. al.,[4], suggested using the PCA-based point distribution model to capture shape variability and employed a Mahalanobis distance classifier to identify vertebral fractures. The National Library of Medicine(NLM) has been for long interested in vertebral classification of spine x-ray images for content-based image retrieval applications. Researchers at the engineering division of the NLM have implemented and evaluated several shape representations for retrieval of spine x-rays using anterior osteophyte pathology. Examples include: Fourier descriptors, polygonal approximations, invariant moments, convex-hull based features, and partial shape matching using dynamic programming [1-3]. Tim Cootes et. al. ,[5], have suggested using active appearance models for segmentation and assessment of vertebral abnormalities, preliminary encouraging results were reported. Marleen de Bruijne et. al ,[6,7], have also proposed a method for vertebral fracture quantification in x-ray images using pairwise conditional shape models.

The work presented in this paper builds upon these efforts by introducing a novel method for quantification of localized vertebral deformities using a sparse shape model that is based on wavelets and Independent component analysis (ICA). The model is able to capture localized pathology-related shape variations, hence it allows for quantification of clinically-relevant vertebral shape deformations. The rest of the paper is organized as follows: section two presents the methodology of the proposed vertebral quantification scheme. Experimental results are presented in section three. Finally, conclusion is drawn in section four.

2. Methodology

This section outlines the details for the proposed vertebral quantification scheme. Using wavelet packets, and Independent component analysis, we first construct a sparse shape model that can capture localized pathology-related deformations. Next, we employ support vector machines and features from the developed model to illustrate the diagnostic capabilities of the method through the discrimination of anterior osteophites in lumbar vertebrae.

2.1. Shape estimation using sparse shape model

First, we build a sparse shape model that decomposes the shape variability within the training set into a number of localized clinically-relevant deformation modes. Given the training set of aligned shapes, a sparse shape representation is achieved by projecting the shapes onto a joint best basis selected from an over-complete dictionary of wavelet packets [8,9] Next, we make use of the approximating power of the wavelet packet basis to achieve a dimensionally reduced representation without significant effect on the approximation accuracy. A reduction of 50 % is achieved with a reconstruction error kept as low as 0.1 %. The n^{th} shape vector in the sparse domain is represented as:

$$S_n = [s^x_{n1} \ldots\ldots s^x_{nm}, s^y_{n1} \ldots\ldots s^y_{nm}]^T \text{, where m < k} \quad (1)$$

Next, we use the Independent Component Analysis (ICA) to model variations in the domain of the dimensionally-reduced sparse shape representations. We consider the projections of the shapes in the training set as mixtures of independent source signals with an unknown mixing matrix. The FastICA algorithm,[10], is used to estimate the demixing matrix. Finally, the linear generative model is formulated as follows:

$$S = \mu + \varphi_{ICA}.b \quad (2)$$

where μ is the mean shape in the sparse domain, and φ_{ICA} is the ICA basis matrix calculated using the estimated de-mixing matrix.

In the shape space, the basis matrix constitutes sets of localized pathology-related deformations. Any shape can then be approximated as a linear combination of the mean shape plus weighted sum of these localized modes of deformations.

2.2. Vertebral quantification using support vector machines

By projecting the shapes onto any specific subset of the localized deformation modes, we obtain a low-dim feature vector that is related to specific vertebra of interest. These feature vectors are then used as an input to a support vector machine classifier to achieve vertebral quantification.

With each vertebra being labeled by expert radiologists as normal or abnormal, the support vector machine classifier (SVM),[11], is then trained to distinguish between normal and pathology populations.

3. Experimental Results

3.1. Experimental Setup

Experiments in this paper were performed on a dataset of lateral lumbar spine x-ray images. Results reported focus on the anterior osteophytes as the pathology of interest. The spine x-ray dataset were provided by the National Library of Medicine [12]. For each x-ray image, the lumbar vertebrae L1-L5 are annotated and labeled as normal or abnormal (i.e with osteophyte pathology) by experienced radiologists. Figure 1 shows how a dataset of lumbar spine shapes is built.

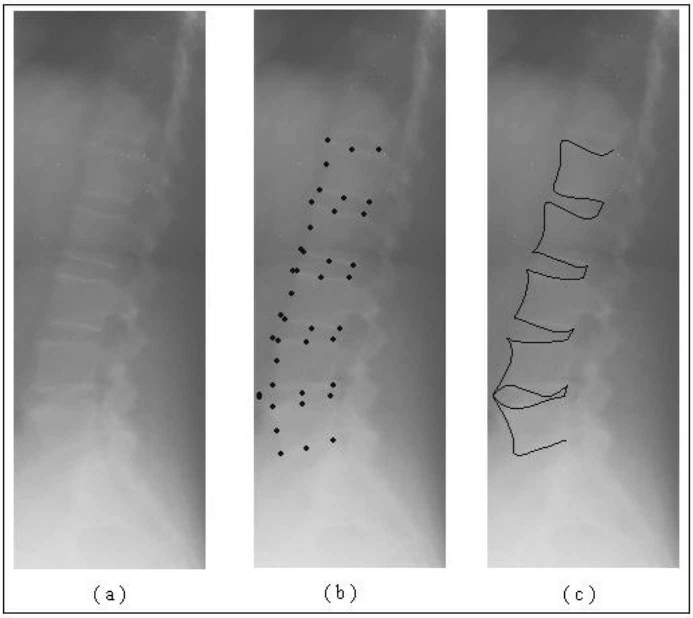

Figure 1. Building a dataset of shapes of the lumbar spine. (a) Sample X-ray image of lumbar spine, (b) Boundary points selected by an expert, (c) Interpolated shape of the lumbar spine.

Experiments were conducted using a set of 150 contours from digital x-ray images of lumbar spine. Each vertebra is labeled as normal or abnormal. Results reported in this work focus on anterior osteophites as the pathology of interest.

3.2. Results

First, we investigated the capability of the model to predict localized pathology related deformations. This was performed using leave-one-out experiment. Figure 2 demonstrates the prediction capability of the proposed shape model, compared to a PCA-based model. Our model tends to better reconstruct shapes of normal and abnormal vertebrae (i.e with anterior osteophyte pathology). Figure 3 shows the prediction error for the proposed model versus the PCA-based model for different number of training samples.

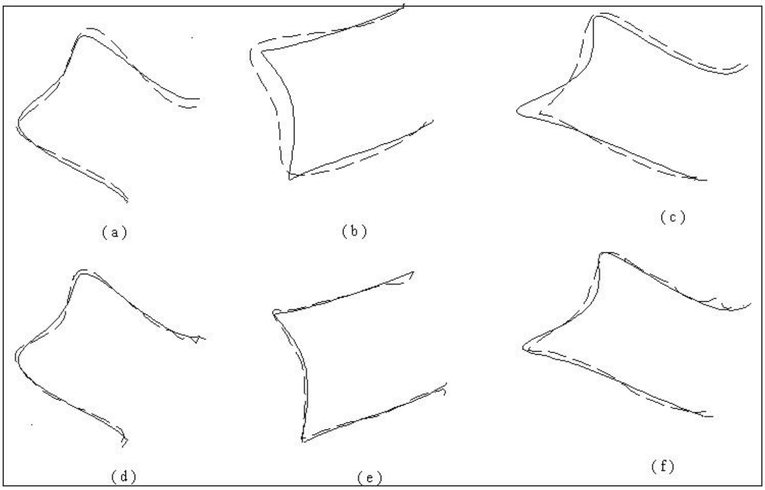

Figure 2. Shape prediction for normal and abnormal vertebrae using PCA-based model (top row), and proposed model (bottom row). (a,d) are normal vertebrae, (b,c,e,f) are vertebrae with osteophytes pathology.

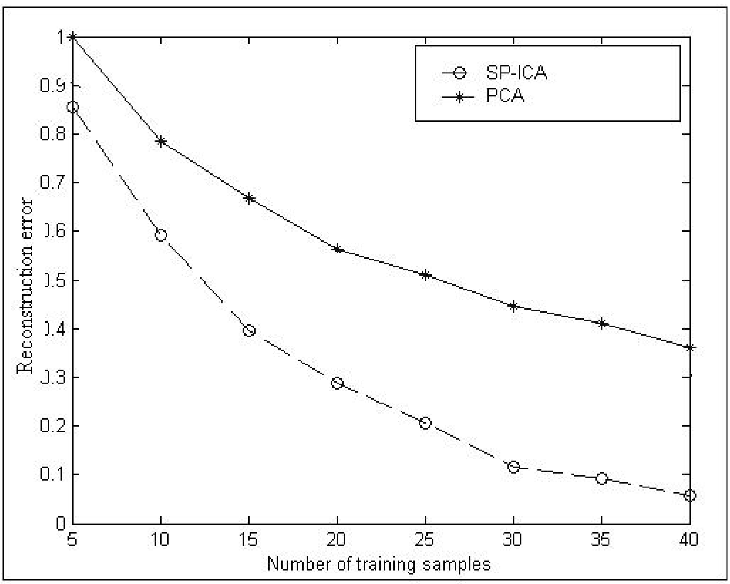

Figure 3. Predication ability of the proposed shape model (SP-ICA),and PCA-based model

The performance of the vertebral quantification scheme is also evaluated using the Receiver Operating characteristics curves (ROC) for vertebral pathology detection. Figure 4 shows the receiver operating characteristic curves for an L1 vertebra. At sensitivity (true positive) of 80 %, our method achieves an average specifity of 96.8 %, versus an average specifity (1-false positive) of 72.5 % for the PCA-based classification..

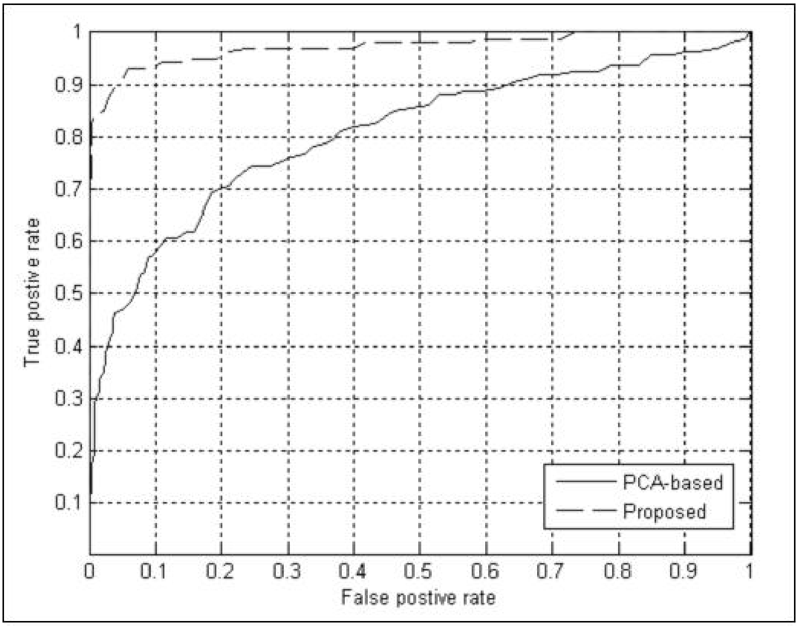

Figure 4. ROC curves for osteophytes detection L1 vertebra.

4. Conclusion

In this paper, we presented a novel method for accurate quantification of vertebral deformities using a sparse shape model. Using wavelets and ICA, we construct a sparse shape model that benefits from the sparsification nature of wavelet packets and the ability of the ICA to capture higher order statistics in the wavelet space. The model efficiently captures localized shape variations, hence it allows for proper quantification of vertebral deformities. The proposed method is able to accurately predict localized pathology-related deformations. Moreover, the method shows promising diagnostic capabilities through the quantification of lumbar vertebrae with respect to anterior osteophites. Future experiments include investigating the performance of the proposed quantification scheme incases of other pathologies such as wedging.

Acknowledgments

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Computer-Assisted Cobb Angle Measurement on Posteroanterior Radiographs

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Abstract. The Cobb angle method is the gold standard to assess severity of scoliosis. A computer-aided method was developed to provide a semi-automatic Cobb angle measurement during a scoliosis clinic. This study was to evaluate the reliability and accuracy of the developed method. Curve types were also tested. The computer method required enhancement of the contrast, normalization of the image size, and selection of the end-vertebrae on the radiographs before the automatic measurement started. The computer-aided process automatically identified the line segments that fitted to the endplates of the end-vertebrae. The Cobb angle was then calculated from the slopes of these lines. Seventy-six radiographs were randomly selected and categorized with Lenke's classification. Among them, 75 cases were used and categorized into 4 types: 1, 3, 5 and 6. One type 2 case was excluded. An orthopedic spine surgeon measured the radiographs manually, serving as the reference standard. Two observers used the developed method and measured twice. For each curve type, the inter-method, inter-observer, and intra-observer variability were analyzed by Intraclass correlation coefficients (ICC[2, 1]). The ICC values were higher than 0.90 in all these types. The developed method was reliable to measure the Cobb angle and was not dependent on the curve type.

Keywords. Cobb angle, scoliosis, computer-aided measurement

1. Introduction

Currently, x-ray is the most commonly used image modality to diagnose and assess scoliosis, and the Cobb angle method [1] is the gold standard to assess the severity of scoliosis. A spinal deformity with a Cobb angle more than 10 degrees is considered scoliosis. Treatment modalities are personalized depending on patient's responsiveness to treatment, expectations, skeletal maturity, curve severity and type, surface deformities, and the risk of progression. Regular observation, orthotic (brace) treatment, and surgery [2] are the most commonly used treatments in North America. In general, a spinal curve with a Cobb angle of 10 to 25 degrees will be examined regularly. Brace treatment is generally considered for curvature between 25 to 45 degrees in a growing child. Surgery is usually considered when the spinal curve progresses beyond 45 degrees. In general, change more than 5 degrees in two successive radiographs is an indication of curve progression or clinically meaningful change beyond measurement error [3].

To measure the Cobb angle, two end vertebrae within the curve were identified. The end-vertebrae chosen tilt most severely toward the concavity of the spinal curve. After the end-vertebrae are selected, the Cobb angle θ is calculated as the sum of the angles of the end-vertebrae, $\theta = \theta_1 + \theta_2$, as shown in Figure 1.

The accuracy and repeatability of manual measurement of Cobb angle depends partially on the operator's experience and judgment. User errors usually are due to selecting different end-vertebrae and/or drawing best-fit lines to the vertebrae endplate. Even the same observer using the same end-vertebrae to measure the Cobb angle can expect to have measurement error of 3 to 5 degrees, increasing to the 5 to 7 degrees range with different observers [3, 4]. This may be beyond the 5 degrees threshold used for progression assessment.

This paper proposes a computer-aided method to reduce variability of Cobb angle measurement. The hypotheses were: (1) measurement would be improved by reducing the judgment required in manual measurement, and (2) computer-aided measurement errors would be insensitive to observer skill levels or experiences.

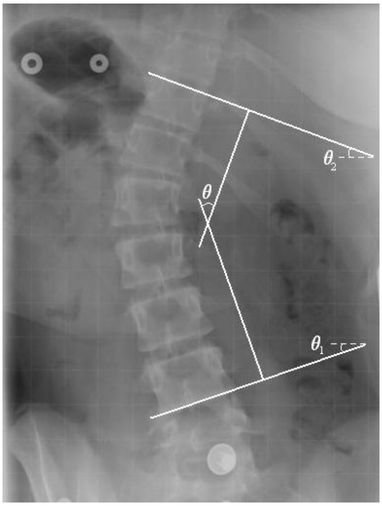

Figure 1. Cobb angle measurement

2. Materials and Methods

To evaluate the proposed method, radiographs were measured by an experienced orthopedic spine surgeon and used as the reference standard. Two observers then used the proposed method twice to determine the measurement variability. The inter-method, inter-observer, and intra-observer variability were analyzed by Intraclass correlation coefficients (ICC[2, 1]) [5].

Seventy six posteroanterior (PA) radiographs were tested (71 F; 5M, age 14.7±2.3 years, Cobb angle 35°±12°), which met the inclusion criteria 1) diagnosis of idiopathic scoliosis, 2) ages between 9-18 years, 3) Cobb angle less than 90 degrees, and 4) no prior spine surgery. The exclusion criteria were patients who had other musculoskeletal or neurological disorders. Ethics approval of this study was granted from the local ethics board. The curves were grouped according to Lenke's classification [6]. There were 29, 1, 14, 16, and 16 cases classified as type 1, 2, 3, 5, and 6, respectively. Since there was only one type 2 case, it was excluded from our study.

Although the spinal radiographs were obtained from only one site, the quality of the spinal radiographs was still inconsistent, due to patient height and weight, curve severity and technician skills. Prior to applying the proposed method, a consistent preprocessing protocol of cropping the spinal radiograph from C7 to Sacrum and resizing the images to a standard height of 1000 pixels was performed. The brightness and the contrast of the resized images were manually adjusted by using Image J software [NIH, USA]. The most tilted end-vertebrae were selected. The regions of interest (ROI) of size 100 × 80 pixels, containing the selected end-vertebrae were created by the algorithm. The anisotropic diffusion algorithm [7] was used to denoise the ROI images. The Canny edge detector [8] was then applied to the denoised ROI images to obtain the edge images which were prerequisite to implement the Hough Transform [9].

2.1. Fuzzy Hough Transform (FHT)

Hough transform (HT) [9] was originally proposed as a technique to detect straight lines. Applying HT to a set of edge points results in the accumulator array $C(\rho_k, \theta_k)$, which represents the number of edge points on the line specified by (ρ_k, θ_k). By finding the local peaks of $C(\rho_k, \theta_k)$, the most likely lines can be detected. Han et al [10] developed the FHT, where each edge point in the region around the ideal line contributed more or less to the accumulator C depending on its distance from the ideal line. Therefore, the FHT can be used to detect distorted line structures.

In order to calculate the Cobb angle, we tried to use the FHT to detect the line segments that fitted to the endplates of the end-vertebrae. However, because of the complexity of vertebrae images, the FHT sometimes failed. Our solution was to incorporate vertebral shape constraints into the FHT.

2.2. Cobb Angle Measurement by FHT with Vertebral Shape Constraints

The vertebral shape satisfied the specific geometric relations: (1) the endplates were close to parallel; (2) the horizontal and vertical sides were close to perpendicular; (3) 45-degree was considered as the maximum angle of a single tilted vertebra possibly met in this study; (4) the vertebrae in the resized images were within a pre-defined size constraint of 30 to 60 pixels in height and 40 to 80 pixels in width.

These vertebral shape constraints were incorporated into the FHT to detect lines that fitted to the vertebral endplates. Firstly, the FHT was applied to the vertebral edge image. In the Hough space, the peaks whose C values were beyond 60% of the maximum C value were chosen. Let $C_1 = (\rho_1, \theta_1)$, $C_2 = (\rho_2, \theta_2)$,…, and $C_l = (\rho_l, \theta_l)$ denote the l peaks selected. Secondly, the peaks satisfying $|\theta_i - \theta_j| < 10$ were paired. Let $\bar{\theta}$ denote the average angle of a pair of peaks, i.e. $\bar{\theta} = |\theta_i + \theta_j|/2$. Thirdly, the pairs, which satisfied $-45 < \bar{\theta} < 45$ and $30 < |\rho_i - \rho_j| < 60$, were selected as the horizontal candidate pairs; the pairs, which satisfied $\bar{\theta} > 45$ or $\bar{\theta} < -45$ and $40 < |\rho_i - \rho_j| < 80$, were selected as the vertical candidate pairs. Let $\bar{\theta}_{\mathbf{H}n}$ and $\bar{\theta}_{\mathbf{V}n}$ respectively represent the average angles of the nth horizontal and vertical candidate pairs. Fourthly, the candidate couples of pairs satisfying $||\bar{\theta}_{Hn}-\bar{\theta}_{Vm}|-90|<10$ were selected. Finally, the two pairs with the maximum average C values, of which the horizontal pair (average angle $\bar{\theta}_H$) was considered as the peaks that corresponded to the endplates were identified. The angle $\bar{\theta}_H$ was considered as the angle of the vertebra. As an example, Figure 2 showed three cases of vertebrae and the line segments detected by the FHT under the vertebral shape constraints. In each case, two lines were fitted to the endplates and the middle line indicated the vertebral direction ($\bar{\theta}_H$). Based on the detected angles ($\bar{\theta}_H$) of the end-vertebrae, the Cobb angle was calculated as the sum of the angles of two end-vertebrae.

2.3. Performance Analysis

Two examiners measured the Cobb angle on each radiograph by using the developed method twice over a 2 weeks period. Examiner 1 (E1) has the scoliosis clinic experiences for 20 years, and examiner 2 (E2) has no clinical experiences to measure Cobb angle. The manual measurement was performed by an orthopedic surgeon (S). The results obtained from the surgeon were considered as the true values. Although some spines had multiple curves, the examiners chose to measure only the largest curve. The intraclass correlation coefficient (ICC, varying between 0 and 1) with 95% confidence intervals (CI) was used to evaluate the reliability.

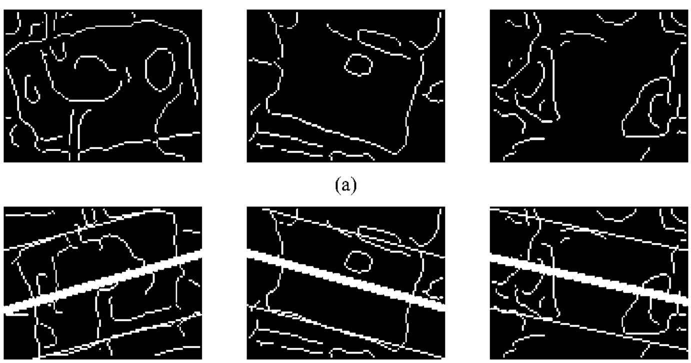

Figure 2. Edge images of vertebrae and detected line segments: (a) edge images of vertebrae; (b) detected vertebral directions and line segments that fit to the vertebral endplates.

3. Results

For each curve type, the Cobb angles from the surgeon and two examiners were listed in Table 1. It can be seen that the average differences of the inter-method, inter-observer and intra-observer were less than 5 degrees, regardless of the curve types.

For each curve type, the ICC values shown in Table 2 indicated the high agreement between the automatic and manual measurements (ICCs > 0.90). The inter-observer and intra-observer analysis results were given in Table 3 and Table 4, respectively. The ICC values of higher than 0.90 indicated the high inter-observer and intra-observer reliability of the proposed method.

Table 1. Cobb angle measured by the surgeon and two examiners

	Type 1 (29 cases)	Type3 (14 cases)	Type5 (16 cases)	Type 6 (16 cases)
S	35.3°±13.0°	41.7°±13.5°	27.8°±11.5°	37.2°±9.9°
E1 1st meas.	34.4°±14.6°	41.1°±13.7°	26.1°±10.6°	35.8°±7.9°
E1 2nd meas.	33.3°±13.3°	40.6°±13.6°	25.4°±12.4°	36.0°±8.9°
E2 1st meas.	34.8°±13.8°	41.5°±13.6°	27.3°±12.21°	36.9°±10.4°
E2 2nd meas.	34.5°±13.9°	42.0°±15.0°	25.9°±12.5°	36.4°±9.2°

Table 2. Inter-method analysis.

	Type 1 (29 cases)	Type3 (14 cases)	Type5 (16 cases)	Type 6 (16 cases)
S vs. E1 1st meas.	0.98 (0.96, 0.99)	0.97 (0.91, 0.99)	0.95 (0.85, 0.98)	0.91 (0.74, 0.97)
S vs. E1 2nd meas.	0.97 (0.93, 0.98)	0.98 (0.94, 0.99)	0.96 (0.88, 0.99)	0.91 (0.75, 0.97)
S vs. E2 1st meas.	0.97 (0.94, 0.99)	0.98 (0.93, 0.99)	0.97 (0.91, 0.99)	0.93 (0.81, 0.98)
S vs. E2 2nd meas.	0.96 (0.91, 0.98)	0.96 (0.86, 0.99)	0.94 (0.84, 0.98)	0.93 (0.79, 0.97)

Table 3. Inter-observer analyses.

	Type 1 (29 cases)	Type3 (14 cases)	Type5 (16 cases)	Type 6 (16 cases)
E1 vs. E2 1st meas.	0.98 (0.95, 0.99)	0.98 (0.94, 0.99)	0.97 (0.91, 0.99)	0.94 (0.84, 0.98)
E1 vs. E2 2nd meas.	0.97 (0.94, 0.99)	0.98 (0.92, 0.99)	0.97 (0.91, 0.99)	0.91 (0.77, 0.97)

Table 4. Intra-observer analyses.

	Type 1 (29 cases)	Type3 (14 cases)	Type5 (16 cases)	Type 6 (16 cases)
E1 1st vs. 2nd meas.	0.98 (0.96, 0.99)	0.99 (0.96, 0.99)	0.99 (0.96, 0.99)	0.97 (0.92, 0.99)
E2 1st vs. 2nd meas.	0.97 (0.94, 0.99)	0.98 (0.95, 0.99)	0.97 (0.92, 0.99)	0.98 (0.96, 0.99)

4. Conclusion

Based on the study of 75 PA radiographs, the proposed computer-aided method was able to provide an accurate and more reliable measurement of the Cobb angles than has been reported for manual measurements. The results were not sensitive to curve types.

However, the developed method still required user judgment in the pre-processing stage. Although the shape constraints were reasonable for most radiographs, false detection might occur if a vertebra tilted more than 45 degrees or the vertebra had a severely deformed shape that did not satisfy the shape constraints. In addition, the proposed method cannot be used to measure the post-surgical cases.

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New Method of Scoliosis Deformity Assessment: ISIS2 System

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Abstract. Scoliosis deformity has been assessed using radiographic angle measurements. Surface topography systems are an alternative and complementary methodology. Working systems include the original ISIS1 system, Quantec and COMOT techniques. Over the last five years the new ISIS2 (Integrated Shape Imaging System) has been developed from basic principles to improve the speed, accuracy, reliability and ease of use of ISIS1. The aim of this study was to confirm that ISIS2 3D back shape measurements are valid for assessment and follow up of patients with scoliosis. Three-dimensional back measurements were performed in Oxford. ISIS2 includes a camera/projector stand, patient stand with a reference plane, and Mac computer. Pixel size is ~0.5 mm with fringe frequency of ~0.16 fringes/mm (~6.5 mm/fringe). Clinical reports in pdf format are of coloured images with numerical values. Reports include a height map, contour plot, transverse section plots, coronal plot, sagittal sections and bilateral asymmetry maps. A total of 520 ISIS2 scans on 242 patients were performed from February 2006 to December 2007. There were 58 male patients (median age 16 years, SD 3.71, min 7, max 25) and 184 female patients (median age 14.5 years, SD 3.23, min 5, max 45). Average number of scans per patient was 2.01 with the range of 1-10 scans. Right sided thoracic curves were the most frequent pattern. The median values and 95% CI are reported of back length; pelvic rotation; flexion/extension; imbalance; lateral asymmetry; skin angle; kyphosis angle; lordosis angle; volumetric asymmetry. ISIS2 scoliosis measurements are non-invasive, low-cost, three-dimensional topographic back measurements which can be confidently used in scoliosis assessment and monitoring of curve progression.

Keywords. Scoliosis, surface topography, ISIS2

1. Introduction

Scoliosis can be defined as a lateral curvature of the spine with concordant vertebral rotation [1]. Scoliosis deformity has1, traditionally, been assessed using radiographic angle measurements. In radiographs, spine deformity is quantified by the Cobb angle measurement [2]. It represents a relatively simple way to measure scoliosis angle and has an agreed interobserver error [3,4]. However, the Cobb angle alone cannot describe surface deformity. The correlation between the degree of the curvature and the rib hump is poor [5]. Spinal radiographs involve significant radiation exposure, so serial measurements need a strong justification. There is some evidence that curve progression can be detected first through rib hump changes rather than Cobb angle [6] and that brace treatment is better at changing the rib hump than the Cobb angle [7]. These have been the main drivers for development of surface topography systems.

Numerous different methods of scoliosis deformity assessment have been developed and described in the literature, but only a few are still used in clinical practice. Problems with operating skills, ease of interpretation, and the value of information provided have all played an important role in why they have not been widely adopted. Techniques that use surface topography, such as the Integrated Shape Imaging System (ISIS1), COMOT and Quantec provide an image to be interpreted, as well as numbers to be calibrated and allocated to the scoliosis deformity for presentation [6, 8-10]. Despite their wide use, the complexity of the skills needed in their operation and interpretation make the continuing use of the apparently simple but often misleading Cobb angle the easy option. Over the last five years the new ISIS2 (Integrated Shape Imaging System 2) has been developed to evaluate the three-dimensional shape of the back in scoliosis assessment, with a specification to make the patient, operator and user experiences as straightforward and repeatable as possible [11].

The aim of this study was to confirm that ISIS2 3D back shape measurements are a valid and effective method of assessment and follow up of patients with scoliosis.

2. Method

ISIS2 consists of: a camera and projector housing; a telescopic column; a patient stand with reference plane; and a computer controlling the projector and camera. Pixel size was ~0.5 mm with fringe frequency of ~0.16 fringes/mm (~6.5 mm/fringe). This gives an accuracy of ±1 mm in the height of the calculated surface. The printout is based on the ISIS1 output. We have added: a height map and contour plot, additional transverse section plots, a new sagittal plot giving kyphosis angle and two bilateral asymmetry maps showing, respectively, any and >10mm asymmetries. All patient data are recorded in an integral database. When more than one scan has been made, serial measurements are plotted graphically. The clinical parameters measured in the system are: back length, pelvic rotation, maximum and minimum skin angles in the transverse plane, coronal imbalance, lateral asymmetry (a proxy for Cobb angle), flexion/extension, lordosis and kyphosis angles, and transverse volumetric asymmetry. Three-dimensional back measurement data were retrieved from our database. Statistical analysis of data was performed using the SPSS 16.0 System for Windows and a paired Student's t-test.

Table 1. ISIS2 measurements

Variable	Median value	CI	Min value	Max value
Back length	421 mm	404.96 to 415.18	245 mm	568 mm
Pelvic rotation	1°	0.24 to 0.84	–17°	13°

Max skin angle	7°	7.57 to 8.57	0°	40°
Min skin angle	–5°	–6.90 to –5.91	–36°	0°
Imbalance	4 mm	0.98 to 3.88	–55 mm	53 mm
Upper lateral asymmetry	–12°	-12.90 to -8.98	–78°	46°
Lower lateral asymmetry	9°	3.02 to 7.85	–67°	70°
Flexion/extension	3°	3.27 to 3.94	–9°	16°
Lordosis angle	35°	34.17 to 36.91	–6°	85°
Kyphosis angle	33°	32.84 to 35.28	0°	79°
Left volumetric asymmetry	4	7.69 to 10.27	0	97
Right volumetric asymmetry	11	14.09 to 16.66	0	90

3. Results

A total of 520 ISIS2 scans were performed on 242 patients from February 2006 to December 2007. The patients include 58 males (median age 16 years, SD 3.71, minimum 7 years, maximum 25 years) and 154 females (median age 14.5 years, SD 3.23, min 5 years, max 45 years). On average, there were 2.01 scans per patient with the range of 1-10 scans. Right sided thoracic curves predominated.

The measured ISIS2 values are presented in Table 1.

4. Discussion and conclusion

The use of radiographs in monitoring the development of scoliosis deformity is the traditional method. A standard posteroanterior radiograph of the spine is usually taken and the magnitude of the curve is used to determine the appropriate treatment. However, most clinicians classify the degree of the scoliosis deformity in terms of coronal plane radiograph without analyzing the three-dimensional components of the spinal deformity.

The value of the ISIS2 system is that it provides a non-invasive coloured three-dimensional assessment of scoliosis deformity in pdf format. Easy to interpret graphical plots of the back in the coronal, transverse and sagittal planes are presented on a single sheet of A4 paper. A second page shows change in values when there are serial observations, and a third a digital photograph of the patient's back. The scan time is brief (<0.1 sec), reducing movement error. A whole examination can be completed in 10 minutes. The repeatability is excellent.

We were not able to compare ISIS2 scans with radiographic measurements in all patients because of the effort to reduce the risk of radiation and avoid unnecessary radiographs in monitoring the scoliosis progression. We compared the two in 111 patients and found no statistically significant difference between them. These data will be reported separately.

This study has limitations because of the relatively small number of patients and the short duration of follow-up. We are expecting that further follow up studies of the patients with the ISIS2 topographic surface measurements will confirm our present opinion that ISIS2 is a significant improvement on earlier surface topography systems. ISIS2 scoliosis measurements are non-invasive, low-cost, three-dimensional topographic back measurements which can be confidently used in scoliosis assessment and monitoring of curve progression, with no exposure to ionizing radiation after the initial assessment.

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A Novel Solution for Registration of Stereo Digital Torso Images of Scoliosis Patients

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Abstract. This paper presents a procedure for registration of a pair of stereo digital images giving an improvement in accuracy and speed over existing methods. It does so by a novel approach combining color based image segmentation and differential geometry. It involves three stages: image segmentation, adaptive local pixel matching, and deferential geometry in a tree weighted belief propagation procedure. The registration was compared to 2 existing registration procedures, segment-based adaptive belief propagation (adaptive BP) and color-weighted hierarchical belief propagation (hierarchical BP). A 3D scan of a mannequin was obtained and errors in reconstruction were measured for each of the 360 cross sections of the mannequin. The proposed procedure outperforms existing methods, particularly for high curvature regions and significantly large cross sections. Its accuracy of reconstruction ranged from 85-100% compared to 75-100% for other existing methods. It was 35% to 40% faster. This work provides a solution to the registration problem and is an important step in developing a cost effective technique for measuring torso shape and symmetry of scoliosis patients using stereo digital cameras.

Keywords. Scoliosis, Registration, Image Segmentation, Pixel Matching, Belief Propagation

1. Introduction

Scoliosis is a condition characterized by lateral deviation of the spine coupled with rotation of individual vertebra resulting in visible torso asymmetries [10]. Assessment of the severity of scoliosis is traditionally done using radiographs of the spine [11]. However, radiographs do not describe the visible torso deformity associated with scoliosis. Torso imaging can describe torso deformities and reduce the need for radiographs, effectively reducing the risk of cancer [11].

Optical/Imaging methods have been used for assessment of scoliosis and monitoring of its progression. Some of these are Moiré topography, ISIS scanning, Quantec system scanning, rasterstereography, laser scanning and stereo vision imaging [11]. Much advancement has been made in improving each of these methods over the past years. However, ISIS scanning is a slow process and produces poor resolution images. The Quantec system scanning, laser scanning and rasterstereography are expensive due to the hardware components involved and also immobile. Images produced via Moiré topography are highly dependent on posture of the patient and provide a relative measure based on contours rather than a quantitative measure. In light of the problems associated with 3D imaging of the torso, stereo vision has become a cost effective alternative.

Progress in computer vision and availability of faster computer processors has lead to development of stereo vision algorithms for simultaneous stereo camera capture, calibration and reconstruction. Stereo capture systems consist of digital or TV cameras positioned with known geometry. Significant advances have been recently made in the area of computer vision, as a result of publically available performance testing such as the Middlebury data set [1], which has allowed researchers to compare their algorithms against all state-of-the-art algorithms [7]. Stereo correspondence or registration of stereo images is one of the most active research areas in computer vision [1]. In the area of stereo vision research, stereo images refer to images captured at different viewpoints using cameras with known geometry [5]. In order to register the stereo images, we need to determine the closest (least error) or best point-to-point correspondence between the two images.

Stereo registration algorithms can be used on stereo images captured using calibrated digital or TV cameras to obtain three dimensional (3D) point set data. A triangulation algorithm is primarily applied on point set data to obtain a 3D surface. 3D surface reconstructions of scenes or localized objects in a scene using stereo vision has modern applications in 3D modelling, computer graphics, facial expression recognition, surgical planning, architectural structural design etc. [2,8]. The 3D scene geometry established from this process can be used to reconstruct 3D torso images to study scoliosis.

However a problem associated with the existing stereo registration algorithms such as that developed by Klauss, Sormann and Karner [4] is that it assumes frontal parallel plane geometry. This means that it assumes depth is constant (with respect to the rectified stereo pair) over a region under consideration [3]. Reconstruction of smooth and curved surfaces where depth is constantly changing violates this assumption. Li and Zucker [8] have tried to solve this problem using differential geometry but they have not applied their algorithm to the one developed by Klauss, Sormann and Karner [4]. Belief Propagation and Graph Cuts are the most commonly used methods for refinement of the registration process [1]. Tree Re-weighted Message Passing, which might become a serious rival to Belief Propagation and Graph Cuts [13], has not been used with differential geometry. Tree Reweighted Message Passing's improvement over Belief Propagation and Graph Cuts becomes significant for more difficult functions [13].

This paper presents a procedure for registration of a pair of stereo digital images using image segmentation, adaptive local pixel matching, and differential geometry in a tree reweighted belief propagation procedure. The major contribution of this paper lies in incorporating differential geometry and Tree Reweighted Message Passing to Segment-Based Stereo Matching Using Belief Propagation and a Self-Adapting Dissimilarity Measure [4] to create a novel procedure with better accuracy and speed.

2. Materials and Methods

Stereo registration methods are assessed using univalued disparity function of one image with respect to the other (referred to as reference image). When first introduced in human vision literature, disparity was used to describe the difference in location of corresponding features seen by the left and right eye [1].

The x, y spatial coordinates of the disparity space are taken to be coincident with the pixel coordinates of a reference image. The correspondence between a pixel in a reference image and pixel in the matching image is linearly related to each other by the disparity function. The disparity function obtained over the 2D images is known as the disparity space image (DSI). DSI gives a 3D point set data using the calibration parameters of the stereo cameras. It represents the confidence or log likelihood of a match implied by the disparity function.

The procedure for obtaining disparity is divided into three stages: mean shift color segmentation, adaptive local pixel matching, and differential geometry in a tree reweighted belief propagation procedure as illustrated in Figure 1.

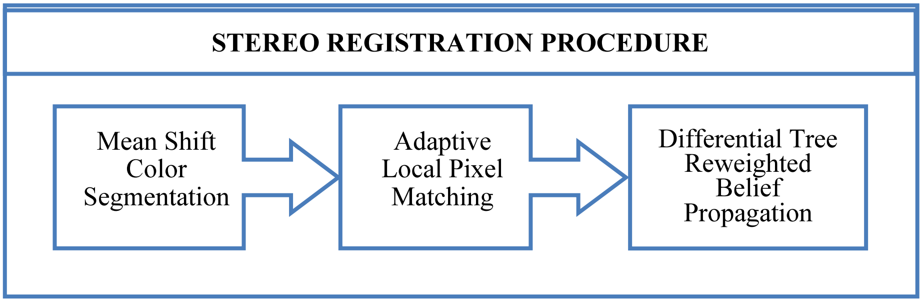


Figure 1. Flow-chart of stereo registration procedure.

The process of color segmentation is to decompose the reference image into regions of color or grayscale [4]. The mean-shift analysis approach is essentially defined as a gradient ascent search for maxima in a density function defined over a high dimensional feature space [4]. Comaniciu and Meer's [13] mean shift segmentation is insensitive to differences in camera gain and is therefore used.

The next step involving local pixel matching is an essential step for defining a disparity plane. The aim of this step is to provide an initial estimate of the disparity space image (DSI). This basic idea is to obtain a measure of disparity that can be optimized and refined. The disparity plane is based on 3D x-y-d space supporting slanted and curved surfaces where x, y are spatial coordinates and d is the inverse depth or disparity. The disparity planes are calculated using local pixel matching. Local pixel matching requires calculation of a matching score and an aggregation window [4]. Matching score is obtained using a self-adapting dissimilarity measure that combines the sum of absolute pixel intensity differences (SAD) and a gradient-based measure as implemented by Klauss, Sormann and Karner [4].

The last stage involves calculation of the final disparities. The algorithms that perform well in this stage are based on an energy minimization framework. This means that we need to choose at each pixel the disparity associated with the minimum cost value [1]. It involves minimizing two separate energy functions that are summed together to calculate the final energy minimization term as given by the equation,

$$E(d) = Edata(d) + \lambda Esmooth(d) \quad (1)$$

where d represents disparity. The symbol Edata(d) measures how well the disparity function agrees with the input image pair and is given by the summation of matching score over the spatial coordinates. The formulation of Edata(d) is

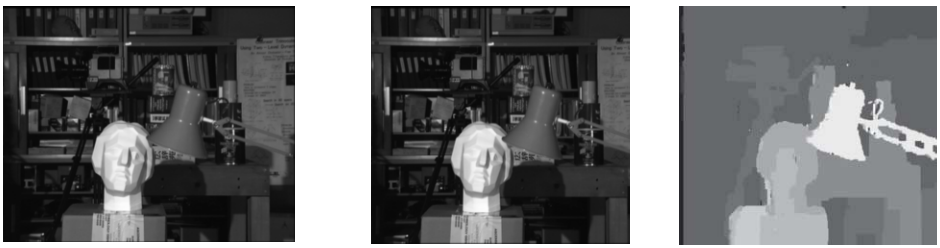
$$Edata(d) = \Sigma\, C(x, y, d(x, y)) \quad (2)$$

where C is the matching score. The symbol Esmooth(d) encodes smoothness in the image by measuring the differences between the neighboring pixels' disparities [1]. It is given by the following equation,

$$Esmooth(d) = \Sigma\ \rho(d(x, y) - d(x+1, y)) + \rho(d(x, y) - d(x, y+1)) \quad (3)$$

where ρ is some monotonically increasing function of disparity difference. The Esmooth(d) operates on the frontal parallel assumption that is altered in this procedure as suggested by Li and Zucker using "floating" disparities [2]. Li and Zucker apply "Floating disparities" on the Max-Product Belief Propagation framework. Tree-Reweighted Message Passing as defined by Kolmogorov [13] is used in this procedure as the energy minimization framework. The key subroutine of the Tree-Reweighted Message Passing algorithm is Max-Product Belief Propagation [13]. The "floating" disparities [2] are therefore added to the Max-Product Belief Propagation component of Tree-Reweighted Belief Propagation. The Tree-Reweighted Belief Propagation is advantageous because messages are passed in a sequential order rather than a parallel order requiring half the space. Convergence is reached in two passes rather than having a convergence condition as in the case of Max-Product Belief Propagation. Therefore applying differential geometry to Tree-Reweighted Belief Propagation produces better results.

Stereo digital images of 400x300 resolution from the Middlebury dataset [1] and the resultant DSI obtained using the above procedure are shown in Figure 2 below.



a b c

Figure 2. A. Digital Image from left camera. B. Digital Image from right camera. C. Disparity Space Image taking image from left camera as reference image and image from right camera as matching camera.

3. Results

The registration was compared to 2 existing registration procedures, segment-based adaptive belief propagation (adaptive BP) and color-weighted hierarchical belief propagation (hierarchical BP). A 3D scan of a mannequin was obtained and errors in reconstruction were measured for each of the 360 cross sections of the mannequin. The proposed procedure outperforms existing methods, particularly for high curvature regions and significantly large cross sections. Its accuracy of reconstruction ranged from 85-100% compared to 75-100% for other existing methods. It was 35% to 40% faster.

4. Discussion

This work provides an improvement over existing stereo correspondence methods. It is an important step in developing a cost effective technique for measuring torso shape and symmetry of scoliosis patients. Future work will focus on validating the procedure on larger and more complex datasets.

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Marker placement for movement analysis in Scoliotic patients: A critical analysis of existing systems

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Abstract Optoelectronic movement analysis systems has provided an opportunity for a detailed study of both normal and abnormal human walking and has contributed to the planning and documentation of corrective surgical procedures. The majority of reported studies have been on the study of lower limbs which, consequently, have received most attention in movement analysis. In contrast, movement of the trunk and pelvis, important in the identification of spinal mobility and maintaining posture, have received limited attention in relation to clinical conditions such as scoliosis. Any movement analysis requires the identification of anatomical landmarks which are essential contributing factors to the accuracy of the analysis. While there are a plethora of studies on marker placements for the lower limbs, there is a paucity of information on the marker locations for spinal analysis. Present study examines a set of markers previously reported in the literature and examines their usefulness in scoliotic gait analysis. The findings highlight the drawbacks in previously reported techniques and leads to the proposal of a new marker set for spine and back movement analysis.

Keywords: Marker placement, Scoliosis, Spine

1. Introduction

Previous reports indicate the usefulness of opto-electronic systems for gait measurement [1]. While, there are some limitations to the measurement of gait and to the interpretation of these measurements for clinical purposes, studies have compared the performance of various commercially available kinematic systems [2]. Generally, these systems employ a set of markers predetermined to be placed in chosen anatomical landmarks. However, due to skin movement, the marker array displaces and rotates rigidly, relative to the underlying bone. Furthermore, the shape of the total array changes. Both effects introduce errors and these skin movement artefacts cannot be eliminated unless markers are applied directly on the bones. Therefore reconstruction of a musclo-skeletal system and the calculation of its kinematics must take account of skin movement artefacts. Previous investigations have shown the adverse effects of skin movement artefacts in the accuracy of calculated joint kinematics, partcularly in the frontal and transverse planes than in the sagittal plane [3]. This factor becomes critical, since abnormalities in subjects with pathological gait, such as children with scoliosis, essentially occur in these planes. Therefore reduction of the effects of skin movement artefacts in the two planes will improve the quality of gait analysis data for clinical purposes. Despite limitations, various investigations have demonstrated the usefulness of 3-D gait analysis in treatment and rehabilitation [1,4].

Research has addressed the technical and instrumentation problems of describing the back shape and the methods used to define the spinal configuration. While, the working group on 3-D terminology of spinal deformities, in a report to the Scoliosis Research

Society, raised an increasing concern about the possible etiologic, surgical and cosmetic significance of axial rotation [5], it was observed that measurement of deformity and classification of curve patterns based on a two dimensional PA radiograph does not accurately predict the progression or response to treatment. This observation emphasises the need for a 3-D measurement and description of scoliotic deformities. Investigations on spine and back measurement in patients with scoliosis using a light emitting diode(LED) marker based system was reported by Dawson et al.[6] . Pearcy [7], while reviewing the techniques for back measurement highlighted the lack of a system for comprehensive measurement of back movement in three dimensions. Later, Pearcy et al, [8] developed a technique involving rigorous mathematical analysis to describe the three dimensional rotations of the upper lumbar spine in relation to pelvis. However, this study employed some specially designed rigs with reflective markers to measure the rotations of the human back. Results indicated higher ranges of movement than those previously recorded for spinal movement. This implied that the recording included some other movement other than pure spinal movement. Another study by using a LED based system, investigated and presented a comprehensive account of trunk movements in the lateral, forward-backward and vertical directions during human locomotion over a wide range of velocities, from slow walking to relatively fast running [9]. Similar studies reported the rotational and translational movement features of the pelvis and thorax during adult human locomotion [10].

Gracovetsky et al. [11], observed that spine marker motion in normal subjects is a good indicator of lumbar spine motion and function. Furthermore, they suggested that the motion of skin is not random but may contain quantifiable information. However, it was indicated that further investigation is still required to ascertain if these patterns are pertinent to the identification of pathology. More recently, Whittle and Levine [12] has measured lumbar lordosis using an opto electronic system and Crosbie and Vachalathiti [13] investigated the synchrony of pelvic and hip joint motion during walking. Studies of patterns and ranges of movement of the lower thoracic and lumbar spinal segments and pelvis indicated an increased range of motion in each segment with increased walking speed. This was accompanied by a significant reduction in the range of motion of the spine with advancing age[14]. While recording the movement of segments about three orthogonal axes, Crosbie et al. [15] observed consistent patterns within and between segments and movements, with apparent consequential trunk motion following pelvic displacements. Spine and back movement associated with walking are linked to the primary motions of the pelvis and the lower limbs. Spinal segments demonstrate coupling movements complementary to the motion of pelvis with respect to spinal flexion-extension and lateral flexion. Although there are drawbacks in the employment of marker rigs and the location of anatomical landmarks, these studies highlight the use of a passive (reflective) marker-based opto-electronic system to measure back and pelvic movements. Therefore the purpose of this study is critically examine all the reported marker sets with a view to develop a reliable marker set and a protocol for spine and back movement.

2 Materials and Methods

Ethical approval was sought and given by the University ethics committee. Children and individuals receiving any type of treatment were excluded from the study. 3 subjects were selected using convenience sampling according to their availability to data collection sessions. Subjects were free of any musculoskeletal conditions and abnormalities which included back pain. All subjects gave an informed consent to take part in the study. Upper age limit was set to 40 to exclude subjects with undetermined early degenerative changes in the lumbar spine. It has been suggested that the pathology peaks between the ages of 35 and 55 [16]. Subjects with obvious lower extremity deformity; particularly marked internal/external femoral or tibial torsion were excluded on the basis that these deformities may affect the translation of rotation up the locomotor chain. Subjects with a leg length discrepancy >2cm were also excluded in line with the European guidelines for the prevention of Low back pain [17].

Kinematic data was acquired using an optoelectronic motion analysis system (VICON, Oxford). The system utilised 8 infrared cameras to track 15mm reflective markers that were placed on specific landmarks on the back and lower limb as specified in previous research in question. One such marker set is given in Figure 1. The system was calibrated using the manufacturer's guidelines at the beginning and end of each data collection session.

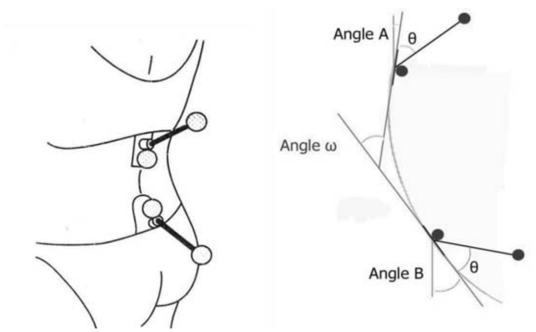

Figure 1: Marker Set proposed by Whittle and Levine. (1997)

A single subject pilot studies were completed and specific positions of the markers identified by the system were verified by using actual measurements.

3. Results and Discussion

This investigation examined the ROM and the movement of markers placed on the back and pelvis, employing a three-dimensional opto-electronic system. Since the marker placement was not clearly defined by the authors in the previous studies, it was not possible to directly compare the results of the present study with the earlier investigations. Furthermore, since there is a paucity of reliability studies in the use of marker systems we concentrated on the reliability of marker placements and the measurements. One of the drawbacks highlighted by the present study is the time taken for subject preparation for data collection, which would raise difficulties for novice operators who are unfamiliar with palpating and locating the spinous processes. We have tried to reduced this by limiting the number of markers placed on the subject. Marker placement procedure similar to the arrangement suggested by Crosbie and Vachalathiti [13] proves to be useful, however more clinical studies are warranted.

While demonstrating the effects of skin movement, this study has indicated the feasibility of a non-invasive technique with a potential to contribute to the dynamic assessment of scoliosis. Further investigation on the compensation due to coupling movements is needed. While this study has looked at the feasibility of applying this technique to assess kinematics between smaller segments within the back, this area needs to be explored in detail.

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The central cord-nervous roots complex and the formation and deformation of the spine; the scientific work on systematic body growth by Milan Roth of Brno (1926-2006)

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1. Introduction and biography.

Professor Milan Roth died on April 4, 2006. He was a professor of neuro-radiology of the J.Ev.Purkynẽ-University (now: Masarek-University) in Brno, Czechoslovakia, now the Czech Republic.

Milan Roth was born on October 6, 1923 in Lelekovice, a small village north of Brno, in local schoolmaster's family. After completing his grammar school studies in Brno in 1942, he spent a year improving his language skills because the Czech universities were closed at the wartime. Since 1943 till the end of World War II, he was a "Totaleinsatz" in an armament factory in Kurim near Brno. After the war, he studied at the Medical Faculty of (now)Masaryk University in Brno, completing his studies on September 29,1949. After completing his studies, he was assigned to the department of surgery at the local hospital in Brunntal in northern Moravia (till January 31, 1950). During 1950-1952 he served in the army, most of the time at the Department of Radiology of the Military Hospital in Plzen (Pilsen). After completing his military service, he spent a short time at the pulmonary department of the local hospital in Prerov, and then at the Central Department of Radiology of the Medical Faculty in Olomouc (now Palacky University- both Prerov and Olomouc are located in central Moravia, northeast of Brno). Since November 1, 1954, he has been with the Central Department of Radiology of the Medical Faculty in Brno (now Masaryk University) that became Department of Radiology and Nuclear Medicine in 1960, and this was his workplace till his retirement in August1989. He had an appointment in research too, in the field of anatomy. In this part of his working live he produced his impressive work, both quantitative and without doubt now also qualitative.

After his retirement on the University he stayed a part-time radiologist of the Radiodiagnostic Clinic of the hospital in Brno-Bohunice. He suffered a brain stroke early in 1999, became seriously afatic. Just before the planned visit of the first author, his medical condition detoriated quickly. Milan Roth passed away peacefully amidst his family on April 4 2006.

His work remained largely unnoticed in the mainstream of the international world of orthopaedics, neurology or neurosurgery.

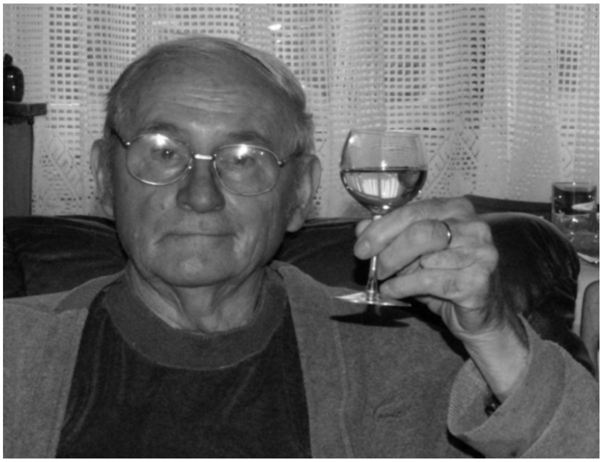

Fig .1 Milan Roth at the age of 80.

Roth had a major disadvantage in exporting his knowledge to a more global scientific forum, that a large part of his career, while developing and unfolding his ideas and concepts, he worked behind the Iron Curtain. Only in his early career he worked as a fellow, not accompanied by his young family as that was forbidden in the communistic regime, at the Karolinska Institute of the University in Stockholm.

His analytical work was first mainly published in German and Czech language, and in publications not well noticed because inaccessible for the mainstream. Only in the beginning of the 1980`s he had a few articles in English more international orientated journals in the field of Radiology. .

At the end of this contribution a bibliography of selected articles is added with the main purpose to disclose them to a wider audience.

His main concept is the concept of skeletal morphogenesis he developed which is based on the existence of 2 different types of growth of the spinal column, viz., the cellular-divisional (mitotic) growth of bone and soft tissues and the extensive (stretch) growth of the nervous structures. The neural extensive growth proceeds at a slower rate than the bone growth. Which is manifested most conspicuously in the ascent of the spinal cord. In his concept a number of normal as well as pathological features of the skeletal morphogenesis- above all the gross deformities of the body-parts which grow rapidly in length such as the spine, the extremities or the facial skeleton – are explained by the disturbed relation of the two growth types caused by an insufficiency of the vulnerable neural extensive growth.

2. Overview of the work of Roth

We are not able to specify, discuss or review all his work in this contribution. It can however be divided it in four main chapters:

1. Analytical work, undertaken mainly during the decade 1960-1970, in which he laid the fundamental of the research examining and integrating interpretation of older work in the fields of biology, embryology, anatomy and physiology.
2. Developing mechanical models of the spine, spinal growth and deformations in order to explain and visualise the processes of interrelated types of growth in the growing body in regard of time and the processing of forces.
3. Proposing the integrated concept of neuro-osseous growth and its role in explaining the normal development of tissues creating the organs and organic systems, viewing the spine as a crucial part of the skeleton
4. Published articles in the 1970 and 1980`s in which he consequently built upon his integrated concepts. This included papers on topics such as the Arnold Chiari malformation and Syringomyelia, and also the role and development of the neural foramen and the deformations in the lumbosacral spine based on secondary changes, like stenosis. These subjects are not discussed in the present paper.

This paper will consider this contribution focussing mainly on the developing of Roth's integrated concept of neuro-osseous growth which was published in several papers the early nineteen-seventies.

2.1. Analytical work

Roth's knowledge of the superb work of European scientists on the spine, which he often quoted, was prodigious, even with his insight into their disputing certain concepts. An increasing number of great scientists were investigating medical problems in Europe in the early twentieth century, which included spinal deformations, with names such as Lorenz, Nicolodani, Albert and Schulthess noted. They conducted anatomical studies, mainly on cadaver vertebrae and discs. Roth was the first to correlate their individual findings from their painstaking anatomical study with his own discoveries resulting from the early application of pneumencephalo- and myelography to the position, calibre, direction and suspected tension of the central cord and vertebral roots in normal and scoliotic spines. He stated: "The traction effect of the spinal nerves is of decisive influence upon the position of the spinal cord within the spinal canal as well as upon the shaping of the vertebral foraminae, a conclusion we reached in our own radiographic studies, published in 1965 and 1966.

2.2 Phylogenetic work.

The hypothesis that the tensionless position of the central nervous system matures into the adult animal vertebrate body was demonstrated in worms and other, more higher developed animals as well as in radiological and cadaver human studies. By applying study to the normal state allowed an development of understanding of the requirements of the central nervous tissues d to grow and develop.

2.3 Experimental teratogenic work.

In order to understand the role biochemistry plays (and still plays) in the development of a range of deformities of the spine, extremities and jaw, Roth conducted experimental studies on teratogenesis to clarify the role of the up to then neglected osteo-neural growth patterns, an area in which the interaction of growth in the nervous system interacts with other tissues. . Roth was able to impair the stretching properties of the nervous system by exposing it (intra-uterinal) to either teratogenic substances or by lowering the level of oxygen within it. In these experiments, he was able to create spinal deformities as scoliosis.

His experiments demonstrated that the so-called passive role of neurogenic tissue, especially in the central cord, was transformed into a major, active role during the development and growth of the spine and the extremities. This ability of nervous tissue to grow by extension is phylogenetically determinate. Growth and errors of growth of the vertebrate spinal skeleton was thus removed, allowing the “intimate relation existing from the very beginning of development between the nervous and the bony tissue to continue working incessantly during the whole growth period of life”.

2.4 Mechanical models of the spine, spinal growth and deformations.

With his interests in the growth and deformation of the spine and knowledgeable in related fields of biological or medical science, Roth developed his own mechanical models for different issues in a quest for an better understanding of the development of the normal, as well as the distorted or deformed spine. He was fully aware that forces in nature are often invisible, such as the growth and tensions within the body. He realised that only the consequences of these forces on a body can be seen and thus a conceptual clarification of the universally adopted relationship between form and function (ie acting forces) is essential in order to understand these important processes in nature.

In an paper on the models of vertebro-neural relations, Roth described an elastic model which could dynamically reproduce the physiological relationships of the growth of osseous structures with that of nervous tissue. Using Plexiglas, rubber, textile and metal he was able to construct an accurate model representing all the components of his concept of proportioned and disproportional growth between different tissues. The dynamic role played by normal living, the tensions created by growth, all superimposed on the pressures present in all living structures maintaining an upright position or on the pretension existing before making any movements, were developed in a range of experiments. Roth created all his models himself. He fully realised that there were contrasts between the early embryological patterns and the later adult state. Radiographs were made of these models in different stages of applied forces of tension, using different planes in order to demonstrate the close similarities with the radiographic images of living individuals. The model also explained the ascent of the conus medullaris during growth, widely seen then as a passive displacement. In some pathological conditions, like myelomeningocele, the ascent is said to be hindered by a tight string of fibrous tissue, the filum terminale, causing a “tethered cord”. Roth claimed that the less elongated or more stretched and tense spinal cord and associated attached roots would explain the impossibility of it “ascending” properly into the position of the conus at the T12-L1 area whereas in other animals the conus is low in the lumbar spine. The ascent was thus seen as an adaptation to the prevailing upright position of the body in mankind. The so-called “tethering” is thus not a passive binding by strings, but an intrinsic quality of nervous tissue. The stressed lordotic component of the thoracolumbar spine required in order to create optimal biomechanical and neuromechanical conditions is also a very interesting aspect of his models.

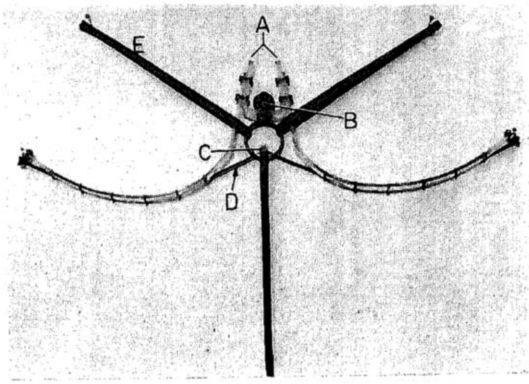

Fig. 1. A thoracic segment in the elastic model, viewed from above and slightly behind. A — vertebral body, B — longitudinal axis of spine, C — spinal cord, D — spinal nerve, E — rubber strip.

Fig 2 A photograph of a single segment of the thoracic spine in the transversal plane with modelling of the ribs, roots and cord. From: Roth M. [Models of vertebro neural relations]. Cesk Radiol 1970 Sep; 24(5): 189-94. (Courtesy of Roth's heirs).

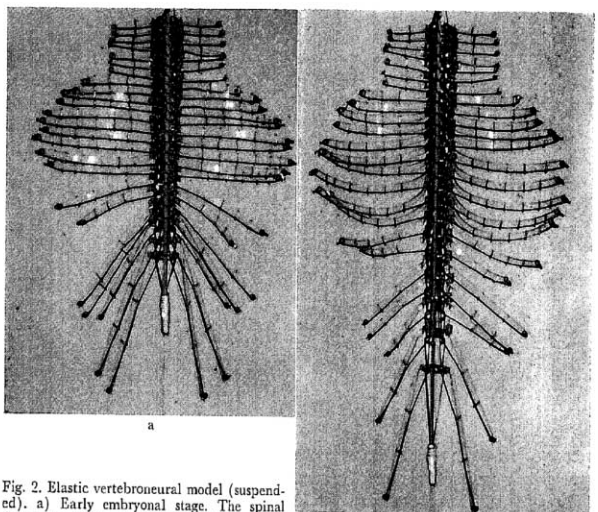

Fig. 2. Elastic vertebroneural model (suspended). a) Early embryonal stage. The spinal (excepting the lumbar) nerves still run horizontally. b) Traction on the lower end of the model reproduces the ascent of the cord; the distances between ribs and the intraspinal elongation of the lumbar nerves increase (cf. fig. 3).

Fig 2b The whole construct of spine, inhabitants and ribs in two different positions distinguished by a certain amount of tension in the combined system of different tissues. From: Roth M. [Models of vertebro neural relations]. Cesk Radiol 1970 Sep; 24(5): 189-94.
(Courtesy of Roth's heirs).

For his concept of the osteo-neural growth concept, Roth devised a very simple model, made from beads on a string. This "necklace" model, which can be easily copied today with materials such as slightly deformable beads, gives an insight in what can happen when nervous tissue is unable to keep up to the extending energy growing bone is delivering. The tension within the bones or the counteracting energy of muscle actions occurring as a result of activity act as supercharged engine dictated by nervous tissue itself.

Normal growth leads to the development of slender and long bones, but as the trend towards lengthening of bones takes place, the resulting retardation of extension of nervous tissue leads to the beads becoming compressed and thereby deformed.

2.5. The concept of osteo-neural growth.

The underlying reason for the focus of Roth's scientific work on the relationship between the central nervous system and the osseous components of, the spine, is not made clear. The quest must have been strong enough to allow him unrestrained research across all fields of biological and medical science. Certainly the existence of scoliotic curves in the human spine, not encountered in other animals, puzzled him as much as it still does today, concentrating his mind in his attempts to clarify the neglected role of the central spinal cord. Furthermore, the biomechanical adage that form always follows or reflects function was a mainstay in his thinking throughout his published work. What is certain is that attention was drawn to the relationship between nervous tissues and the spinal canal by his pioneering work as a neuro-radiologist, employing the techniques of pneumencephalography, myelography and positive contrast examinations of the scoliotic spine.

2.6 Biological studies

The comparison of the growth of animal nervous tissue by extension and the growth of central fibres in plants has already been fully explained and is undeniable. It has also been demonstrated that there is no cell proliferation of nervous tissue after birth in animals. Nervous tissue, in vertebrates as in all other animals, must possess an alternate pattern of growth, unlike all other tissues in the body. These grow or renew themselves at all stages of life, by rapid and intensive cell proliferation during growth. ``As in trees, the growth pattern is by extension of the cells (extensive growth; German: Streckungswachstum). Roth compared the governing phytohormon auxine, a trypthophane derivate driving this type of growth in plants which is said to be highly susceptible to a number of growth inhibitors (Gutenberg, Lehrbuch der Botanik) with the role of serotonine in the growth of nerves in animals. The energy necessary to stretch cells is generated by tensile power in the surrounding tissues during growth. In the spine, the vertebrae and discoligamentary complex, growing by cell proliferation, is responsible for the energy needed to stretch associated nervous tissues: "tag on tow".

With his interest in biology and, specifically the biological literature relating to plant and animal growth, Roth adapted the law of cephalocaudal differential growth in which growth in animals, just as in plants, is found to be directed from the first embryological components to develop such as the central tissue of an animal. In the vertebrate, the central cord, in the early embryological stages, is advanced when compared to the first segmentation of adjacent tissues. Although describing a leading role for the osseous structures to play by acting in the lengthening of the central nervous structures, by application of the law of cephalocaudal differential growth, Roth placed the phylogenetically oldest part of nervous system, the central cord and brainstem, as an initiating, architectural and controlling component and contributor to the lay-out of the surrounding tissues. These in turn form the basis of the biomechanical properties of the even more intriguing spine.

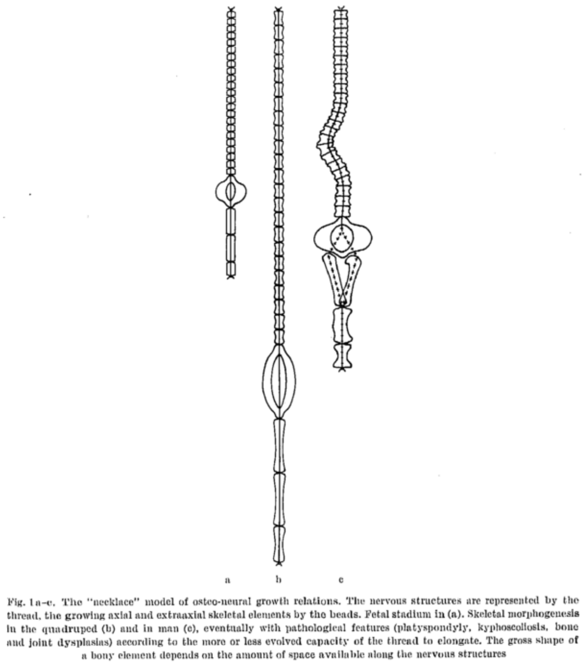

Fig 3. A schematic drawing of the necklace model in which prolonged or progressive tension on the string gives deformation of the vertebrate skeleton like beads. From: Roth M.: The relative osteo-Neural growth; a concept of Normal and pathological (Teratogenic) skeletal Morphogenesis.Gegenbauer's morph. Jahrb. Leipzig 119 (1973)2, S.250-274 (courtesy of Roth's heirs)

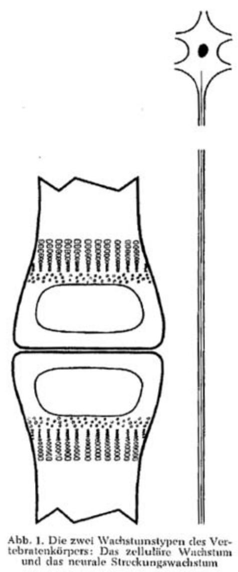

Fig. 4 A schematic drawing showing the difference in how tissues in vertebrate animals grow, namely by cell proliferation comparing the epiphyseal zones around a schematic joint at the left, and the elongation by stretching of a none proliferating nervous tissue cell. (From: Roth M. [Idiopathic scoliosis--a special type of osteo-neural growth disproportion]. Z Orthop Ihre Grenzgeb 1969 Nov;107(1): 37-46). Courtesy of Roth's heirs.

3. The leading role of the nervous tissue in morphogenesis of the axial skeleton.

Roth stresses that, prior to his work (and not really changed subsequently), the primary role and place of the nervous tissue in development and growth of the body in the context of other systems, such as the vascular, gastrointestinal or musculo-skeletal, was ignored.

By demonstration of an exaggerated ventral-concave curvature (hyperkyphosis) of the early embryo, Roth referd to and used schematic drawings, with examples, of earlier work of Blechschmidt.

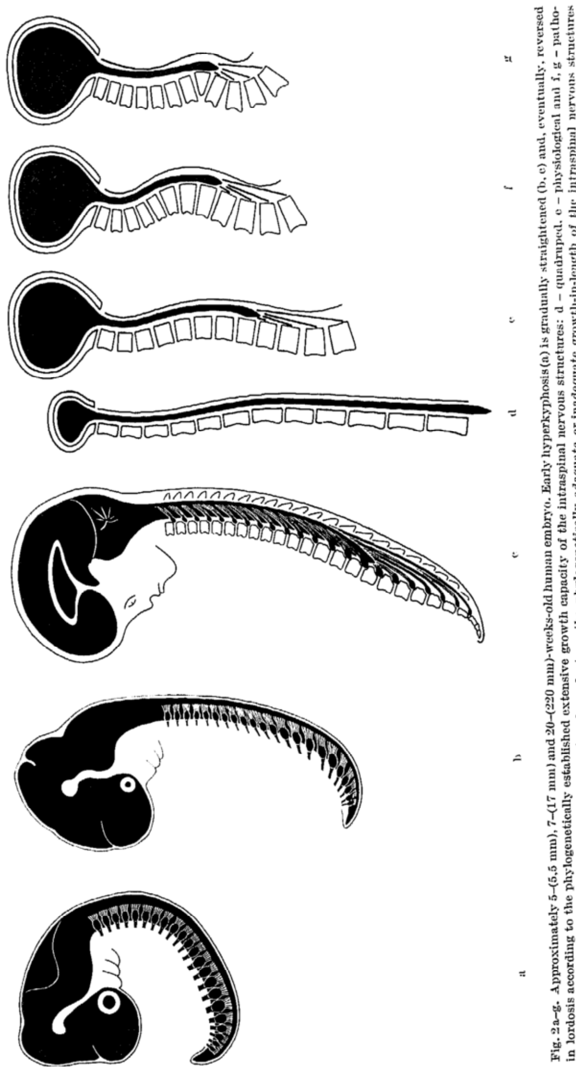

Fig. 5. Schematic drawing of embryological stages in which the enormous relative volume of the nervous system and the comma like shape is depicted, gradually changing to a stretched and more slender configuration, before the biomechanical needed cervical and lumbar lordosis is created. From: Roth M.: The relative osteo-Neural growth; a concept of Normal and pathological (Teratogenic) skeletal Morphogenesis.Gegenbauer's morph.Jahrb., Leipzig 119 (1973)2, S.250-274 (courtesy of Roth's heirs)

When the ascent of the conus-cauda occurs, until now seen as a passive event, the associated lengthening of the spinal nerve roots are widely considered as being dragged along by the rapid growth of the spinal column. Roth, however, hypothesized an opposite view, suggesting that there is also a controlling role for the central nervous system in achieving the final form of the spine in adulthood. He compares it to the leading role the unrolling and growing brain substances play in the formation of the skull (calva) at the end of growth. Roth also explained why the conus in man is present at the thoracolumbar joint other than in the lower lumbar spine as it is in almost all other quadrupeds.

4. Summary

It is clear from his writings that Roth applied his on-going practical experience of the clinical picture of children with deformations of the spine to his postulations. He observed that a normal lordotic shape of the lumbar and thoracolumbar spine is of great importance in allowing the correct functioning of the complexities of this area, the most mobile part of the spine in childhood. He described the requirement that the lower thoracic ribs should elevate, but also to retro-pulse, aided by the bellows-like function of the diaphragm. The tension placed on the neuromuscular structures can be measured by applying the mechanical law's of Robert Hooke on properties of tensile bodies. However, while springs may be of value in understanding the complexities involved in biomechanics and nervous system control, this was not foreseen by Roth . The deformation of intervertebral discs and the osseous elements of the spine the result of the same forces which allow standing, sitting, balancing and movement. delivered by the muscular system. No muscle acts without nervous instruction.

5. The consequences of Roth's work on scoliosis and practice.

Roth applied his concepts and explanations of the mechanism of the deformities of: scoliosis. Roth stated that:

"*There exists a most intimate interrelationship between the rapid cranio-caudal growth-in-length of the axial skeleton and the slower, proceeding, extensive growth of the spinal cord and the nerve roots. The latter type of growth requires a greater energy supply and, consequently, is more vulnerable than the former one. The vertebro-neural growth relationship is similar to that existing between the developing brain and the skull. The growth in length of individual vertebrae, and of the spine as a whole, is adapted to the growth-potentiality of the intraspinal nervous structures, viz.; the former is determined by the availability of space among the latter. Idiopathic scoliosis may be interpreted as an adaptive morphogenetic reaction of the vertebral column to the growth insufficiency of the intraspinal nervous structures: The growth processes of the vertebral column, though continuing undisturbed at the cellular level, is adapted at the organ level by "waves" of the growth-insufficient cord-nerve complex. Morphological features of the scoliotic vertebra, coupled to the typical position of the spinal cord within the spinal canal, support the hypothesis of a vertebro-neural concept which offers a plausible explanation of both congenital and experimental scoliosis."*

It might be argued that restoring the form e.g. by bracing; is not that harmful because it lengthens the spine, and thereby increases tension on the cord. Roth again provided an answer:

"*Adjustment or rectification of a deformed structure like a scoliotic spine is not accompanied by lengthening, notwithstanding the fact that the scoliotic trunk is elongated; the curved spine is adjusted, not lengthened. This adjustment involves a contraction or reduction of the convexe side of the intervertebral discs. Consequently in adjusting– paradoxally but irrefutably- the spinal canal is rather shortened.*" [15].

6. The work of Milan Roth: new challenges for future research

Science is an ongoing process possessing its own dynamics. Several recent publications indicate that Roth's hypotheses and concepts are now receiving attention.

We are convinced that full disclosure and understanding of the work of Roth will inspire many of our colleagues to start new research and that these challenges will be taken up in many different fields of (medical) science.

This will include:

1.) Reproducing and clarifying several of his analytical studies (pneumencapholgraphy) by using modern technologies such as MRI, Spiral CT-scan. Also neuro-physiological studies, using SSEP and surface EMG, can be undertaken in situations with higher tensions in the neuromuscular structures. For instance, the recent publication of Cheng et al (2008) on the short spinal cord with scoliosis is evidence that this kind of work is already in progress.

2.) Research on what can cause differences in the quality of stretch growth of the cord in order to elicit if this is the background of the misunderstood variation of spinal forms such as curvature, disc-height, vertebral height and shape. Should genetic backgrounds also be investigated?

3.) A new coordinated effort between biomechanics and biochemistry to clarify the mechanism behind and between the growth (proportionate or disproportionate) of bone and tissues in relation with the stretch growth of the neural tissues. For biomechanics, following Roth, this includes the role of tension, tension patterns and tension regulation. For biochemistry, this requires research on the role of transmitters, such as serotonine, already implicated in a range of processes and diseases. What is their role, how do they work in the period of growth and is their function altered in body with deformations, even mild ones? How is the process of distribution of the lava-like material surrounding the notochord, as Roth calls it, organised? Roth concepts could give clues as to the final form of the body and organs.

4.) New concepts for treating patients by conservative or operative treatments with emphasis on the requirements for the nervous system as part of the complex "game" of compressive and tensile forces

References

Milan Roth: a selected list of his publications

This bibliography with relevant publications by Roth consists of publications collected by the first author in recent years. Some of the articles were acquired from Roth's family.

The publications are presented in chronological order.

To allow maximum disclosure all articles are presented in the following way:

- An English version of the title
- Statement of the language in which the original was published
- An English summary or abstract (mostly original, sometimes extended) is added

[1] Roth, M (1965), *Caudal end of the spinal cord*, Acta Radiologica Diagnosis Vol. 3 (1965)
Original Language: English

Abstract: The normal position of the spinal cord with special emphasis on the "dorsolumbar junction" as the part of the spine lacking a detailed knowledge of gross anatomic features as demonstrated at negative contrast myelography is discussed. Material consisted of 34 adults and 8 children without symptoms in this part or known remote disorders. The variation in position, the calibre and the intrinsic curvature of the cord at the different levels is explained by developmental factors, among which the morphology of the vertebrae is stressed. A cadaver study with fresh spinal cords specimen hanging freely showed a constant intrinsic curvature in the distal cord as a "reminder "of the embryological existent complete rounded configuration. Also the eccentric "lodgement" of the roots in the neuroforaminae is depicted as a consequence of the ascent of the cord, as seen in humans.

[2] Roth, M. (1966), *Vertebro-medullary interrelations as observed in gas myelography*, Acta Radiologica Diagnosis Vol. 4 (1966), p. 569-580
Original language: English
Abstract: The typical position of the spinal cord within the membranous sac, possibly derived from the close developmental relations between the neural tissue and the vertebral column, is described. The significance of the characteristic shape of the intervertebral foramina in predicting the depth of the ventral subarachnoid space is discussed. It is shown that small thoracic disk protrusions, with a narrow ventral subarachnoid space especially at the level of the lumbar intumescences, may give rise to myelopathy.

[3] Roth, M. (1968), *Idiopathic scoliosis caused by a short spinal cord*, Acta Radiologica Diagnosis Vol. 7 (1968), p. 257-271.
Original language: English
Abstract: An explanation of the pathogenesis of idiopathic scoliosis based on the disturbance of the relative vertebro-neural growth is presented. This concept is supported by neuroradiologic, experimental and clinical observations.

[4] Roth, M. (1969), *Models of vertebro-neural relations*, Acta Radiologica Diagnosis. Vol. 9 (1969)
Original Language: English
Abstract: The basic principles of vertebro-neural growth relations with special reference to the pathogenesis of idiopathic scoliosis are discussed. Plexiglas models, constructed to assist in the demonstration, are described. All models have in common that they do not only reflect a static three-dimensional condition but represent the incorporated forces in life and growth by visible movements and represent also a condensation of what happens in the fourth dimension: time.

[5] Roth, M. (1971), *The relative osteo-neural growth-some phylogenetic, ontogenetic and clinical aspects*, ad. Diagn. 1971, 1, p 81-97
Original language: German
Abstract: The growth in length of the nervous structures necessitates a higher energetic level than that of the bones. A harmonic side-by-side growth course of the growth rates, cellular-divisional and neural-extensive, is indispensable for the normal body growth in length. Comparisons are made with features of growth in different animals and embryological knowledge. The relative osteo-neural growth represents therefore an important factor in the phylogenetic and ontogenetic development of the skeleton as well as in the pathogenesis of bone dysplasias.

[6] Roth, M., *The relative osteo-neural growth*
Part 1: Gegenbaur Morph. Jahrb. , Leipzig 117 (1971) 2, S. 232-255
Part II: Gegenbaur Morph. Jahrb. , Leipzig 117 (1972) 3, S. 312-334
Part III: Gegenbaur Morph. Jahrb. , Leipzig 117 (1972) 4, S. 421-440
Original language: German
Abstract: These three articles compose a total concept and explanation of the osteo-neural growth by extracting supporting evidence out of first class previous research in biological, anatomical, embryological, histological and orthopaedic and neurological textbooks and literature. With own modelling, all sort of research, and stepping over of "scientific" boundaries, he tries to fit all visible formation and deformation of at least the skeletal development in his holistic explanation of how Nature "works".
In Part I the function of the Ascensus Medullae in Homo erectus is discussed.. The inhibititive ("braking") power of the more energy asking stretch type of growth of the neural system on the growth by mitosis of the osseous and arthrogenic skeleton gives an insight in the complex system of tension regulation and strive for optimalisation growth in nature is. The earlier discovered and described craniocaudad and posteroanterior directed growth in ante- and postnatal growth in animals is completely incorporated in Roth's conceptual thinking. The change in relative size of the primitive

neural structures from huge to small is depicted and discussed as is the very clear present brachy-or Platyspondylie in siblings. The position, direction and calibre of the nerve roots in the neuroforaminae found at earlier pneumencephalographic studies at all different levels are made understandable. Different types of vertebral forms, especially the incisura vertebrae caudalis (roof of the foramen) are clarified. Different affections like Scheuermann, Platy- (or better: brachyspondylie, Dysplasia spondylo-epiphysealis tarda are according to Roth examples of clear "braking" of growth by hindered stretching capacity of the neural tissue. The formatted bone is like the narrow disc spaces diverged in horizontal directions.
Roth destilles out of his daily practice, that the thoracolumbar junction is the most inflicted in flattening of the discs and vertebrae in adolescent kyphotic deformities. There fore he ends with the statement that the length of the total spine is fixed by the intraspinal nerve structures.

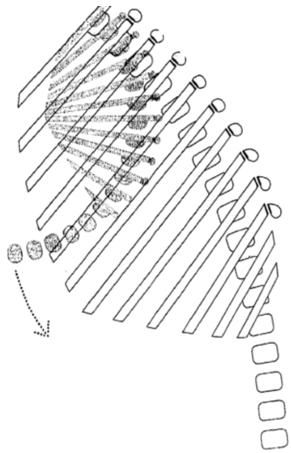

Abb. 3. Die Bildung der Lungenfurche hängt mit der Aufrichtung des ursprünglich zusammengerollten Embryonalkörpers (punktiert) zusammen

Fig.6 The formation of the pulmonary groove depends on the extension of the completely kyphotic and rolled up configuration of the embryonic body. Roth created a beautiful mechanical model on the change of all dimensions and relationships initiated by the gradual extension of the body.

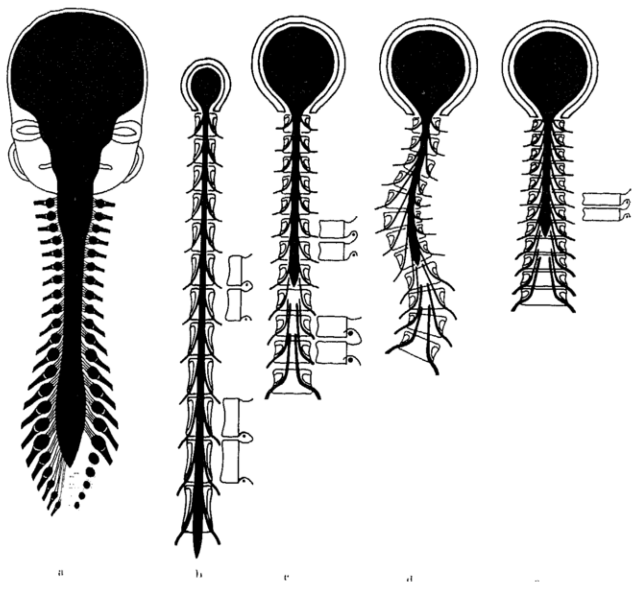

Fig.7 The impressive relative change in proportions between cord and roots and vertebral bodies in animals, normal human spine, a scoliotic spine and a platyspondylic spine.

Part II. Roth tries to come to a complete system of growth and formation of the body especially the complete skeleton based on earlier work of scientists and own studies. What seems true for the vertebra seems true for every piece of bone.

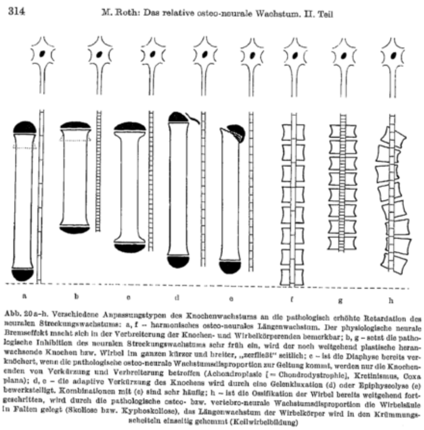

Fig 8. Schematic drawing of different skeletal deformities with the suspected relation with the concomitant, but primary events in the stretching type of growth of the central cord.

Part III.

On the form of the body and the physiological curvatures of the spine out of animal experiments in rats and frogs: "The nervous structures exert an influence on the morphogenesis of the skeleton even for the very reason of their existence in space, by their mass of a certain size and shape. The surrounding and /or accompanying skeletal masses adapt their general shape to that of the nervous structures. obviously under mediation of a "trophic" neural effect. Through this primary neural influence the gross shape of the skeleton most appropriate for the given species in a given environment is elaborated. The stimuli and information reaching the organism by neural pathways are thus reflected in the morphogenesis of the skeleton .The role of the blood and the vessels (hormones-authors), of the physical stresses and of the hereditary (genetics- authors) appear only of secondary importance only in the light of osteo-neural growth relations".

[7] Roth, M. (1973), *The relative Osteo-Neural growth: a concept of normal and pathological (Teratogenic) Skeletal Morphogenesis*, Gegenbauers morph. Jahrb. Leipzig 119 (1973) 2, S. 250-274
Original Language: German
Abstract: A concept of skeletal morphogenesis is proposed which is based on the existence of 2 different types of growth in the vertebrate body, viz., the cellular-divisional bone growth and the extensive (stretch-) growth of the nervous structures. The latter type requires a higher energy and oxygen supply than the former. Consequently, the neural extensive growth proceeds at a slower rate than the bone growth. Which is manifested most conspicuously in the ascent of the spinal cord. The slower growth rate, however, is a general feature of the nervous structures throughout the vertebrate body. A number of normal as well as pathological features of the skeletal morphogenesis- above all the gross deformities of the body-parts which grow rapidly in length such as the spine, the extremities or the facial skeleton – can be readily explained by the disturbed relation of the two growth types caused by an insufficiency of the vulnerable neural extensive growth.

[8] Roth, M. (1975), *Spinal cord and Scoliosis. The cause and the Effect*, Acta Chir. Orthop. Traumas. Czech. 42, 1975, no. 6, p. 507-517.
Original language: Czech
Abstract: There exist the most intimate interrelation between the rapid craniocaudad growth-in-length of the axial skeleton and the slower proceeding extensive growth of the spinal cord and the nerve roots. The latter type of growth requires a higher supply with energy and, consequently, is more vulnerable than the former one. The vertebro-neural growth relation is similar to that existing between the developing brain and its bony case. The growth in length of the individual vertebrae and of the spine as a whole is adapted to the growth-potentiality of the intraspinal nervous structures, viz.; the former is determined by the availability of space among the latter. Idiopathic scoliosis may be

interpreted as an adaptive morphogenetic reaction of the vertebral column upon the growth insufficiency of the intraspinal nervous structures: The growth process of the vertebral column, though continuing undisturbed at the cellular level, is adapted at the organ level by "waves" to the growth-insufficient cord-nerve complex. Morphological features of the scoliotic vertebra together with the typical position of the spinal cord within the spinal canal speak in favour of the suggested vertebro-neural concept, which offers a plausible explanation of the congenital and experimental scoliosis as well.

[9] Roth, M. , *The vertebral groove*, Acta Radiol.9; 1965 p. 740-745.
Original language: English
Abstract: Roth shows the presence, and gives name to the peculiar anatomical bilateral groove at the posterior surface of the bony spine. The development of the vertebral groove at the posterior side of the lamina as a unique feature in the human skeleton is explained and its influence via the spinal nerves on the shape of the intervertebral foramina is described. It fits in Roth's view about the supposed working of the musculature to provide forces on bony structures that will add in their final shape as form is dictated by functional request. In the axiom that form follows function it is the far more posterior presence of the facet joints and processi mammilaris in human that is specific for the species and originates from the tremendous greater pulling forces of the musculus Erector Trunci in the osseous insertions in the upright man.

[10] Roth, M. (1969), *Idiopathic scoliosis- A special form of osteo-neural growth disproportion* Z Orthop Ihre Grenzgeb 1969 Nov;107(1):37-46)
Original language: German
Abstract: Idiopathic scoliosis is explained as a pathological increase of the vertebro-neural growth disproportion, the physiological degree of which is reflected in the ascent of the spinal cord. This disproportion roots in the two different types of growth occurring in vertebrates, viz., the cellular-divisional and the neural-extensive. The latter is generally encountered in plant-kingdom. The morphological findings on scoliotic vertebrae as well as model experiments point to the primary growth insufficiency of the intraspinal nervous structures as the actual cause of the idiopathic scoliosis.

Roth, M., The experimental Teratogenesis of the skeleton. An experimental disturbance of the relative osteo-neural growth.Gegenbaur Morph. Jahrb. , Leipzig 122 (1976) 5, S. 686-730
Original language: German
Abstract: The previously suggested concept of the closest growth relations existing between the bony and the nervous tissue at the organ level of the spinal cord and the peripheral (including the facial) nervous trunks is experimentally buttressed. It is shown that the normal gross-morphological features of the vertebrae as well as of the tubular bones (viz., their length, physiological curvatures and terminal expansions) result from the adaptation of the bone growth to the slower proceeding and vulnerable neural extensive growth, viz., from a physiological osteo-neural growth disproportion. The more or less conspicuous growth in the length of the facial skeleton depends upon the phylogenetically established, more or less evolved extensive-growth potentially of the facial nervous trunks as well.
The growth relation existing between the developing brain and its bony case applies essentially even for the axial organ, the extremities as well as for the facial skeleton.
The experimental findings speak in favour of the theoretical expectation that the typical teratogenic deformities of the extremities (micromelia), of the spine (scoliosis, defects of the vertebrae and of the ribs) as well as of the beak (jaws) which may be produced by a great number of most diverse teratogens, result from the adaptation of the bone growth to the growth-insufficient nervous trunks, viz., from the pathologically enhanced osteo-neural growth disproportion. The cleft palate and the digital defects (syndactylia, oligodactylia) may be readily explained by the growth-inhibition of the palate and digital nervous structures as well.
The vertebrate body may be thus conceived as composed of 2 growth types, viz., the neural-extensive and the cellular-divisional (mitotic). The former is represented by an extremely dense felt work of nerve fibers and trunks (the Donaldson's " nervous skeleton"), which is " stuffed " with the other, mostly mitotic growing tissues. The 2 growth types are closely related partly at the macro- (organ-) level concerning the normal and teratogenic morphogenesis of the skeleton, partly at the micro-level of the utmost periphery, viz., of the terminal extensive meshwork and the individual cells or groups of cells. The cells which escape from the extensive felt work (i.e. from the " nervous skeleton") such as the superficial cells of the epidermis or mucous membranes and, in all probability, the elements of the haemopoetic organs, perish under normal conditions, suffer a planned, highly purposeful death. With regard to the lack of normal nerves within malignant tumors, the malignant cell may be conceived as

the one escaped from the limiting confines of the extensive felt work and, in spite of that, continues to live instead of " committing suicide".

[11] Roth, M., J. Krkoška and I. Toman Morphogenesis of the spinal canal, normal and stenotic, Neuroradiology 10, 277-286 (1976)
Original language: English
Abstract: The shape of the canal in transverse view, the shape and the position of the facet joints and the foraminate are discussed in normal and pathological conditions, like the developmental stenosis (Verbiest) and degenerative stenotic and degenerative changes are explained by the conductive role the neural tissues play in growth. Histological specimens are used. New models of the relationship between roots and vertebrae are introduced (fig). But nevertheless the base of the early base of any deformation seems still orchestrated by the necessary normal or disturbs the developmental balance between the two tissues (neural and osseous- discoligamentary). Roth states firmly in this paper that the role of the Notochord, a prominent structure in fishes, amphibians and reptiles is vestigial in higher mammals and its morphogenetic role in the developmental events of the axial skeleton is grossly overestimated (The Dispensability of the Notochord).

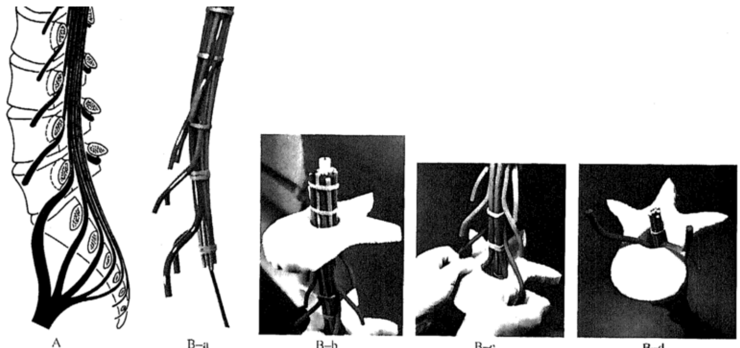

Fig. 9. Lumbar vertebroneural relations demonstrated in a complex drawing (A) and in a model made of plastic material (Ba-lateral view). Detailed views show the neural-dependent shaping of the vertebral foramina L_1 (Bb) and L_5 (Bc). The positional distad shift of the L_5 vertebra during the growth of the vertebral column meets with a high resistance from the massive L_5 nerves which results in a triangular shape of the vertebral foramen with the ventrolateral imprints of the nerves, best seen in the view from below (Bd)

Fig 9 Modelling of the relationship of the roots, their directions and the presumed thight contact between the roots and the bony surroundings in the lumbar spine.

[12] Roth, M. (1981), *Idiopathic scoliosis from the point of view of the neuroradiologist*, Neuroradiology (1981) 21: 133-138
Original language: English
Abstract: There is a simple morphological interrelation between the growing spinal cord-nerve root complex and the vertebral column, not unlike that between the growing brain and the skull. The shape of the enveloping vertebral skeleton mirrors the anatomical features of the enclosed neural contents. During the cranio-caudally directed growth, spurts of elongation of the vertebral column may be too rapid for the slower growth rate of the spinal cord and nerve roots. The resulting disproportion of growth between spine and nervous system is compensated for by adaptive scoliotic curvature of the otherwise normally growing spine. The proposed pathogenetic concept readily explains the main clinical features of the deformity and is supported by a spring model experiment.

[13] Roth, M. (1981), *Idiopathic scoliosis and Scheuermann "disease": Essentially identical manifestation of neuron-vertebral growth disproportion*. Radiol. Diagn. 22 (1981), H.3, 380-391
Original language: German
Abstract: With the knowledge postulated on the disproportionate growth between the nervous tissue and the spine, Roth gives with his spring models a true to nature morphological presentation of the proportioned relations of the cord and the deformed vertebrae (compression of the spring windings at the concavity, rope in the concavity). As the eccentric position of the cord and cauda was already known in literature (Lindgren 1941, Jirout 1964) Roth reverses this with arguments as it was seen as a secondary effect of the deformity towards a primary position with the deformity of the spine as a nervous tissue conducted developmental feature of the surrounding bony tissue. To Roth` s finding the lower thoracic and thoracolumbar spine function as the most predilected area for the first dicongruencies between the two types of growth in otherwise healthy children in their growth. In his

view the modificated muscular activity to keep the new posture with its relocated axial loading and unloading.
He also gives a understandable discussion in his concept of the existence of congenital scoliosis and kyphosis.

[14] Roth, M. (1985), *Once more spinal cord and scoliosis*, Acta Chir. Orthop. Traum. Czech. 52, 1985, no. 6, p. 532-543
Original Language: Czech
Abstract: Morphogenesis of the spine as well as of the neurocranium cannot be understood from the growing bone tissue alone, regardless of the morphology and growth peculiarities of the neural content, the brain and the spinal cord-nerve roots complex. Idiopathic scoliosis may be explained as a consequence of excessive discrepancy between the neural and the vertebral growth rates. Growth rate differential is a well-established factor of morphogenesis resulting, among others, in curvature of two adjacent structures growing in length at different rates. The periods of growth spurt are particularly prone to neurovertebral growth disproportionateness since the spinal cord-nerve roots complex may be unable to keep pace with the too rapidly growing spine. The latter is then laid in adaptive kyphoscoliotic curvatures alone the growth insufficient neural content. The relative growth deficit of the "Wirbelbogenreihe"as compared with the "Wirbelkorperreihe", a feature characteristic for idiopathic scoliosis seems to result from the primary retarding effect of the spinal nerves, which run reins like along the pedicles. This neural retarding effect may be elicited either by excessive stimulation of the vertebral growth or by inhibition of the spinal neural growth, or by combination of both. The basic gross features of idiopathic scoliosis including the deformity of the thoracic cage and the concave sided eccentric position of the spinal cord may be reproduced by means of a neuro-costo-vertebral model.

[15] Roth, M. (1986), *Cranio-cervical growth collision: another explanation of the Arnold Chiari malformation and of basilar impression*, Neuroradiology (1986) 28: 187-194
Original language: English
Abstract: Analysis of neuro-cranio-spinal development suggests a cranio-cervical growth conflict as the cause of the Arnold Chiari malformation and of basilar impression .In gross (Meningomyelocele) and slight (adolescent deformities) impairment of distal spinal growth, a reversal of cervical growth occurs, the initial descent (uncoiling) of the primordial brain curvatures is compromised owing to the growth collision with the ascending cervical spine. The availability of space is subject of the struggle.

[16] Roth, M (1989', *The `Enveloping` versus the Biomechanical function of the spine*, Cs. Radiologie 43, 1989, No. 1, c. 1-13.
Original language: Czech
Abstract: As a continuation of argumentation presented in a number of previous communications, the author advocates the view according to which the developing spine and its neural content (" spinal cord-nerve roots complex") are linked by an equally intimate morphogenetic relation like that existing between the brain and its skeletogenic envelope. A specific feature of the neurovertebral developmental relation consists in the fact that the elongated spinal cord-nerve roots complex is enveloped by its skeletogenic case both in the transversal and in the longitudinal direction. The matter is further complicated by lagging of the spinal neural growth behind that of the vertebral column. The development of the basic anatomical features of the individual vertebrae such as their length and width, the girth of the vertebral body as well as the shape of the intervertebral foramina cannot be understood without taking into account the gross developmental dynamics of the two main components of the axial organ, viz., of the spinal cord-nerve roots complex and of the vertebral column.

[17] Roth, M. (1994), *Traumatic Spondodylolysis in the hedgehog. A contribution to the Problem of Dysplasia of the Isthmus*, Z. Orthop. 132 (1994), p. 33-37
Original language: German
Traumatic Spondylolysis in a hedgehog is reported. On the basis of that rare thinning of the vertebral isthmus frequently associated with Spondylolysis in man is claimed to be related to the "neuro-enveloping "function of the spine shared with that of the neurocranium. Dysplasia of the isthmus results from abnormal ganglio-foraminal interrelation in the embryo rather than from any primary derangement of the vertebral bone growth proper.

Acknowledgments
We thank Milan Roth's widow Mrs. Milada Rothova and sons Tomas and Michal for their help in providing his biographical material and photographs and their approval to use all his published work to be brought under attention of the present medical world interested in unanswered questions on growth.
Also thanks to Dr.Kayo Styblo PhD, now orthopedic surgeon in Zaandam the Netherlands. who originates from Czechoslovakia, translated the Czech articles of Milan Roth into Dutch.

Chapter 4

Etiology

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Research into Spinal Deformities 6
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Leg-arm length ratios correlate with severity of apical vertebral rotation in girls after school screening for adolescent idiopathic scoliosis (AIS): a dynamic pathomechanism in the initiation of the deformity?

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[1]Centre for Spinal Studies and Surgery, Nottingham University Hospitals Trust, Queen's Medical Centre Campus, Nottingham, UK, [2]TheUniversity of Liverpool and Staffordshire University, UK, [3]Department of Orthopaedic Surgery, King's Mill Hospital, Mansfield, UK, [4]Department of Spinal Surgery, Royal Adelaide Hospital, Adelaide, Australia,
(Supported by AO)

Abstract. There is increasing support for the view that the unique human bipedalism and the erect posture are prerequisites for the pathogenesis of adolescent idiopathic scoliosis (AIS). How human bipedalism may contribute to the pathogenesis of AIS is not clear. In normal humans, axial rotations and counter-rotations of the trunk are carried out frequently and forcibly in activities that are not performed by quadrupeds. Some workers have analysed gait in AIS subjects, others have studied torsions in lower limb bones, but there are only two reports on leg-arm ratios in relation to AIS. In this paper, leg-arm ratios studied in relation to the spinal deformity in scoliosis screening referrals, reveal a highly significant correlation with the apical vertebral rotation but not the Cobb angle of the scoliosis curves. We suggest that leg-arm proportions and movements during gait involving pelvi-spinal axial rotations and thoracic counter-rotations contribute a dynamic pathomechanism to early AIS from whatever cause and involving the thoracic cage. Curve progression needs other mechanisms that may include a central nervous system failure to control structural asymmetry of vertebral axial rotation, and biomechanical spinal growth modulation.

Key words. Idiopathic scoliosis, pathogenesis, spine, leg, arm. intermembral index

1. Introduction

There is increasing support for the view that the unique human bipedalism and the erect posture are prerequisites for the pathogenesis of adolescent idiopathic scoliosis (AIS). How human bipedalism may contribute to the pathogenesis of AIS is not clear. In normal humans, axial rotations and counter-rotations of the trunk are carried out frequently and forcibly in activities that are not performed by quadrupeds (Figures 1 and 2). Some workers have analysed gait in AIS subjects [1,2], others have studied torsions of lower limb bones [3,4], but there are only two reports on leg-arm ratios in relation to AIS.
The length of the arms to the legs is of anthropological and comparative anatomical interest as the *intermembral index* (arm length/leg length) [5]. During normal human adolescence

legs grow less than arms [6]. In girls with AIS, subischial height-arm ratios were markedly greater at maturity in operated than in untreated and brace-treated patients [7]. Girls with AIS who underwent spinal fusion had progressively increasing leg-arm ratios post-operatively from bone age 14-15 years onward compared with those treated with a brace [8].

In this paper we evaluate leg length/arm length ratios in relation to the spinal deformity in girls referred after routine school screening for scoliosis. A preliminary report of the findings has been published [6]

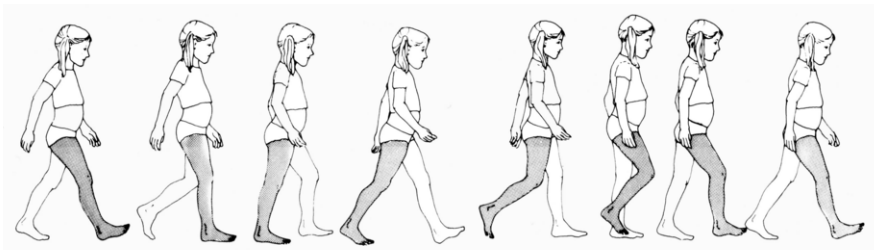

Figure 1. Walk cycle of a normal 7-year old normal girl (from Sutherland et al [9]).

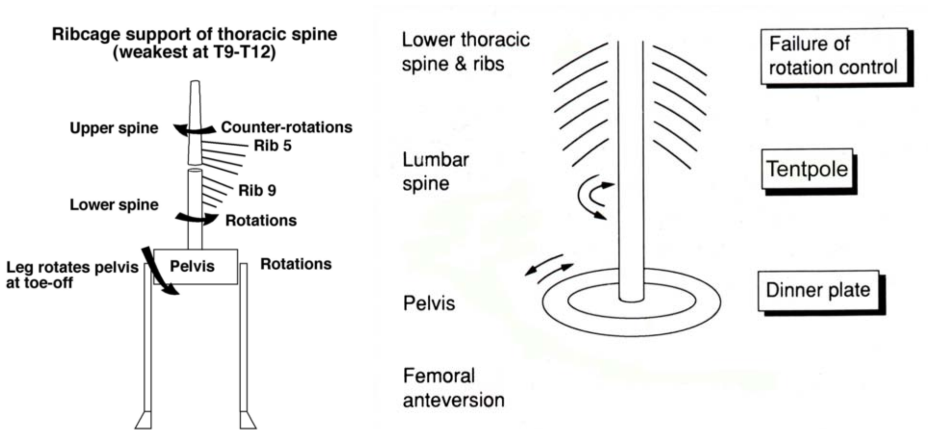

Figure 2. Left: Rotation control of the spine in gait showing pelvi-spinal rotations and counter-rotations in the upper spine based on the findings of Gregersen and Lucas [14, see 15]. (Modified from Burwell [17,18]). Right: Schematic drawing to show the gait-driven spinal rotation (Nottingham) concept for AIS (Modified from Burwell et al [17,18, see 19].

2. Methods and subjects

In screening by a routine quantitative protocol [10], 225 subjects were referred to hospital during 1993-9 where clinical evaluation (RGB) identified types of scoliosis. 138 girls age 11-18, postmenarcheal 115, had leg and arm measurements with Cobb angle and apical vertebral rotation (AVR [11]) recorded (right curves 85, left 53, spinal scoliosis, thoracic 38, thoracolumbar 39, lumbar 33, double 15, pelvic tilt scoliosis 10, straight spine 3).

Controls were 279 normal girls age 11-18. Total lengths of legs and arms were measured with a tape by one observer (RGB) using standard anthropometric (upper limb) and orthopaedic (lower limb) methods [12]. The radiographs were measured by the same observer including Cobb angle and apical vertebral rotation [13]. The intra-observer errors of the anthropometric [12] and radiological [13] methods are established.

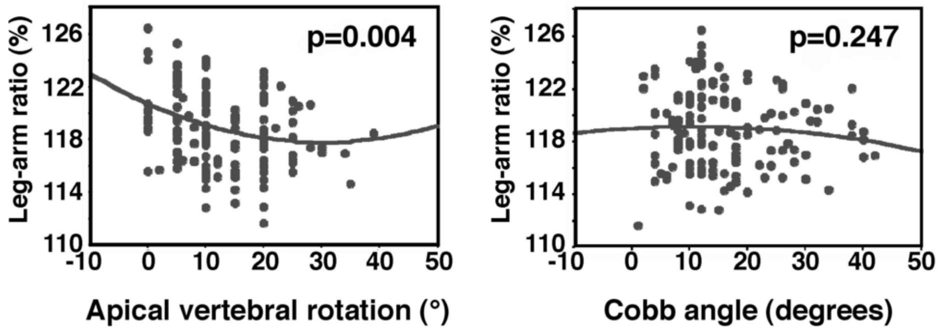

Figure 3. Right leg-arm ratios plotted against apical vertebral rotation (AVR) and Cobb angle. Quadratic regression analyses. Note the highly significant association between the leg-arm ratio and AVR but not Cobb angle. Longer arms relative to legs are associated with more apical vertebral rotation.

3. Results (Figure 3)

Leg-arm length ratios of referrals are not significantly different from normals. Quadratic regression analysis of referrals by age shows leg-arm ratios decrease (right $p<0.001$, left $p=0.004$,) and AVRs increase ($p=0.042$) but not Cobb angles. Leg-arm ratios correlate negatively with absolute AVRs (right $\rho = -0.246$ $p=0.004$, left $\rho = -0.284$ $p=0.001$, Spearman) but not Cobb angles. After correcting for age, curve side and apical vertebral level, leg-arm ratios correlate with AVRs (right $p=0.002$, left $p<0.001$, ANOVA).

4. Discussion

We suggest that leg-arm proportions and movements, which during gait and involving pelvi-spinal axial rotations and thoracic counter-rotations, contribute a dynamic pathomechanism to early AIS from whatever cause. Curve progression needs understanding of other mechanisms including the ribcage [20] and biomechanical spinal growth modulation [21]. At this Meeting and elsewhere and we discuss possible pathomechanisms for AIS that may involve the somatic [22,23] and autonomic [24,25] nervous systems.

5. Conclusion

We suggest that leg-arm proportions and movements during gait involving pelvi-spinal axial rotations and thoracic counter-rotations contribute a dynamic pathomechanism to early AIS from whatever cause and involving the thoracic cage [20]. Curve progression understanding needs consideration of other theoretical mechanisms [22-25], and of biomechanical spinal growth modulation [21].

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New clinical observations connected with "biomechanical aetiology of so called idiopathic scoliosis" (2006-2007).

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Abstract: Over the last few years, an etiological cause of scoliosis has been developed at Lub,in, Poland. This is based on the findings of was limited adduction or abduction contracture of right hip, coupled to asymmetry of movements between right and left hip which influences growth of spine through "asymmetrical gait" and asymmetrical standing

1. Introduction

Over many years the etiology of so-called idiopathic scoliosis remained unknown. In the past lack of an understanding of the etiology meant a lack of prophylactic treatment with a lack of appropriate exercises for children with early scoliotic curvatures.

A number of biomechanical explanations for the causes of scoliosis were described in 1995 in Lublin/Poland. During the following years between 1997 and 2007, the understanding of the problems of scoliosis were further developed and hypothesis tested and proven. This allowed for the postulation of a new atiopathological (epg) classification of scoliosis. Each type of scoliosis begins as the child starts to stand and to walk at about 2 to 4years of age.

The findings are based on a study which investigated 1450 children.

2. Three models of development of scoliosis.

Etiological factors found in children have been shown to be associated with a limited adduction or abduction contracture of right hip (often with flexion and external rotation contracture). Then, another factor influencing the development of spinal deformity is an asymmetry of the movements between the right and left hips which the influences the growth of spine through "asymmetrical gait" and an asymmetrical standing position "at ease". The primary cause of these asymmetries is attributed to the "syndrome of contractures and deformities" [1, 2]

3. Biomechanical models

3.1 'S' double scoliosis (I epg)

In an S shaped double curve, development of both curves occurs at the same time. and is associated with contracture in the right hip and large movements of left hip. In this biomechanical model, the consequences of changes to gait and the effects on the standing position on the right leg leads to the establishment of an "S" double scoliosis with associated stiffness of the spine and a rib hump on the right side. In some cases "lordoscoliosis" also is present. In these curves, progression is commonly observed.

3.*2 'C' one curve scoliosis (II/A epg)*

In the right hip, small limitation of movement is found but associated with a full range of movement in the left hip. In this biomechanical model, with the presences of a permanent standing position "at ease" on the right leg, a physiological deviation of the lumbar spine to the left side develops first to be followed by the appearance of a "C" shaped scoliosis. In older patients, this produces the clinical picture of "degenerative scoliosis". This type of curve rarely has progression.

In children with joint laxity, or those in whom the wrong types of exercises have been provided, a "S" double scoliosis (II/B epg) develops. with a secondary thoracic curve.

In the same biomechanical model as in II/A epg but associated with a permanent standing position on the right leg, no spinal stiffness is present. These a small curves, lack significant rib hump and in some instances there may be a kyphoscoliosis. This type of scoliosis shows no progression.

3.3 'I' scoliosis (III epg)

In scoliosis without significant curves but with a significant stiffness of spine, there is a right hip contracture and small left hip movement (1). In such a biomechanical model rotation deformity develops as a result of gait (stiffness of spine). This type of scoliosis is without progression but the children have difficulties with sporting activities and go on to develop back pain as adults. These cases require careful differential diagnosis by specialists in internal medicine, cardiology, rheumatology, neurology, gynecology etc.

4. Which children and in which countries do not have scoliosis? Why the blind children do not have so-called idiopathic scoliosis?

The biomechanical models of scoliosis have answered many questions. Firstly, they explain that scoliosis develops in the context of gait and of standing upright at ease on the right leg. As an example, the incidence of scoliosis is very low in Mongolia where the children mostly ride on horses and are thus not walking [3, 4, 5].

Why is scoliosis absent in blind children? My answer was reported in 2007. Blind children walk differently than children with normal sight and, because of this factor, they do not have scoliosis. Blind children, walking without eye control, utilize thinking-muscle control, employing care with every step, which results in changes in the manner of walking. They walk using short steps, slowly and with greater care than sighted individuals, and do not lift their legs. Furthermore, ophthalmologists have confirmed that blind children will stand in abduction, with symmetrical loading on both legs [6].

5. Influences of the CNS in small children and "scoliosis in future".

Recent observations in 2007 have confirmed the influences of the central nervous system on extension contracture (positioning) of the trunk and later vulnerability to the development of scoliosis. Anamnesis of pregnancy and labour is therefore very important. If factors of minimal brain damage and the syndrome of contractures and deformities appear in a child, the scoliosis will develop as type I-st epg . In our practice, we have identified many examples of coexistence of both these factors in children with scoliosis, but the problem still requires further observational research.

6. Conclusion

1. The etiology of so-called idiopathic scoliosis is strictly biomechanical. The link with right hip contracture or limitations results in asymmetries of walking, loading and growth of the pelvis and spine.
2. There are three groups ("S" – I epg, "C"-II/A epg & "S"-II/B epg, "I" – III epg) identified in the development of scoliosis, depending on the range of asymmetry of movements of hips (biomechanical models of development of scoliosis), all associated with gait and a standing position "at ease" on the right leg.
3. Even in cases of abduction contracture and external rotation contracture of the right hip but without biomechanical influences occurring during walking/gait and standing in the position "at ease", the scoliosis does not develop, as, for example, in blind children.
4. The coexistence of minimal brain damage (MBD) and contractures of the trunk extensors muscles and the syndrome of contractures and deformities exposes children to a vulnerability to develop so-called idiopathic scoliosis, especially in I epg.

Future investigations will include clinical observations associated with the biomechanical aetiology of idiopathic scoliosis.

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Etiologic theories of idiopathic scoliosis: autonomic nervous system and the leptin-sympathetic nervous system concept for the pathogenesis of adolescent idiopathic scoliosis

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Abstract. The autonomic nervous system through its hypothalamic neuroendocrine control of puberty, skeletal growth and menarche contributes importantly to the pathogenesis of adolescent idiopathic scoliosis (AIS). Melatonin dysfunction detected in AIS subjects also involves the autonomic nervous system. The thoracospinal concept for the pathogenesis of right thoracic AIS in girls thought by some to result from dysfunction of the sympathetic nervous system (SNS), is supported by recent vascular and peripheral nerve studies. Lower body mass index (BMI).in girls with AIS is associated with decreased circulating leptin levels. Leptin, secreted by adipocytes, is a master hormone with many regulatory functions for growth and reproduction, including: 1) appetite repression, *anorexigenic*; 2) initiation of puberty in girls in a permissive action, and 3) in mice, longitudinal bone growth, *chondrogenic and angiogenic*, and in bone formation, *antiosteogenic* acting centrally through the SNS and possibly directly. In AIS girls, autonomic nervous system activity was reported to be higher than in controls. We suggest that in AIS susceptible girls, given adequate nutrition and energy stores, circulating leptin talks to the hypothalamus where dysfunction leads to an *altered sensitivity to lepti*n *resulting in increased SNS activity* contributing with neuroendocrine mechanisms to: 1) earlier age at, and increased peak height velocity, 2) general skeletal overgrowth, 3) earlier skeletal maturation, 4) extra-spinal skeletal length asymmetries, including periapical ribs and ilia, 5) generalized osteopenia, and 6) lower BMI. The SNS-driven effects may also add adventitious changes to the spine including asymmetries complicating the neuroendocrine effects on adolescent spinal growth. In AIS pathogenesis, the *leptin-SNS concept* is complementary to our *NOTOM escalator concept* involving the somatic nervous system. Together these two concepts view AIS in girls as being initiated by a hypothalamic dysfunction of energy metabolism (bioenergetics) affecting skeletal growth in the trunk. Where, in susceptible girls, the postural mechanisms of the somatic nervous system fail to control the asymmetric spinal and/or rib growth changes in a rapidly enlarging adolescent spine; this failure becomes evident as mild back-shape shape asymmetry, or scoliosis. The environmentally-enhanced stature of normal subjects in the last 300 years, in girls susceptible to AIS, may have exaggerated any developmental dysharmony between the autonomic and somatic nervous systems being fought out in the spine and trunk of the girl – possibly making mild back-shape asymmetry, or scoliosis more prevalent today than hitherto.

Key words. Idiopathic scoliosis, pathogenesis, spine, leptin, hypothalamus, sympathetic nervous system

1. Introduction

1.1. Autonomic nervous system and the new neuroskeletal biology

In reviewing the new field of neuroskeletal biology Patel and Elefteriou [1] summarize long-standing clinical observations relating to bone and the nervous system including reflex sympathetic dystrophy, hyperplastic callus associated with head injury and myelomeningocoele, and osteopenia associated with stroke, spinal cord injury and peripheral neuropathy. They comment that the hypothalamus with its 'sensing' functions and capacity to send efferent hormonal and neuronal signals has the capacity to integrate skeletal physiology with the daily physiological changes triggered by the environment and by endogenous rhythms. Conflicting reports on the effect of β-adrenergic blockers for risk of fractures are published [2-4].

The new field of neuroskeletal biology involves leptin, the hypothalamus, sympathetic nervous system and skeletal tissues [1]. Here, we consider a theoretical appraisal of how this new field of neuroskeletal biology may relate to growing skeletal tissues and AIS pathogenesis (Figure 1).

1.2 The leptin-hypothalamic-SNS concept (leptin-SNS concept, Figure)

We suggest that in AIS susceptible girls, given adequate nutrition and energy stores, circulating leptin talks to the hypothalamus where dysfunction leads to an *altered sensitivity to lepti*n *resulting in increased sympathetic nervous system (SNS) activity* contributing to skeletal changes (mainly in the trunk and upper arms) including putative asymmetric changes to the spine complicating the traditional neuroendocrine effects on spinal growth. In AIS pathogenesis. the *leptin-SNS concept* is complementary to our *NOTOM escalator concept* involving the somatic nervous system [14,15]. Together these two concepts view AIS in girls as being initiated by a hypothalamic dysfunction of energy metabolism (bioenergetics) favouring growth and where, in susceptible subjects, the postural mechanisms of the somatic nervous system fail to control the asymmetric spinal changes in a rapidly enlarging adolescent spine; this failure becomes evident as mild back-shape shape asymmetry, or scoliosis deformity.

In this paper 1) we review evidence on which the *leptin-SNS concept* for AIS pathogenesis is based, and 2) outline the hypothesis.

1.3. Autonomic nervous system and AIS

1.3.1. Menarche

In AIS, the age at menarche has been reported as early, normal and delayed [5].

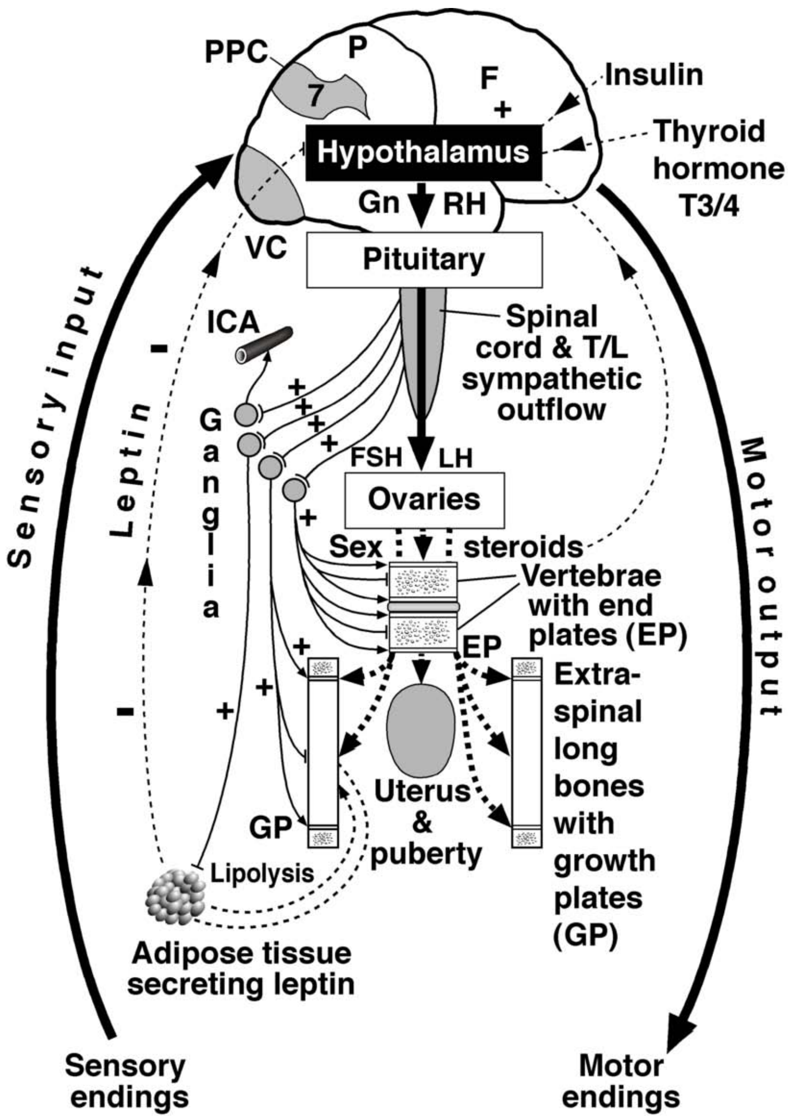

Figure 1. Concepts for the pathogenesis of AIS involving the autonomic and somatic nervous systems. The sensory input, motor output and PPC relate to the somatic nervous system and the rest to the autonomic nervous system. Shown are some neuroendocrine controls ('infantry') and sympathetic nervous system ('cavalry') of skeletal and adipose tissues. Ganglia=ganglionated sympathetic trunk. Sympathetic nerves are shown as thin continuous lines and hormones as interrupted lines. Pre- and post-ganglionic sympathetic nerves are shown on one side with arrows indicating enhancement of function and blunted lines as inhibition. F=frontal lobe, P=parietal lobe, PPC=posterior parietal cortex (Area 7 with body schema), VC=visual cortex, GnRH=gonadotropin-releasing hormone, FSH=follicle stimulating hormone, LH=luteinizing hormone, ICA=intercostal artery,., T/L=thoracolumbar. For further details of the somatic nervous system concept see [13-15].

1.3.2. Skeletal growth velocity

An undisputed factor in AIS curve progression is pubertal skeletal growth and its velocity as it affects the spine [5]. In AIS girls, greater peak height velocity of growth in early puberty may be related to the increased secretion of growth hormone [7-9] dehydroepiandrosterone (DHA) and plasma testosterone [7,10,11] with normal estrogens [10,11]. The pathogenesis of AIS in girls evidently involves the autonomic nervous system and neurendocrine mechanisms.

The mechanism(s) by which velocity of skeletal growth contributes to the pathogenesis of AIS in girls is unclear [12]. Castelein [12] states that the role of growth in the pathogenesis of AIS may be causative, conditional, amplifying, or coincidental. We suggest [13-15] that the dependence of AIS progression on growth is explained by rapid skeletal enlargement beyond the capacity of the postural mechanisms of the somatic nervous system to control the initiating deformity rather than by the velocity of growth, i.e. the role of skeletal growth is conditional [12].

1.3.3. Circulating melatonin and melatonin-signaling pathway dysfunction

In AIS subjects, a deficiency of circulating melatonin [16] and a systemic melatonin-signaling pathway dysfunction affecting osteoblasts and other cells [17] have been reported. The latter may represent a dysfunction of circadian rhythms in peripheral tissues similar to that detected in skin fibroblasts [18]. Any deficiency of circulating melatonin in AIS subjects could reflect altered sympathetic activity since the pineal gland is controlled by sympathetic fibers from the superior cervical ganglion – though normally one would expect any increased sympathetic activity to be reflected in greater nocturnal secretion of melatonin from the hypothalamus [Ebling FJP personal communication].

1.3.4. Generalized osteopenia

In girls with AIS, Cheung et al [19] found that the lower bone mass compared with controls could be explained by faster anthropometric growth, higher bone turnover, and lower calcium intake. The calcium intake in AIS patients was found to be very low with low consumption of dairy products, and likely to be insufficient for normal bone mineralization. Suh et al [20] reported evidence implicating imbalance and disturbed interaction of RANK ligand (RANKL) and the osteoprotegerin (OPG) decoy receptor in the osteopenia of AIS girls.

1.3.5. Disordered eating behavior

There are several reports of lower body mass index in girls with AIS [5,19,21-23] but not all [24,25] and there is some evidence of disordered eating behavior [21,26,27]. The low body-mass index of girls with AIS is said not to be the result of the eating disorder [26].

1.3.6. Right thoracic AIS in girls, sympathetic nervous system and rib-length asymmetry

Sevastik's thoracospinal concept [28-30] based on experimental, anatomical and clinical evidence, applies only to right thoracic adolescent idiopathic scoliosis in girls. There are six sequential processes as follows *(linear causality):*

1) Dysfunction of the autonomic nervous system[30].
2) Increased vascularity of left anterior hemithorax.
3) Overgrowth of left periapical ribs which -

4) disturbs the equilibrium of the forces that determine the normal alignment of the thoracic spine, that –
5) triggers the thoracospinal deformity simultaneously in the three cardinal planes.
6) Biomechanical spinal growth modulation [31].

This concept is supported by recent vascular [32] and peripheral nerve [33] studies

1.3.7. Leptin and AIS in girls

In AIS girls, Qiu et al [23] reported a marked decrease in circulating leptin compared with controls. Positive correlations were found between leptin and each of age, menstrual status, weight, corrected height, body-mass index (BMI), Risser sign, bone mineral content and bone mineral density (lumbar spine and femoral neck) but not Cobb angle. Qiu et al comment on evidence strongly suggesting that leptin may -

1) act on bone tissue through both central and peripheral pathways; a central pathway mediated by hypothalamic nuclei and the sympathetic nervous system (SNS), and peripherally "…by stimulating osteoblastic differentiation and inhibiting osteoclastic activity…" resulting in enhanced bone formation and reduced bone resorption;
2) regulate body growth during childhood and adolescence; and
3) mediate energy expenditure in females.

1.3.8. Body-mass index (BMI) and skeletal growth in the trunk of AIS and normal girls

Elsewhere [25] we present a preliminary report showing in three groups of adolescent girls – normals, screened and preoperative - that body-mass index above and below mean levels separates subjects in all three groups with larger and smaller skeletal growth mainly in trunk width. It is hypothesized that:

1) normal trunk widening of the thoracic cage by hormones in human adolescence is supplemented via the sympathetic nervous system under leptin-hypothalamic control influenced by energy stores (metabolic fuel); and
2) hypothalamic dysfunction with altered hypothalamic sensitivity to leptin through a SNS-driven asymmetric effect may create skeletal length asymmetries in vertebrae, ribs, upper arms and ilia, and initiate AIS.

1.3.9. Autonomic nervous system activity in AIS girls

In a study of 56 AIS patients compared with 25 controls, a higher level of autonomic nervous system activity was found [34]. The authors suggested that this finding may be another manifestation of a systemic neurologic imbalance in AIS subjects. Cutaneous patterns of sympathetic activity are found in association with other clinical abnormalities of the musculoskeletal system [35].

1.4. Hypothalamus (Figure)

Buijs et al [36] write:

The hypothalamus integrates information from the brain and body; this activity is essential for the survival of the individual (adaptation to the environment) and the species (reproduction). As a result, countless functions are regulated by the neuroendocrine and autonomic hypothalamic processes in concert with the appropriate behavior that is mediated by neuronal influences on other brain areas.

1.5. Energy balance and signals in relation to growth and reproduction

Energy balance requires precise coordination between peripheral nutrient-sensing molecules (related to food intake and stores) and central regulatory networks [37-42]. Fertility is gated by nutrition and the availability of energy reserves (metabolic fuel) stored as fat and glycogen to allow for growth and reproduction [41,42]. So that the normal female is ready for pregnancy and lactation, there is a link between body fat and the timing of puberty with leptin playing a permissive role [43] and kisspeptin activation of the G-protein coupled receptor-54 [41,44] providing a critical metabolic signal initiating puberty through pulsatile GnRH secretion [45] (Figure1). Other hypothalamic gates, or stiles, may have to be opened before menarche is reached [39].

1.6. Leptin and the sympathetic nervous system – the new field of neuroskeletal biology

Leptin, best known as a signal of energy sufficiency, is one of several hormones secreted by adipocytes. In girls there are gradual age- and body-weight related increases in circulating leptin levels [46]. Lower leptin levels, found in boys than girls [46], also rise until the early stages of puberty after which they decline [47]; leptin levels in men are lower than in women at all decades of life [40]. The sex difference may result from stimulatory effects of estrogen on leptin production and inhibitory actions of testosterone [47]. Leptin is a master pleiotropic hormone involved in the regulation of a variety of physiological processes, including [41,48]: 1) appetite repression, *anorexigenic*; 2) thermogenesis, 3) metabolism of glucose and lipid, 4) initiation of puberty in girls with kisspeptin stimulating GnRH secretion; and 5) complex effects on growing bones with fat having a protective effect on bone tissue [49].

Leptin is reported to stimulate linear growth by regulating the energy balance of the body and by stimulating the production and secretion of growth hormone; at the same time it has a direct effect on chondrocytes of the growth plate and is involved in bone remodelling [48]. Iwaniec et al [50] propose the hypothesis that hypothalamic leptin plays a role in coupling energy homeostasis and bone growth. Leptin appeared in evolution with the bony skeleton [51].

The coupling of skeletal growth to energy balance [48,50] involves leptin and Y2-receptors on neuropeptide Y (NPY-ergic) hypothalamic neurons [52,53]. Other metabolic hormones, insulin and thyroid hormone as well as sex steroids also target hypothalamic neurons (arcuate nuclei) to ensure metabolic efficiency [41](Figure1).

In mice, adipocytes talk to bone through leptin acting centrally through a hypothalamic pathway via the SNS [54,55] which releases the neurotransmitter noradrenaline to increase longitudinal bone growth and inhibit osteoblast function and proliferation [1,47,50,52]. In mice, leptin stimulates longitudinal bone growth, being *chondro-osteogenic and angiogenic*, and in bone formation, *antiosteogenic* acting centrally through the SNS and possibly with an opposite direct effect on bone [47,50,52].

The skeleton exerts an endocrine regulation of energy metabolism. [51,56] (Figure 1).

1.7. Sympathetic nervous system (SNS) and innervation of white adipose tissue

White adipose tissue in rats and Siberian hamsters is innervated by the SNS [39,57,58] which may play a significant role in lipid mobilization [39,57], and inhibition of proliferation [57](Figure).

2. Hypotheses

2.1. Leptin-SNS concept - effects on skeletal and white adipose tissues in girls with AIS

In AIS susceptible girls, given adequate nutrition and energy stores, in the *leptin-SNS concept* circulating leptin talks to the hypothalamus with dysfunction and altered sensitivity to leptin which *leads to increased SNS activity* contributing with neuroendocrine mechanisms to (Figure 1):

a) earlier age at, and increased peak height velocity [5,9,59]
b) general skeletal overgrowth [5,60]
c) earlier skeletal maturation [5,25]
d) extra-spinal skeletal length asymmetries, including periapical ribs [5,13,14] and ilia [61]
e) generalized osteopenia [19,21], and
f) lower body fat and BMI [5,19,21-23].

The extra-spinal skeletal length asymmetries are a manifestation of developmental stress in hypothalamic neurons as they adjust to lower leptin levels which they helped to create. The SNS-driven effects also add adventitious changes to the spine including asymmetries complicating the neuroendocrine effects on spinal growth.

The SNS contributes to the osteopenia of AIS by activating β2-adrenergic receptors on osteoblasts [62] causing them to produce RANKL which acts on the osteoclast receptor RANK to stimulate osteoclast formation [63]. In young ballet dancers, the high prevalence of scoliosis, fractures and delayed menarche attributed to hypoestrogenism [64] may also involve low circulating leptin levels and increased hypothalamic-SNS-driven activity on growing bones.

2.2. Putative changes in the spine and the somatic nervous system in AIS

When the SNS-driven putative adventitious changes in the enlarging adolescent spine are associated with relative postural maturational delay in the somatic nervous system the spine deforms [13-15]. The postural mechanism may be linked to higher testosterone levels in AIS girls affecting brain white matter maturation in girls [7,10,11,15]. There is direct and indirect evidence suggesting that asymmetries affect vertebral body growth plates [13,14,65].

2.3. Putative hypothalamic dysfunction and the NOTOM escalator concept

In AIS girls, we hypothesize that the hypothalamic gates controlling skeletal growth via neuroendocrine and autonomic outputs open earlier to advance skeletal maturation [Ebling FJP, personal communication]. The leptin effect via the SNS may add to the neuroendocrine effect of both growth hormone and estrogen driving adolescent skeletal growth in girls [5-8].

Alternatively, the dysfunction in hypothalamic neurons as putative altered sensitivity to leptin may result from an abnormality of a Gprotein-coupled receptor to leptin, or Gprotein - possibly as the critical part of a systemic abnormality similar to the melatonin-signalling pathway dysfunction detected in osteoblasts, muscle cells and lymphocytes [66].

In AIS pathogenesis, the *leptin-SNS concept* is complementary to our *NOTOM escalator concept* involving the somatic nervous system [14,15]. Together these two concepts enable AIS to be viewed as being initiated in girls by a hypothalamic dysfunction of energy metabolism (bioenergetics) favoring growth in a secular trend; and where, in susceptible subjects, the postural mechanisms of the somatic nervous system fail to control the adventitious spinal changes in a rapidly enlarging adolescent spine; this failure becomes evident as mild back-shape shape asymmetry, or scoliosis deformity.

2.4. A secular trend in normal stature with significance for AIS pathogenesis?

Stature has increased since the mid 18th century due to environmentally-induced changes [67,68]. This secular height increase, attributed to better nutrition and reduced infections by advances in technology resulting in vital organs having improving robustness and capacity, is interpreted by the *hypothesis of technophysio evolution* [69]. The biological mechanism underlying this secular trend in stature like the declining age at puberty [42] is likely to be driven by the hypothalamus [Ebling FJP, personal communication]. We suggest that in those girls who develop AIS the increased size for age from these secular changes in spine and trunk may be a factor weakening control by postural mechanisms for holding a spine straight. This environmentally-enhanced stature of normal subjects in the last 300 years in girls susceptible to AIS may have exaggerated any developmental dysharmony between the autonomic and somatic nervous systems being fought out in the spine and trunk of the girl – possibly making mild back-shape asymmetry, or scoliosis more prevalent today than hitherto.

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Etiologic theories of idiopathic scoliosis. Somatic nervous system and the *NOTOM* escalator concept as one component in the pathogenesis of adolescent idiopathic scoliosis

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Abstract. There is no generally accepted scientific theory for the causes of adolescent idiopathic scoliosis (AIS). In recent years encouraging advances thought to be related to the pathogenesis of AIS have been made in several fields. After reviewing concepts of AIS pathogenesis we formulated a collective model of pathogenesis. The central concept of this collective model is a normal neuro-osseous timing of maturation *(NOTOM)* system operating in a child's internal world during growth and maturation; this provides a dynamic physiological balance of postural equilibrium continuously renewed between two synchronous, polarized processes (*NOTOM* escalators) linked through sensory input and motor output, namely: 1) *osseous escalator- increasing skeletal size and relative segmental mass*, and 2) *neural escalator* – including the *CNS body schema.* The latter is recalibrated continuously as the body adjusts to biomechanical and kinematic changes resulting from skeletal enlargement, enabling it to coordinate motor actions. We suggest that AIS progression results from abnormality of the neural and/or osseous components of these normal *escalators* in time and/or space – as asynchrony and/or asymmetries – which cause a failure of neural systems to control asymmetric growth of a rapidly enlarging and moving adolescent spine. This putative initiating asymmetric growth in the spine is explained in separate papers as resulting from dysfunction of the hypothalamus expressed through the sympathetic nervous system (leptin-sympathetic nervous system concept for AIS pathogenesis). In girls, the expression of AIS may result from dysharmony between the somatic and autonomic nervous systems – relative postural maturational delay in the somatic nervous system and hypothalamic dysfunction in the autonomic nervous system, with the conflict being fought out in the spine and trunk of the girl and compounded by biomechanical spinal growth modulation.

Key words. Idiopathic scoliosis, pathogenesis, spine, skeletal growth, body schema, neuro-osseous timing of maturation.

1. Introduction

Encouraging advances thought to be related to the pathogenesis of adolescent idiopathic scoliosis (AIS) have recently been made in several fields: bone mass, bone growth, spinal growth modulation, extra-spinal left-right skeletal length asymmetries, lower limb proximo-distal and other skeletal disproportions (allometry), magnetic resonance imaging of vertebral column, spinal cord, brain and skull, and molecular pathogenesis. These findings have lead to new concepts of pathogenesis (Figure 1) and to new treatments including attempts at minimally invasive surgery on the spine and periapical ribs. From these concepts, a *collective model* for AIS pathogenesis was formulated [1]. The central concept [2] of this collective model is a normal neuro-osseous timing of maturation *(NOTOM)* system operating in a child's internal world during growth and maturation; this provides a dynamic physiological balance of postural equilibrium continuously renewed between two synchronous, polarized processes (*NOTOM* escalators) linked through sensory input and motor output, namely: 1) an *osseous escalator - increasing skeletal size and relative segmental mass*, and 2) a *neural escalator* – including the *CNS body schema.* The latter is recalibrated continuously as the body adjusts to biomechanical and kinematic changes resulting from skeletal enlargement, enabling it to coordinate motor actions. We suggest that AIS progression results in part from abnormality of the neural and/or osseous components of these normal *escalators* in time and/or space – as asynchrony and/or asymmetries – which cause a failure of neural systems to control asymmetric growth of a rapidly enlarging and moving adolescent spine. This putative initiating asymmetric growth in the spine is explained in separate papers [3,4] as resulting from dysfunction of the hypothalamus expressed through the sympathetic nervous system (leptin-sympathetic nervous system concept for AIS pathogenesis).

2. Neurological research and three pathogenetic concepts for AIS

Several workers but not all have detected subclinical neurological abnormalities in subjects with AIS [see 5-11]. Three concepts of AIS pathogenesis including neurological abnormalities are 1) *motor control problem* [12]; 2) *body-spatial orientation concept* [13]; and 3) *neurodevelopmental concepts* [14-16]. In our recent neurodevelopmental concept [16] four requirements were identified: a).curve initiation process; b) rapid spinal elongation in the adolescent growth spurt; c) maturational delay of *CNS body schema*; and d) upright posture and movements.

None of these three concepts addressed how the *CNS* may adapt with age.

3. Premise for neuro-skeletal development in humans

Sporns and Edelman [17] write: "*There is overwhelming evidence that the emergence of coordinated movements is intimately tied to both the growth of musculoskeletal system and to the development of brain. The neural development and learning cannot be considered outside of their biomechanical context. A key theoretical issue is how the changes in brain circuitry controlling muscles and joints become matched to simultaneously occurring developmental changes at the periphery*"

4. Neuro-osseous timing of maturation (*NOTOM*) in normal development

In normal health, the skeletal system and nervous system evidently grow and mature together in harmonious development of a normal neuro-osseous timing of growth and maturation (*NOTOM*)[1,2,11,16,18-21]. Such normal neuro-osseous development occurs between the spine and spinal cord [1,11,18-21], and between the brain and body

[1,2,16,22] as a whole in establishing the sensory-motor control of posture and coordinated movements.

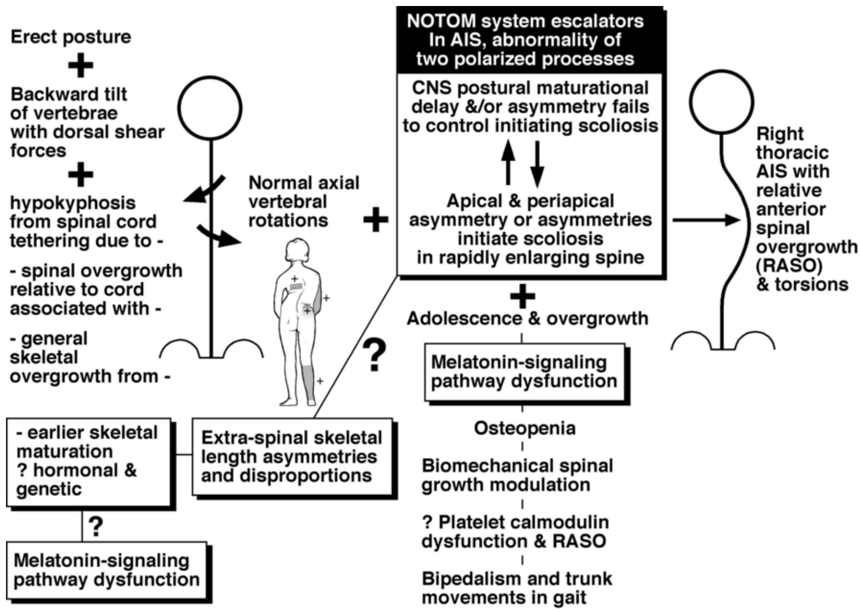


Figure 1. *A collective model for AIS pathogenesis involving abnormality of the escalators of a normal neuro-osseous timing of maturation (NOTOM) system as the central concept. In normal growth and maturation, the two polarized processes are synchronous and symmetric linked through sensory input and motor output. In AIS pathogenesis, the polarized processes are asynchronous and asymmetric in one or both processes. In the diagram of the AIS girl the + signs indicate some detected skeletal length asymmetries including ribs with relative overgrowth on that side, correlating significantly with scoliosis severity in upper arm and ilia but not tibiae; skeletal disproportions and lower limb torsions are not shown. NOTOM=neuro-osseous timing of maturation. RASO=relative anterior spinal overgrowth. From [1] with permission of the Editor and IOS Press.*

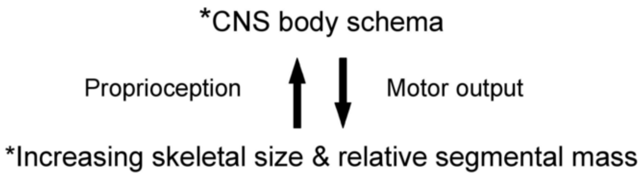
5. CNS body schema ('body-in-the-brain') and the *NOTOM* escalators in normal growth and AIS

5.1. CNS body schema (Figures 2 & 3)

The CNS body schema in the adult is defined as a *".....system of sensory-motor processes that continually regulate posture and movement – processes that function without reflective awareness or the necessity of perpetual monitoring."* [23]. This control involves frames of reference in the posterior parietal cortex which participate in the dynamic representation of the *body schema* integrated with other cortical areas [23-26].

5.2. Osseous and neural NOTOM escalators in normality (Figure 2)

Figure 2 provides an outline of the *NOTOM* escalator concept for normality.



- = two polarized processes of the *NOTOM* escalators

Figure 2. Normality. Neuro-osseous timing of maturation (NOTOM) escalators [1,2]. The CNS body schema ('body-in-the-brain', 'unconscious body awareness') is considered here for simplicity in the traditional proprioceptive modality.

We postulate that during normal growth and maturation, a physiological balance is continuously renewed between two synchronous polarized processes that we term escalators, namely:

1) *Osseous escalator:* increasing skeletal size, changing skeletal shape and relative mass of the different body segments which through posture and motion of the body by producing developmental biomechanical and kinematic changes at the periphery create developmentally altering proprioceptive inputs including balance, to the neural escalator in the brain.

2) *Neural escalator and postural control:* the *CNS body schema* is recalibrated as it continuously adjusts to skeletal enlargement, shape and relative mass changes to enable it to coordinate motor actions. The *posterior parietal cortex* in human clinical and experimental studies has been shown to participate in the dynamic representation of the body schema [23-26].

The term escalators are applicable only during growth. Muscles are not included in this terminology because they do not drive skeletal growth, but have key roles in sensory and motor function and contribute to segmental masses. Similar mechanisms are being evaluated in robotics and specifically the learning in, and from, brain-based devices [27-29].

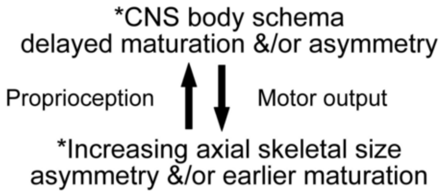
5.3. Osseous and neural NOTOM escalator concept for AIS (Figure 3)

Figure 3 provides an outline of the *NOTOM* concept for AIS pathogenesis.

In AIS, putative abnormalities of the two polarized components of the *NOTOM escalators* – with asynchrony and asymmetry(ies) - provide the central concept of our *neuro-osseous developmental concept* for AIS pathogenesis:

1) in the *spine* (growing rapidly with asymmetry(ies)[1,3,4,11], and

2) in the *CNS body schema, mainly maturational delay*, absolute or relative to the skeletal system, possibly with brain asymmetries [22,30,31]; the maturational delay in the *CNS* may arise from an abnormality in afferent, central, or motor mechanisms [1,16], or be *relative to earlier skeletal maturation* (see below 7.2).



* = two polarized processes of the *NOTOM escalators*

Figure 3. AIS pathogeness. Abnormal neuro-osseous timing of maturation (NOTOM) escalators as applied to the spine [1,2].

The fate of early AIS – to progress, become static or resolve (rarely) - according to this concept depends mainly on the degree of failure in postural control of a rapidly enlarging and actively moving adolescent spine and trunk with or without asymmetries. Progression may occur in some curves because of strong spinal asymmetries in up to three dimensions. These may arise from dysfunction in the autonomic nervous system [3,4].

6. A complementary role for the autonomic nervous system in the pathogenesis of AIS?

Elsewhere [3,4] we suggest that in AIS susceptible girls given adequate nutrition and energy stores, circulating leptin talks to the hypothalamus where dysfunction leads to an *altered sensitivity to lepti*n *resulting in increased SNS activity* contributing with neuroendocrine mechanisms to: 1) earlier age at, and increased peak height velocity, 2) general skeletal overgrowth, 3) earlier skeletal maturation, 4) extra-spinal skeletal length asymmetries, including periapical ribs and ilia, 5) generalized osteopenia, and 6) lower Body Mass Index (BMI). The SNS-driven effects may add adventitious changes to the spine including asymmetries complicating the traditional neuroendocrine effects on spinal growth.

In AIS pathogenesis the *leptin-SNS concept* [3,4] of the autonomic nervous system is complementary to the *NOTOM escalator concept* of the somatic nervous system. Together these two concepts enable AIS in girls to be viewed as being initiated by a hypothalamic dysfunction of energy metabolism (bioenergetics) favoring growth in a secular trend. Where, in susceptible girls, the postural mechanisms of the somatic nervous system fail to control the asymmetric spinal and/or rib growth changes in a rapidly enlarging adolescent spine; this failure becomes evident as mild back-shape shape asymmetry, or scoliosis.

7. Skeletal findings for AIS interpreted by *NOTOM* escalator concept

7.1. Velocity of growth, skeletal maturity and AIS curve progression

The relation of skeletal growth velocity and skeletal maturity to curve progression in AIS is established [32] but its mechanism of action is unclear – causative, conditional, amplifying, or coincidental [33]. In the *NOTOM escalator* concept, the dependence of AIS progression on growth is explained by rapid skeletal enlargement beyond the capacity of the postural mechanisms to control the deformity rather than by the velocity of growth.

7.2 General skeletal overgrowth, earlier skeletal maturation and relative postural maturational delay in AIS girls

In AIS girls, widespread skeletal overgrowth has been detected [34-36]. While there is no direct evidence of constitutional *CNS* maturational delay of postural mechanisms in AIS subjects, the *earlier skeletal maturation* in AIS girls explains their early skeletal overgrowth [1,4,37,38] to which a normal *CNS body schema* has to adjust. An earlier skeletal maturation may upset the physiological balance of the *neuro-osseous escalators* and create a *relative* postural maturational delay.

7.3 Extra-spinal skeletal length asymmetries, disproportions and lower limb torsional abnormalities (Figure 1)

In AIS subjects, the authors and their colleagues have found widespread extra-spinal skeletal length asymmetries, proximo-distal lower limb skeletal disproportions and torsional abnormalities, and other skeletal disproportions [see 1,11,39,40]. It is not known whether the extra-spinal left-right skeletal length asymmetries, skeletal disproportions and torsions signify any local involvement in the spine. We speculate that they do [1,3,4,16] as does the general skeletal overgrowth [41,42]. There is direct evidence suggesting a primary disturbance of vertebral growth plates in scoliosis [43].

A speculation suggests *vertebral symphyseal dysplasia* involving type IX collagen may initiate the development of progressive AIS [44].

7.4 Indirect evidence that AIS may be initiated by triggering from within the spine by the sympathetic nervous system

In presumed AIS, Davids et al [45] found that the most valuable single MRI indicator for abnormal central nervous system findings was the *absence of a thoracic apical segment lordosis*. These findings, confirmed by others [see 1], suggest that in adolescent *idiopathic* scoliosis, each of the *lordotic* and *axial rotation components* of the deformity may be determined, at least in part, by mechanisms expressed *locally in the spine.* According to the *leptin-sympathetic nervous system concept* [3,4] these changes may result from increased sympathetic nervous system activity expressed asymmetrically in spine and/or rib growth about the curve apex.

8. Preliminary MR brain studies on normals and AIS subjects

Learning processes have long been associated with the synaptic plasticity of gray matter [46]. Recent MR brain studies have shown that white matter is possibly affected by learning [47].

8.1. Normal young brain – white matter volume at 12-18 years

Females and males at 12 years of age have about the same relative volume of white matter in their brains. At 18 years normal girls have a significantly lower volume of white matter than do the males at this age [48]. May girls with a susceptibility to progressive AIS have a maturation of their white matter more like that of boys – in association with other factors? Girls with AIS are reported to have elevated circulating testosterone levels [3,49].

8.2. Girls with left and right thoracic AIS – white matter density

In a pilot study [31], girls with left thoracic AIS (n=9) have statistically less white matter density in the left supra-tentorial brain in three sites compared with age matched controls (n=11) – genu of corpus callosum, anterior limb of internal capsule and the white matter underlying the orbitofrontal cortex. In girls with right thoracic AIS (n=20) no significant differences were detected in white matter density compared with normal girls (n=17). This contrast between the brain white matter associated with left and right thoracic AIS suggests that lower white matter density of left thoracic AIS is not secondary to the scoliosis.

8.3. Girls with right thoracic AIS – volume studies

In MRI brain studies, 20 AIS girls compared with 20 normal girls showed significant unilateral regional differences at several sites [22].

9. Future research

9.1. MRI brain studies

Larger samples are needed for subjects with thoracic AIS, other curve types, boys with AIS as well as of subjects with secondary scoliosis.

9.2. Developmental disharmony between the autonomic and somatic nervous systems in the pathogenesis of AIS?

In girls, the expression of AIS may result from disharmony between the somatic and autonomic nervous systems – relative postural maturational delay in the somatic nervous system and hypothalamic dysfunction in the autonomic nervous system with the conflict being fought out in the spine and trunk of the girl and compounded by biomechanical spinal growth modulation [44]. Future research on the *NOTOM escalator* concept of the somatic nervous system needs to be integrated with an evaluation of the leptin-sympathetic nervous system concept for the pathogenesis of AIS [3,4].

9.3. Systems-biology approach (the new holism)

In addition to the historical reductionist approach, a systems-biology approach is now needed [50,51] to evaluate these *two* concepts of pathogenesis for AIS. This will involve multidisciplinary research including brain imaging and function, neuropsychology, the hypothalamus, sympathetic nervous system, neuroendocrinology, neuropharmacology, computer modeling and robotics [27-29] all leading to new theories and new experiments.

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Chapter 5

Screening and Prevention of Scoliosis

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Carrying a Rucksack on either Shoulder or the Back, Does it matter? Load Induced Functional Scoliosis in "normal" young subjects

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Abstract. Approximately 40 million students in the United States and a similar number in Europe carry school rucksacks. The average student carries a rucksack weighing almost one fourth of his or her body weight. This has led to more than 7,000 A&E referrals each year related to carrying school bags in the US. The purpose of this study was to investigate the effects of carrying a rucksack (on each shoulder or on both), on 3D spinal curvature in healthy young students. A convenience sample of 30 healthy young adults participated in this study. A Microscribe 3DX digitiser recorded the three dimensional coordinates of thirteen key anatomical landmarks along the spine in four different loading conditions; no rucksack (reference) carrying a rucksack (17% body weight) simultaneously on both shoulders and solely on the right or the left shoulder. The data obtained was analyzed using standard statistical methods. Carrying the load on both shoulders resulted in no difference in the frontal plane angle but significantly decreased the thoracic kyphosis in the sagittal plane. However, carrying the load on the right shoulder significantly increased the thoracic lateral curvature in the frontal plane and decreased the thoracic kyphosis in the sagittal plane. This study confirms that even carrying a 17% load causes significant changes in spinal alignment. It is essential that Health and Safety professionals promote the awareness and effects of diverse rucksack carriage modes and excessive rucksack weight to avoid the early onset of low back pain.

Keywords. Rucksack, loading, symmetrical, asymmetrical

1. Background

Rucksacks are carried by approximately 92 percent of students and result in more than 7000 emergency visits in the US alone each year.[1] Typically the Rucksacks are loaded with between 17% to 22% of the students body weight [2]. Overloading the back can result in numerous detrimental effects to the body, including back, neck and shoulder pain, nerve injuries, decreased blood flow to the shoulder and arm as well as loss of fine motor control and negative postural adaptations [3][4] Whilst numerous studies have been conducted into the effects of Rucksack use on school children [5], work occupations (e.g. postal workers) and the military [6], studies investigating the biomechanical effects of Rucksack carriage on young adult students are limited.

Previous work conducted by the authors [7] has demonstrated that *asymmetrical cross-body* loading of *satchel type bags* in students has less overall impact on posture than *asymmetrical same-sided* loading; the biomechanical impact of symmetrical versus asymmetrical loading of Rucksacks was not evaluated in this previous study. The purpose of the current study was to evaluate the effects of carrying a Rucksack asymmetrically on either shoulder or symmetrically on both shoulders.

2. Methodology

2.1. Participants.

A convenience sample of 30 students was recruited for this study (n = 31), 18 females and 12 males. Ages ranged 20 – 35 years (mean = 25), height ranged 149 – 186.7 cm (mean = 169.2cm), weight ranged 48 – 90 kg (mean = 66 kg) with 86.6% of participants being right handed and 13.3% left handed. Any subjects previously diagnosed with upper or lower limb conditions, spinal pathologies, proprioceptive, vestibular or neurological conditions or any known allergies to self-adhesive stickers were excluded from the study. Ethical approval was granted by the University of Teesside School of Health and Social Care Ethics Committee.

2.2. Instrumentation.

The 'MIDAS'system (Middlesbrough Integrated Digital Assessment System) Microscribe 3DX digitizer (immersion Corporation Ltd) was used to measure the 3D shape of the spine [8].

2.3. Rucksack design.

The design of the Rucksack was adjusted from that of a normal Rucksack. The centre of the bag was cut out and the sides re-stitched with Mersilk 2-0 (an extremely strong surgical thread, W321 Ethican, Inc). This created a gap in the centre of the Rucksack to access the spinal landmarks, creating two pockets on either side which enabled the lead weights to be distributed equally.

2.4. Procedure.

Participants had their height and weight measured. The Rucksacks were then loaded with 17% of the subjects' body weight. Thirteen key anatomical spinal landmarks were marked with 8mm diameter self-adhesive stickers in standing [8]. Each anatomical landmark was then recorded using the stylus tip, firstly without the Rucksack, then on both shoulders and finally on the right and left shoulder respectively. The Rucksack was carried in this static posture for two minutes for each test condition allowing any postural adaptations to occur. A rest period between each test condition was undertaken to unload the spine. This brief loading time was selected as while most participants had no problems carrying the weight on both shoulders for a period of four minutes, some participants became extremely uncomfortable during the third minute whilst carrying the Rucksack on one shoulder.

Figures 1-3 Symmetrical and Asymmetrical load carriage on both shoulders and the left and right shoulder respectively

2.5. Statistical analysis.

Results were analyzed using SPSS version 13.0. A within sample repeated-measures Analysis of Variance (ANOVA) was conducted to compare load carriage methods, to distinguish any significant results within the data collected to $p<0.05$. A Sidak post hoc test was used to determine where significant differences lay.

3. Results

Table 1: Mean values and standard deviation for different modes of rucksack carriage in mm

Frontal Plane Values in degrees			Sagittal Plane Values in degrees	
Load location	Thoracic curvature	Lumbar Curvature	Thoracic Kyphosis	Lumbar Lordosis
No load	22.0 SD 14.5	16.5 SD14.3	42.2 SD 17.1	25.84 SD 16.0
Both shoulders	20.4 SD 17.4	15.8 SD13.9	34.3* SD 17.6	25.83 SD 17.8
Right shoulder	36.7* SD 15.5	19.1 SD 14.0	30.6* SD 16.8	26.85 SD 26.8
Left Shoulder	22.7 SD16.9	15.3 SD 12.0	44.1 SD14.0	26.71 SD 15.8

*Value was significantly different from base-line at $p<0.001$

4. Discussion

This study confirms that there are significant three-dimensional changes in spinal alignment in response to symmetrical or asymmetrical carriage of Rucksacks following just 2 minutes of loading. Carrying a load on the right shoulder significantly increased the thoracic curvature in the frontal plane and significantly decreased the thoracic kyphosis in the sagittal plane resulting in a left convex thoracic scoliosis (figure 3. Carrying the load on the left shoulder resulted in no statistically significant overall differences; however a right thoracic convex functional scoliosis was seen in a number of females (figure 2). Carrying the load on both shoulders resulted in no significant difference in the frontal plane however the thoracic kyphosis in the sagittal plane decreased significantly to produce a flat back posture.

This study clearly demonstrates that carrying a Rucksack for a very brief period of time results in significant negative postural adaptations. This study suggests that a 17% load is too heavy for several hours of daily Rucksack carriage. In the long term this amount of Rucksack weight may result in significantly overloading the back and producing all the aforementioned medical problems.

As the use of Rucksacks within today's population increases in popularity, it is increasingly apparent that education and correct information are essential for Rucksack safety. Public awareness needs to be intensified, to make all students aware of the importance of carrying a Rucksack on ***both*** shoulders. The authors suggest that the appropriate Rucksack ***weight*** as well as the ***method*** of carriage are key considerations in decreasing the negative effects of spinal loading. From a public health and safety perspective, the results of this study strongly suggest that concerted efforts should be directed at decreasing Rucksack loads, ensuring correct usage with two symmetrical straps, increasing awareness of poor spinal posture and initiating educational seminars as ways for students to avoid long term medical problems in the back, shoulder, neck, arms and hands.

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Ultrasound femoral anteversion (FAV) and tibial torsion (TT) after school screening for adolescent idiopathic scoliosis (AIS)

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Abstract. Torsion and counter-torsion in the spine are features of the three-dimensional deformity of adolescent idiopathic scoliosis, Vertebral axial rotation has recently been found in the normal adult thoracic spine. Torsion in the lower limbs, femora and tibiae is a feature of normal human skeletal postnatal development. In recent years, femoral anteversion (FAV) and tibial torsion (TT) have been studied in normal children by imaging techniques, especially ultrasound. This paper reports summaries of the application of real-time ultrasound to FAV and TT of normal children and scoliosis school screening referrals. In the scoliosis girls and boys, the FAV decrease and FAV asymmetry compared with normals may result from abnormally increased femoral detorsion maturationally earlier with left-right asynchrony which, if repeated as a growth plate anomaly in the trunk (spine and/or periapical ribs), might initiate the AIS deformity, given other requirements. In scoliosis boys relative to girls, the TT decrease without asymmetry may result from sexually dimorphic maturation at knee tibial growth plates ? maturationally delayed TT with left-right synchrony.

Key words. Idiopathic scoliosis, pathogenesis, spine, ultrasound, femoral anteversion, tibial torsion, growth plate

1. General introduction

Farkas [1] suggested that the cause of *physiological scoliosis* is the human gait. In the early 1990s we attempted to interpret AIS pathogenesis with an evolutionary perspective of the human unique upright posture and gait (*Nottingham concept)* [2-6]. More recently, other workers have considered that human fully erect posture and bipedalism [7] are prerequisites for the development of idiopathic scoliosis [8-14]. The spine of normal human adults has been shown to possess structural vertebral axial rotation [12,13]. Human upright posture is associated with normal axial torsional changes in lower limbs during post-natal growth in femora as decreasing anteversion (femoral detorsion [15,16]) and in tibiae as increasing external torsion [16,17] (Figure 1).

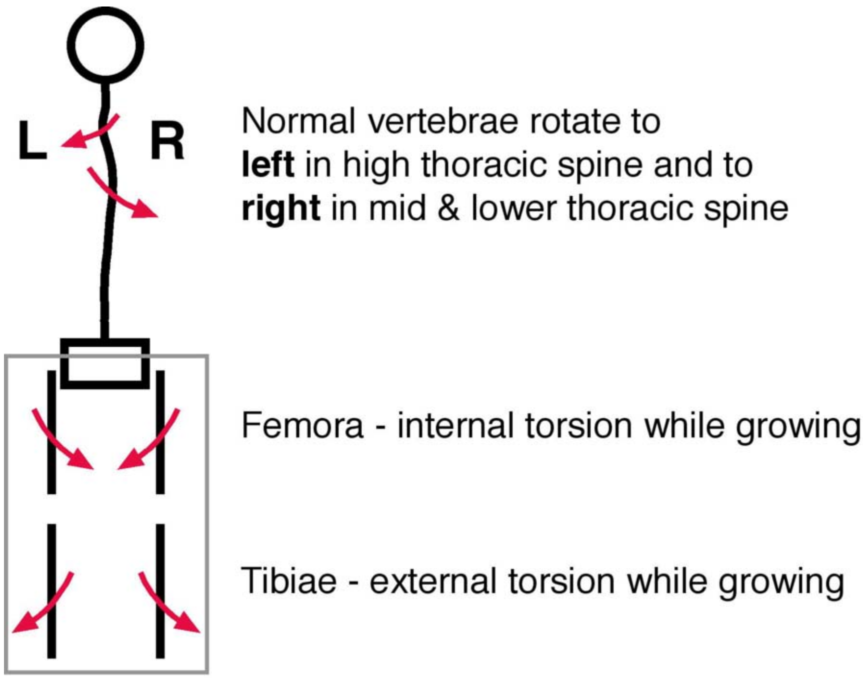

Figure 1. Schematic drawing to show axial vertebral rotations in the thoracic spine of normal adults [12,13] and normal torsional changes in the femora (internal torsion) and tibiae (external torsion) of girls and boys while growing [15-20].

Prochiantz [21] used CT to study femoral anteversion (FAV) in eight patients with idiopathic scoliosis and wrote, "It appears that a number of cases of idiopathic scoliosis originate in asymmetric femoral anteversion." The introduction of ultrasound to measure FAV by Moulton and Upadhyay [22] led us to apply B-mode and later real-time ultrasound methods to estimate FAV and tibial torsion (TT) in both normal subjects [15,16] and subjects with adolescent idiopathic scoliosis (AIS)[23-28].

In this paper we report summaries of findings for FAV and TT in AIS patients referred to hospital after routine screening for AIS [29] and in normal subjects. Preliminary reports of the recent findings for FAV [27] and TT [28].have been published.

2. FAV is decreased and asymmetric: femora show torsional anomalies that if in the spine may initiate the scoliosis deformity

2.1. Postnatal changes

Femoral anteversion (FAV), or torsion, decreases postnatally and attributed to muscular forces across the hip [30] and other biomechanical forces[31](Figure 1).

2.2. Methods and subjects

Real-time ultrasound was used to measure FAV in adolescents age 11-18 years: scoliosis screening referrals by a routine quantitative protocol [27] during 1993-99 (girls 93, boys 35), and normals (girls 157, boys 144). Clinical evaluation (RGB) identified types of AIS:

thoracic (30), thoracolumbar (38), lumbar (25), double (14), pelvic tilt scoliosis (16) and straight spine (5). The spinal radiograph measurements made by one observer (RGB) included Cobb angle and apical vertebral rotation [32]. FAVs were measured between upper end of femur and femoral condyles by a radiographer (RKA or ASK).using the method of Zarate et al [33].

2.3. Results (Figure 2)

Mean FAVs (degrees) are: girl referrals right 22.5, left 24.1, normals, right 25.6, left 25.6; boy referrals right 18.3, left 22.9, normals, right 24.4, left 25.3. FAVs decrease significantly with age in normal boys, but not in normal girls or referrals. FAVs are less than normal in scoliosis girls and in right FAV of scoliosis boys (girls right p=0.014, left p=0.027; boys right p<0.001, left p=0.181, ANOVA correcting for age). FAV asymmetry (right *minus* left) is significant in referrals (boys mean -4.6°, p<0.001; girls mean –1.6°, p=0.031). FAV and FAV asymmetries are not significantly associated with scoliosis side or severity.

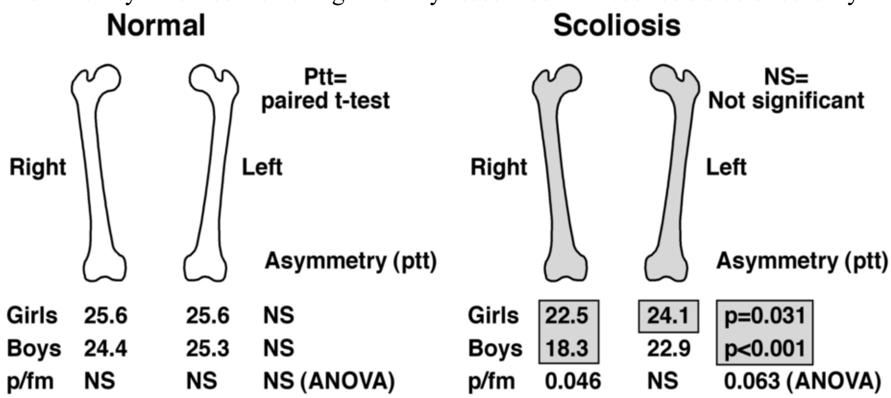

Figure 2. Findings for femoral anteversion (FAV) in normals and scoliosis subjects. The shaded areas in the scoliosis group are significantly different from normal. Mean FAV values in degrees are shown for right and left femora with statistical comparisons for 1) right/left FAVs (Ptt and asymmetry ANOVA), and 2) sex (Ptts and FAV asymmetry ANOVA). Between normal girls and boys, FAVs are not significantly different (NS=not significant) but in scoliosis subjects right FAV is significantly lower in boys than girls (p/fm=p-values for female/male). FAV asymmetry using a paired t-test (Ptt) shows no statistical significance in the normal girls or boys but does in the female and male scoliosis subjects; FAV asymmetry between girls and boys in normals is not significantly different, and approaches significance in the scoliosis subjects (ANOVA).

2.4. Conclusion

In the scoliosis girls and boys, FAV decrease and FAV asymmetry may result from abnormally increased femoral detorsion maturationally earlier with left-right asynchrony which, if repeated as a growth plate anomaly in the trunk (spine and/or periapical ribs), might initiate the AIS deformity, given other requirements.

3. Ultrasound tibial torsion (TT) and TT asymmetry are not abnormal: in scoliosis boys TT (right and left) is decreased relative to scoliosis girls without asymmetry - the result of altered maturation at knee tibial growth plates?

3.1. Postnatal changes

Tibial torsion (TT) increases postnatally (Figure 1).

3,2. Methods and subjects

The subjects, normal and AIS, and the methods used were as for the ultrasound method used for TT which was measured between tibial condyles and talus by a radiographer (RKA or ASK) using the method of Kirby et al [34].

3.3. Results (Figure 3)

Mean TTs (degrees) are: girl referrals right 29.5, left 28.7; normals, right 27.0, left 27.7; boy referrals right 25.1, left 24.6, normals, right 28.3, left 26.1. *Normals:* TTs and TT asymmetry (right *minus* left) show slight increases or no change with age; boys are more asymmetric than girls (respectively +2.2º -0.7º, p=0.002, ANOVA with age and sex corrections). *Referrals:* with age TT and TT asymmetry in girls show no significant change and in boys an increase of both right TT (p<0.001) and TT asymmetry (p<0.004). TT and TT asymmetry in the scoliosis subjects are not significantly different from the normals (ANOVA correcting for age). TT is decreased in boys relative to girls (right p=0.025, left p=0.015); TT asymmetry in boys (+0.5º) compared with girls (+0.8º) is not significant (ANOVA correcting for age); TTs and TT asymmetry are not associated with scoliosis side or severity.

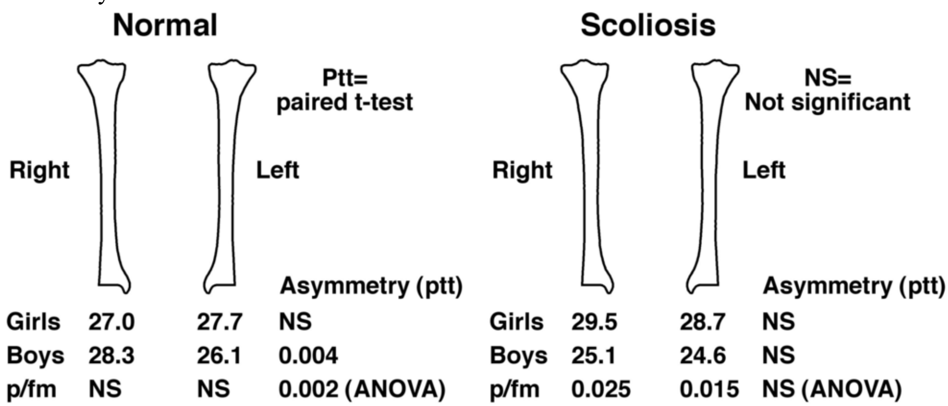

Figure 3. Findings for tibial torsion (TT) in normals and scoliosis subjects. Mean TT values in degrees are shown for right and left tibiae with statistical comparisons for 1) right/left TTs (asymmetry), and 2) sex (Ptts and asymmetry ANOVA). Between normal girls and boys, TTs are not significantly different (NS=not significant) but in scoliosis subjects TTss are significantly smaller in boys than girls (p/fm=p-values for female/male). TT asymmetry using a paired t-test (Ptt) shows statistical significance for the normal boys but not in the normal girls and not in the scoliosis subjecrs, female or male. TT asymmetry between girls and boys in the normals is significantly different, but not in the scoliosis subjects (ANOVA).

3.4 Conclusion.

In scoliosis boys relative to scoliosis girls, TT decrease without asymmetry may result from sexually dimorphic maturation at knee tibial growth plates ?maturationally delayed TT with left-right synchrony.

3.5. The relation of FAV-to-TT

The raw data for FAV and TT in normals and screened subjects provide the basis for evaluating the relation of FAV-to-TT by an *FAV/TT ratio* and an *index* (TT minus FAV) [20].

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Positional relationship between leg rotation and lumbar spine during quiet standing

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Abstract. Healthcare professionals frequently evaluate spinal posture on visual assessment during the clinical examination. While this visual assessment of the spine has been shown to be unreliable, the use of a plumbline as to aid clinical visual assessment has also been reported. There is a "normal" sagittal contour that functions quite well in healthy people. It positions the head in space, it protects the neural axis, and it allows efficient, pain-free motion. Lumbar lordosis is routinely evaluated in most spine patients, but what constitutes a normal sagittal contour is less well defined. A key component of normal sagittal contour is lumbar lordosis. Changes in the lumbar lordosis frequently occur in pathological gait, usually in association with alterations in pelvic tilt, and commonly as a compensation for a limited range of flexion/extension at the hip joint. Recent investigations looked at the effect of hyperpronation on pelvic alignment in a standing position and supported the existence of a kinematic chain in healthy subjects, where hyperpronation can lead to an immediate shank and thigh internal rotation and change in pelvic position. While there is a wealth of research is available on the effectiveness of functional foot orthoses, the present investigation reports the effect of pronated foot position on the lumbar region of the back by employing an optoelectronic movement analysis system.

Keywords: Lordosis, Lumbar, Spine, leg, foot, calcaneus

1. Introduction

Lower back pain is a disabling condition that affects both the general and working population. While, Burton et al [1] indicated that shoe insoles are not recommended in the prevention of back problems, previous investigations have looked at the effectiveness of shoe inserts on back pain. The rationale for the use of foot orthoses to prevent or modify back pain is based on their impact attenuation ability during walking [2]. However, Dananberg [3, 4] has provided some evidence for an alternative rationale for treatment of back pain with functional foot orthoses. There is a "normal" sagittal contour of the spine that functions effectively in healthy people. It protects the neutral spine axis, and precipitates efficient, pain-free motion. Lumbar lordosis (LL) is a key component of the normal sagittal contour, it is routinely evaluated in most spine patients, but is not well defined. Changes in the LL frequently occur in pathological gait, usually in association with alterations in pelvic tilt, and commonly as a compensation for a limited range of flexion/extension at the hip joint [5, 6]. Although the invasiveness and risk of radiation preclude the use of the radiograph as a routine measurement in clinical practice, the gold standard measurement of LL is still a plain film x-ray [7,8,9,10]. Other spinal measurement techniques have been developed and reported [11], such as Goniometry [12], skin markers over the spinal processes [13] inclinometers [14] [15] and the use of flexible rulers [16]. These external measurements are easy to apply and non-invasive [17] [10].

Whittle & Levine [6] define the angle of LL as the difference in angle between the areas of skin over the T12-L1 junction and the L5-S1 junction, projected in the sagittal plane. Other researchers have reported different points of measurement relative to the technique being used [7, 8]. Whittle & Levine [6, 18-20] performed a range of studies to promote the use of gait analysis for measuring LL. They demonstrated a high level of significance and reliability when measuring LL based on extensive previous work using motion capture techniques. The relationship between the mechanics of the foot and lower extremity has been confirmed in various studies [21, 22] [23] [24, 25]. However the relationship between foot mechanics and the knee, hip and pelvis are less clear [26][27][28]. Studies investigating the lumbo-pelvic region demonstrated that increasing anterior pelvic tilt increased the LL and increasing posterior pelvic tilt did the opposite [18]. Later work showed the average pelvic tilt and average lumber lordosis relationship was out-of-phase. Pelvic tilt data was relatively consistent across subjects, but the LL showed a complete variety of patterns [6]. They concluded that LL has a highly individualist pattern of movement and that during gait appears to be variable from one subject to another which contrasted previous work which reported patterns of movement in the lumbar spine complemented those of the pelvis in the sagittal plane [29].

The maintenance of postural stability is a complex task that requires the coordination of visual, vestibular and somatosensory inputs [30]. Balance is defined as the process of maintaining the centre of gravity within the body's base of support [31]. Centre of gravity (COG) is described by Winter [32]. Postural sway [33] compensates for small perturbations in stance; however the body cannot be considered as a complete segment. The trunk will always move independently to contribute to balancing the COM. Over time postural changes can occur due to muscular stretch-weakness and weaknesses in proprioception. The current study investigates whether subtalar movement affects limb rotation and pelvic alignment, and if prevalent attempts to corrleate movement at the subtalar joints to movement and alterations in the lumbar lordosis.

2. Materials and Methods

Ethical approval from appropriate ethics committee was received. Children and individuals receiving any type of treatment were excluded from the study. . Subjects were selected using convenience sampling according to their availability to data collection sessions. 17 subjects were recruited to the study (8 males and 9 females) between the ages of 18 and 40 (mean 26.23 years). Subjects were free of any musculoskeletal conditions and abnormalities which included back pain. All subjects gave an informed consent to take part in the study. Inclusion and exclusion criteria are detailed in Table 1.

The upper age limit was set to 40 to exclude subjects with undetermined early degenerative changes in the lumbar spine. It has been suggested that the pathology peaks between the ages of 35 and 55 [34]. Subjects with obvious lower extremity deformity; particularly marked internal/external femoral or tibial torsion were excluded on the basis that these deformities may affect the translation of rotation up the locomotor chain. Heavily pronated subjects were excluded from the study and only those with Foot Posture Index [35] score from -1 to +7 were admitted. Flexibility on the positive side of the score was permitted from subjects presenting easily palpable bony landmarks. Subjects with a leg length discrepancy >2cm were excluded in line with the European guidelines for the prevention of Low back pain [1].

Inclusion criteria	**Exclusion criteria**
Ages between 18 and 40	Current or past back pain
No known lower extremity dysfunction	Obvious lower extremity dysfunction; particularly marked internal/external femoral or tibial torsion.
No LLD or LLD <5mm	Leg Length Discrepancy (>5mm)
Palpable bony landmarks on the lumbar spine	Subjects where bony landmarks were not easily palpable.
Foot Posture Index (Redmond et al 2006) score from -1 to +7	Foot Posture score (Redmond et al 2006) of 7 or greater, <-1

Table 1: Inclusion/Exclusion

Kinematic data was acquired using an optoelectronic motion analysis system (VICON, Oxford). The system utilised 8 infrared cameras to track 15mm reflective markers that were placed on specific landmarks on the lower limb, pelvic area and lumbar spine. The system was calibrated using the manufacturer's guidelines at the beginning and end of each data collection session. Ground reaction forces (GRF) were collected using a force plate (AMTI).

Pilot Study

A single subject pilot study was completed and specific positions of the markers identified by the system were verified by using actual measurements. Two marker sets for evaluating lumbar spine curvature had previously been developed, 3-marker set and a 4-marker set [6]. The 4-marker set was chosen. Two standard VICON rigs were used each consisting of a flat baseplate, from the centre of which protruded a 100mm long wand with a retroflective marker mounted at its end. The marker on the upper baseplate was directly over L1 and the marker on the lower baseplate was directly over S2. The raw data was then exported to Microsoft Excel to calculate the magnitude of lumbar lordosis using a previously described method [6].

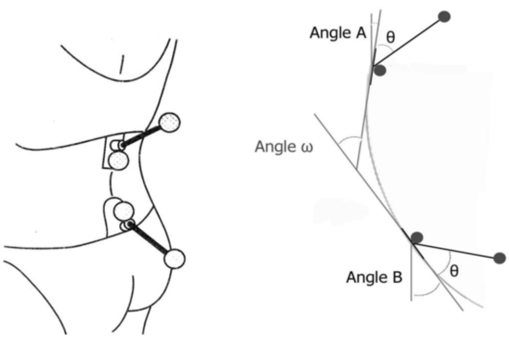

Figure 1: 4 Marker Set (Whittle and Levine 1997)

	Mean	Standard Deviation	Range
Age (years	26.2	± 5.0	21 - 36
Weight (Kg)	72.1	± 11.4	53 - 97
Height (m)	1.7	± 0.1	1.6 - 1.87
BMI (Kg/m^2)	23.7	± 2.4	19.2 - 28.4

Table 2: Participant characteristics n=17 (9 F: 8 M)

Standard anthropometric data (table 2) was collected and the Foot Posture Index (FPI) was determined by the same researcher (NP). Furthermore for every subject the skin markers for kinematic data acquisition were applied by the same researcher (NP).

Prior to fixing the two rigs to the skin, the angle of the wand to the baseplate was validated on a supporting surface manually and by the system. The angle between the baseplate and the line joining the centres of the two markers was then calculated to be 42.84º. The subject was asked to stand in a relaxed position with their arms crossed and the palms of the hands resting on their shoulders to standardise the position and minimise any affect upper limb placement may have on the centre of pressure. Three dimensional kinematic data was collected for all conditions and reported in table 3:

Test Conditions
Relaxed Standing
3.5° Rearfoot Wedges
3.5° Forefoot Wedges
3.5° Full foot Wedges
5° Rearfoot Wedges
5° Forefoot Wedges
5° Full foot Wedges
10° Rearfoot Wedges
10° Forefoot Wedges
10° Full foot Wedges

Table 3: Wedged conditions tested

3. Results

Changes in magnitude of Lumbar Lordosis

Results for all subjects (Fig. 2) showed no substantial similarities between subjects.

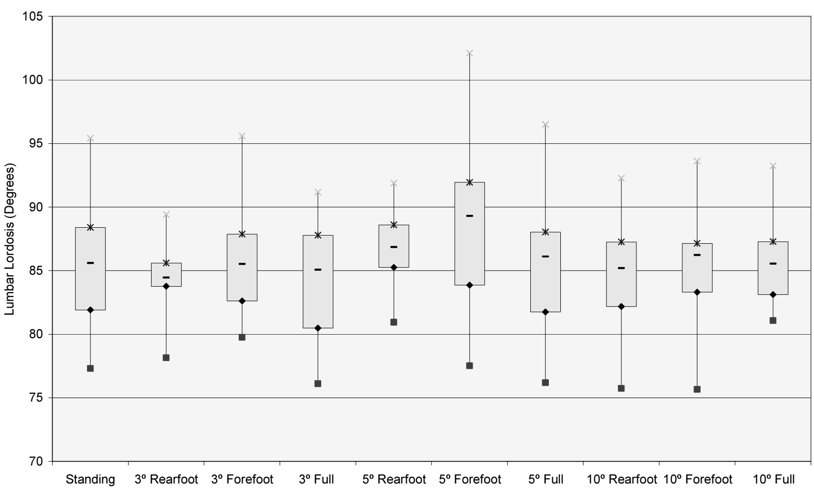

Figure 2: Magnitude of Lumbar Lordosis

Analysing the change in LL from relaxed standing at rearfoot modes only shows a reduction that approaches a linear relationship (Figure 3).

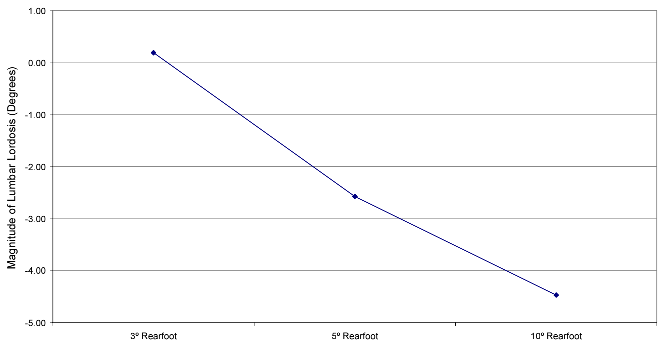

Figure 3: Change of Magnitude of Lordosis from relaxed standing for Rearfoot Conditions

Results were analysed according to Foot Posture Index (FPI) score. The objective of this exercise was to find if certain foot types affect the kinetic chain and therefore the magnitude of the LL in the standing position (Figure 4).

The results suggest there may be a correlation between the slightly more pronated feet and an increased lumbar lordosis. There may also be correlations between the 3º and 5º rearfoot and forefoot wedge modes however the same cannot be said for the 10º results. Regarding the subjects with FPI scores of 2:2 there appears to be limited uniformity to the results, however all results except one are in the negative presenting a reduction in lordosis.

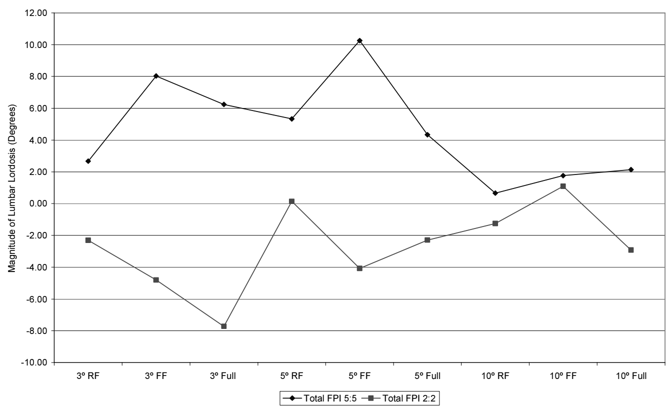

Figure 4: Subjects with Homogeneous FPI scores of 5:5 (n=4) and 2:2 (n=3)

Changes in the projection of the centre of gravity in the transverse plane (PCOG)

Results from a sample of subjects were analysed to assess the translation of the centre of gravity. A negative change indicates that body posture had swayed anteriorly. The converse is true for a positive change in the COP.

Mean values (Figure 6), show all points producing negative values, indicating an anterior translation of the centre of gravity. There is a wide variety of results with little pattern. Standard deviations show that this may not be the case for larger populations

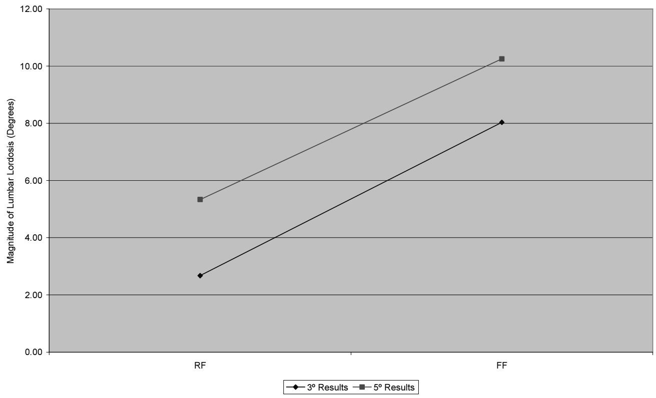

Figure 5: Subjects with Homogeneous FPI scores of 5:5 (Rearfoot and Forefoot only)

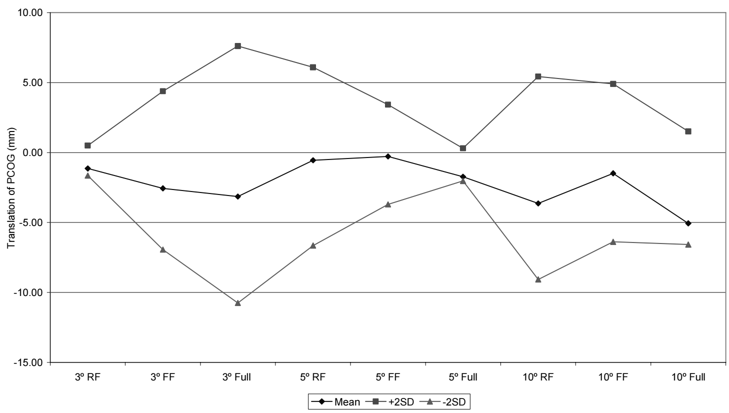

Figure 6: Mean Translation of Projection of COG (-ve = Ant Translation)

4. Discussion

The main aims of the study were; to develop a measurement technique to show that LL can be measured successfully, via non-invasive motion capture analysis; to measure the relationship of the LL to foot function and to consider the effect of foot function on the centre of gravity of the body. The pilot study confirmed the work of previous studies [6, 18, 36]. In standing posture, increasing the amount of pelvic tilt increases the angle of lumbar lordosis, and vice versa. The intention of this research was to deliver normative data on the topic as a baseline before studying pathologic subjects. The direct foot to lordosis relationship was studied as previous investigations pertinent to other links had already been presented [23-27]. Post study evaluation was unable to elucidate trends from the findings.

Changes in magnitude of Lumbar Lordosis
Changes in LL showed no general patterns across the range of subjects. This agreed with previous research where an out-of-phase relationship between the average pelvic tilt and the average LL was found [20]. Different effects were found at the lumbar level depending where the wedge is placed, but with no noticeable patterns. Descriptive data from the present study supports the null hypothesis that, as wedges are applied to the rearfoot in increasing amounts the lordosis decreases (Fig. 3), but not with any direct relationship. Making comparisons across foot posture type there appeared to be a correlation between the slightly more pronated feet and an increased lumbar lordosis. The 3° and 5° rearfoot and forefoot wedge modes seemed to show a general increase, however the same cannot be said for the 10° results. This may be because the foot reached maximal pronation or calcaneal eversion and further eversion was not possible. By inference, and notwithstanding the small sample size, the question of whether such interventions can really alter anything at lumbopelvic level by altering foot posture remains.

Changes in the projection of the centre of gravity in the transverse plane (PCOG)
Hertel [37] postulated that the interface between differently shaped feet (as described by Root [38]) and a force plate could influence ground reaction forces and thus postural control measures during objective assessment of postural stability during single-leg stance. The purpose of this part of the study was to investigate if a foot more akin to pes planus posture affected postural stability by causing an anterior shift in the COP. There was a general movement of the PCOG in the anterior direction (Figure 6), suggesting that foot pronation induced a forward movement of the PCOG across the small sample size. The standard deviations show that this might not be the case for a larger population. If the body maintains balance in response to an anterior shift in the PCOG by altering the upper limb to lower limb relationship, then it did not show in the magnitude of the LL results and may take place elsewhere. Results of the present study suggest excessively pronated feet may cause an anterior translation of the PCOG although the findings are not supported in the literature. This reinforces the common anecdotal belief that pronated feet alter body posture in the anterior/posterior direction. Unfortunately no clear pattern evolved from the results and a larger sample size is recommended for future studies. Correction of excessive pronation may help to prevent the change in PCOG, although this study didn't demonstrate a link to lumbar posture. The results do not support the research aim which was to find whether subtalar movement affects limb rotation and pelvic alignment, and if prevalent attempts to corrleate movement at the subtalar joints to movement and alterations in the lumbar lordosis.

5. Limitations

The primary limitation of this study is the small sample size. A larger population of subjects would have contributed more validity to the results. Tighter Inclusion criteria would have made demonstrating trends in the results more achievable. Direct comparison of the results with previous studies was not possible due to the different methodology accompanied with the innovative parameters being measured.

Reproducing previous studies [25] to validate their results could have been incorporated into the study methodology to allow direct comparisons with previously reported research (REFERENCES). Using smaller wedges may have limited the study to very small fluctuations in lumbar posture in the test group whereas larger wedges, although not representative of the clinical situation may have produced better results. The results of this study were dependent on visualizing changes within a static model, with the lack of conclusive results from this study, further investigation where dynamic stresses are in place and can be assessed, should be considered.

6. Conclusion

The response of the Lumbar lordosis to changes in foot posture is varied and the paucity of relationships suggest further studies are required. There may be merit in investigating subjects with different back postures to establish a degenerative link. The results suggest that pronated feet cause an anterior movement of the centre of gravity and reinforce the common anecdotal belief that pronated feet alter body position and posture, although compensation for these changes may not be taking place exclusively in the lordotic region.

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Aetiology of Idiopathic Scoliosis. What have we learned from School Screening?

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Abstract. The value of school screening as a research tool for Idiopathic Scoliosis (IS) aetiology has not been recognized adequately in the literature. The aim of the present study is to summarize the contribution of school screening in research of IS aetiology. All the relative publications about research of IS aetiology which originated from our scoliosis school screening program were analyzed. Information is provided about a) the influence of environmental factors in IS prevalence, b) the IS prevalence in girls with visual deficiency, c) the role of melatonin in IS pathogenesis, d) the age at menarche in IS girls and its relation to laterality of the curve, e) the role of the brain in trunk asymmetry and IS pathogenesis, f) the role of the thoracic cage in IS pathogenesis, g) the impact of the lateral spinal profile, h) the role of the intervertebral discs in IS pathogenesis, i) the association of cavus foot with IS and j) anthropometric data in IS patients. The present study provides evidence to support that school screening programs should be continued not only for early detection of IS or for health care purposes, but also as a basis for epidemiological surveys until we learn much more about the aetiology of IS.

Keywords. Idiopathic scoliosis, school screening, aetiology of idiopathic scoliosis

1. Introduction

Scoliosis school screening (SSS) continues to be controversial. There are studies which both support [1, 2] and discourage [3, 4] routine SSS. The initial goal of SSS is to detect scoliosis at an early stage when deformity is likely to go unnoticed [5] and a less invasive treatment is more effective [6], although it is not a diagnostic process. Negativists to SSS programs have focused on concerns about a low predictive value of screening and the cost effectiveness of referral. There have also been concerns about the possibility of unnecessary treatment including brace use and the effect of exposure to radiation when radiographs are obtained [5, 7, 8, 9].

On the contrary there is evidence that SSS provide valuable data for research on IS aetiology [10, 11, 12, 13, 14, 15]. Even the opponents of SSS agree that it has a role and should be carried out as a basis for epidemiological surveys until we know much more about the aetiology and factors likely to determine the natural history of late-onset IS [16].

The present study highlights the input of our SSS program in research of IS aetiology.

2. Material and Methods

We reviewed all the relative publications which originated from the "Thriasio" SSS program [17] and provided some input in research of IS aetiology.

3. Results

IS prevalence at "Thriasio Pedio", which is a heavily industrialized area was found similar to the prevalence reported in other non-industrialized areas of Greece. This implies that industrial environmental factors do not play any role for a possible difference in IS prevalence [18].

IS prevalence has been reported to be different in various geographic latitudes and demonstrates higher values in northern countries. This observation could be related to the influence of the geography of a specific region on human biology and could be determined by socioeconomic and environmental factors such as temperature, humidity and light. [19] Furthermore, in a different study the regression of prevalence of IS and age at menarche by geographical latitude was found statistically significant ($p < 0.001$) and both they were following a parallel course of their regression curves, especially in latitudes northern than 25 degrees, which means that late age at menarche was parallel with higher prevalence of IS. The positive association between prevalence of IS and geographic latitude is present only in girls and not in boys. We hypothesized that the increased levels of melatonin in northern countries with poor light environmental conditions are reducing the secretion of LH and causes delayed age at menarche. Delayed puberty results in a prolonged period of spine vulnerability when other aetiological factors are contributing to the development of IS [20]. Interestingly, in blind girls who were found to have a delayed age at menarche, IS prevalence was found to be 42.3%! [21, 22].

An aetiopathogenic role of cerebral cortex function in the determination of the thoracic surface morphology of the trunk was hypothesized after finding a possitive correlation between trunk asymmetry and lateralization of the brain as expressed by handedness in in children who are entitled at risk to develope IS. [23, 24]

In a study of rib vertebra angles (RVAs) we showed that scoliotic children with small curves had under developed thoracic cage compared to non scoliotic counterparts. It was suggested that the differences of the RVAs between right and left side were the expression of asymmetric muscle forces acting on the thoracic cage, which deforms early and possibly transfers the deforming forces to the spine [13].

In a different study no correlation was found between the Cobb angle and the "rib index" [12] of thoracic, thoracolumbar and lumbar curves. A positive correlation of the "rib index" with each of T2, T3, T4, T5, T6 and T7 Lateral Spinal Profile (LSP) in girls with lumbar curves was found. The mean age of non-scoliotics was 1.5-2 years younger than scoliotics. Rib index was approximately 1.5, which implies pronounced thoracic asymmetry in terms of rib hump, in all SSS referrals who presented with an already developed deformity of the thorax. 70% of them were scoliotics, 10% had a curve $< 9^o$ and 20% had straight spines, as confirmed by an x-ray. This observation supports the hypothesis that in idiopathic scoliosis the deformity of the thorax precedes the deformity of the spine [12, 25]. Furthermore, the correlation between the rib cage deformity and the deformity of the spine is weak in younger children, [25] as 25% of children with ATI ≥7º had a spinal curve under 10º or had a straight spine. As a result of the effect of growth on the correlation between the thoracic surface deformity and the spinal deformity, the predictive value of the existing formulas which calculate the Cobb angle from surface measurements is poor. Therefore our recommendation is to take into consideration the effect of growth when developing such predictive models, otherwise they can be inaccurate.

In a study of the LSP of mild (10º-20º) scoliotic curves, we demonstrated that hypokyphosis of the thoracic spine by alleviating axial rotation is not a predisposing factor but rather a compensatory mechanism for the initiation of mild scoliotic curves [14].

In a radiological study of SSS referrals, we showed that in mild scoliotic curves, the deformity appears first at the level of the intervertebral disc (IVD), which is found wedged. The deformity of the vertebral body or of the spinal column follows. 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 deformation of the apical IVD seems to be an important progressive factor in IS pathogenesis [26].

Flat foot, as well as cavus foot which was previously reported that is correlated positively with IS was not confirmed in our study [10].

A variety of findings regarding the stature and weight of IS children has been published. In a study in Mediterranean population, the somatometric parameters of height and weight in children with scoliosis, regardless of curve type and site, are not statistically different from their non scoliotic counterparts [15].

Finally, studying the age at menarche in IS girls it was found that there was not statistically significant difference of this variable between scoliotic and non scoliotic girls in the Mediterranean population studied [11].

4. Discussion

The important findings on the lack of statistically significant difference of the age at menarche between scoliotic and non scoliotic girls in the studied Mediterranean population and the similar findings on the somatometric parameters of height and weight in children with scoliosis, which are not statistically different from their non scoliotic counterparts motivated us to explore the possible role and impact of the geography - environmental factors (the light) on the pathogenesis of scoliosis. The findings are reported in our results. These observations could not be figured out without running a SSS program.

The early detection of IS has been a major and growing commitment of Orthopaedists since the early 1960s. Early detection implies early treatment and by that less surgery. Although SSS's aim is prevention and it should be regarded as a criterion of welfare of our civilization, it has been criticized for its negative cost-effectiveness. It is clear that a realistic evaluation of the cost is not feasible and could result in inaccurate overestimation of the total cost as it might take into consideration many qualitative and subjective factors [17]. On the other hand the financial profit from research of IS aetiology, which was analyzed in the present study cannot be estimated.

The present study provides evidence to support that school screening programs should be continued not only for early detection of IS but also as a basis for epidemiological surveys until we learn much more about the aetiology of IS.

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Suggestions for improvement of School Screening for Idiopathic Scoliosis

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Abstract. There is skepticism and the worth of school screening for the purposes of health care has been challenged. Numerous reasons are raised by the negativists to abandon these programs, even though the value of school screening is well documented in the literature. The aim of the present study is to update the evidence based recommendations for the improvement of school screening effectiveness, in order to support its continuation. All the relative research papers which originated from our scoliosis school screening program were analyzed. Specific suggestions for a) the organization, b) the optimal age of screening according to the geographical latitude, c) the best examined position, d) the standardization of referrals, e) the follow up of younger referrals with trunk asymmetry and f) the reduction of the financial cost are made. Today there is evidence that the incidence of surgery can significantly be reduced in areas where idiopathic scoliosis can be detected at an early stage through these programs. The introduction of these recommendations to all the existing school screening programs is strongly suggested, to reduce the negative impact they may have on families and on the health system and to improve their effectiveness.

Keywords. Idiopathic scoliosis, school screening, improvement of school screening

1. Introduction

There are numerous problems that prevent school screening for IS from being universally accepted. The low prevalence of IS, the high false positive referrals and the excessive cost, both direct and indirect, are raised by the negativists as reasons to abandon school screening programs. To our knowledge, there is no study in the literature to provide suggestions on how to improve the weak points of scoliosis school screening.

The American Academy of Orthopaedic Surgeons, Scoliosis Research Society, Pediatric Orthopaedic Society of North America and American Academy of Pediatrics in their most recently published joint information statement on scoliosis screening do not support any recommendation against scoliosis screening, given the available literature [1]. Scoliosis screening has proven effective in many ways, and it is considered beneficial among the Orthopaedic community [2]. Furthermore, it provides the opportunity for early diagnosis and conservative treatment, which is often missed in the absence of screening [3].

The initial goal of scoliosis school screening was to detect IS at an early stage when deformity is likely to go unnoticed [3]. In an effort to enhance the effectiveness of school screening programs, the International Society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT) recommended as a new goal to identify those children who will be at risk for developing scoliosis [2] and those children who have curves likely to require conservative treatment [4]. This would require better organization, selective screening of high-risk children, improved examination techniques, standardization of the referral process and cost reduction.

2. Material-Method

We reviewed all the research papers which originated from the “Thriasio” school screening program [5] and provided evidence based recommendations for the improvement of school screening effectiveness.

3. Results

School screening has to be set up on a district basis after obtaining permission from the state authorities to approach and examine the school children. A permanent team of examiners should be created, after adequate experience. The examiners should have a core of 2-3 health professionals who are experienced in screening techniques, data entry and occasionally can be staffed by other health professionals on a voluntary basis. The examiners and all the involved individuals (children and their families) must have easy access to the referral hospital. It is important to inform and train if necessary all the interested parties in advance, by distribution of informative material and lectures. Before visiting a school the parents or carerers must fill a consent form (Europe) or be notified by letter as a courtesy in countries where school screening is legislated (North America) and the pupils must fill a particular form regarding their personal and demographic data. The facilities for examination should be prepared by the school stuff in advance and the timetable of that day should be modified accordingly, so that the examination time is kept effectively to a minimum.

In a previous study we reported that the regression curve of both the IS prevalence and age at menarche by geographical latitude is following a parallel ascending course, especially in latitudes northern than 25^{o}, which means that late age at menarche was parallel with higher prevalence of IS [6]. In order to increase the predictive value of school screening, we should screen children for scoliosis at a range of age adjusted for the geographical latitude.

In a study of trunk asymmetry of 2071 children and adolescents we found a significant reduction in the proportion of asymmetry between the standing and sitting forward bending position during examination [7, 8]. By screening children in sitting position with the use of a scoliometer, the number of referrals can be decreased dramatically because the effect of leg length inequality and pelvic obliquity on the spine is eliminated. [8] Children with leg length inequality could be referred independently for further consultation. Sitting position reveals the true trunk asymmetry which could be associated with IS and therefore it is recommended as a standard examination method in a school screening program as well as a second level test for all potential referrals.

It is essential when we set up the screening process to collect information about the gender, the chronological age, the age at menarche, the pattern and the magnitude of asymmetry and the growth potential. All these are very important prognostic factors for progression of a detected asymmetry. [9,10]. Trunk asymmetry should be measured by the use of a scoliometer in three sites of the spine (thoracic, thoracolumbar and lumbar) [7] and a cut-off point of 7° together with the prognostic factors should be used for referral. The same factors can be used in scoliosis clinic to determine whether it is necessary to x-ray a child or not, by the more experienced Orthopaedic surgeons, as a second stage of screening. In the model we propose [5] we standardize the referral process, by documenting all these factors, Table 1.

Table 1. Recommended criteria for referral in scoliosis school screening

1. Trunk asymmetry (scoliometer reading)	2. Gender	3. Chronological age	4. Age at menarche for girls
5. Pattern of asymmetry	6. Growth potential	7. Maturation	

Although asymmetry in skeletally mature children is unlikely to be associated with a progressive scoliotic curve, we noticed in a previous study that in some younger referred girls from the school-screening program there is a discrepancy between the thoracic scoliometer readings and the morphology of their spine [11]. After statistical analysis no significant correlation was found between the surface and the spinal deformity in the younger referred girls aged 8-13 years old, while in older referred girls aged 14-18 years old, this correlation was statistically significant. Therefore, all the younger individuals who are identified with a surface deformity but without a severe scoliotic curve are at risk for IS development and need to be kept under observation and not be discharged from regular follow up.

The financial cost of a school screening program can be either direct or indirect [12]. There is no general consensus among economists as to what constitutes the indirect cost in a cost effectiveness analysis because the indirect cost cannot be measured accurately as it is related to the effectiveness of the school screening program. A more effective screening program has lower indirect cost. Therefore the economic information on screening for scoliosis which is available to decision-makers should mainly be based on studies of the direct cost of such programs. In a six year performance of the “Thriasio” school screening program, the direct cost for the examination of each child was 2.04 €, which is considered low [5]. This study provides evidence that the direct cost of a screening program can be reduced to a minimum, if it is well organized and it is performed according to the model we propose [5].

4. Discussion

School screening programs are performed in different ways around the world. Unfortunately there is no consensus among the experts on specific criteria of screening. As a consequence of the luck of standards of scoliosis screening, there is no adequate evidence based on outcome results necessary to either enhance or eliminate the school screening process.

Today there is evidence that the incidence of surgery can significantly be reduced where conservative treatment is available on a high standard [13, 14, 15]. In areas where scoliosis school screening has stopped, the referral mechanisms for IS are leading to a suboptimal case-mix in orthopaedics in terms of appropriateness of referral and resulted in increased late referrals with regards to brace treatment indications [16]. School screening through detection of IS at an early stage is the only tool we have to detect mild and moderate spinal curves which can be treated conservatively in an effective way. Physicians should be more interested in quality of care for their patients than in epidemiology, numbers, statistics, or money. Prevention instead of treatment, which was an axiom in Ancient Greece, must return as a standard health policy in civilized societies. And school screening is primarily a preventive process. Our screening vision should be strongly focused on how to improve its effectiveness so that we can change the paradigm from today's "correction" and "fusion" goal to a stronger goal of maintaining the natural shape and mobility of the spine and "preventing" a spinal deformity from developing.

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Can Future Back Pain in AIS Subjects be Predicted during Adolescence from the Severity of the Deformity?

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Abstract. Back pain is frequently reported as a symptom of adolescent idiopathic scoliosis (AIS). Prediction of pain in adulthood would be useful to identify subjects requiring follow-up. The aim is to determine adolescent predictors of adult back pain. This study is a retrospective review of 27 females with AIS who attended our pediatric scoliosis clinic and later completed the SRS-22 questionnaire as young adults (range 18-25 years). Subjects with surgery at baseline (age 14-16 years) were excluded. The relationships between largest curve size, decompensation and trunk twist at baseline and pain as measured by the SRS-22 pain domain as young adults were studied. At baseline, subjects had a largest curve of 47 ± 15^{o}, decompensation of 18 ± 14 mm and trunk twist of 14 ± 6^{o}. At follow-up, 5.3 $\pm$1.9 years later, the total SRS-22 score was 3.9 ± 0.3 and the pain domain score was 3.9 ± 0.7. Pearson correlations between the SRS-22 pain domain and largest curve, decompensation and trunk twist were 0.17, -0.11 and -0.25, respectively ($p>0.05$). Individual questions within the pain domain had similar correlations. Even though the sample represented a wide range of scoliosis severity at baseline and a wide range of pain scores (2.4 to 5) at follow-up, baseline scoliosis deformity parameters of largest curve size, decompensation and trunk twist did not predict scoliosis-related pain in young adulthood.

Keywords. SRS-22, questionnaire, back pain, AIS, quality of life

1. Introduction

Back pain is a common reason for young adults with idiopathic scoliosis to seek treatment after being discharged from a pediatric spine service. Questionnaires have been developed to assess health-related quality-of-life in subjects 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.

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. Prediction of pain in adulthood would be useful to identify subjects requiring follow-up

2. Objective

The objective of this study is to determine if spine deformity features measured during adolescence can predict future adult back pain.

3. Methods

Inclusion criteria: Female subjects with a diagnosis of AIS who had baseline surface topography and radiographic examinations between the ages of 14 and 16 years were eligible. Subjects with surgery at baseline (age 14-16 years) were excluded. This study is a retrospective review of 27 females with AIS who attended our pediatric scoliosis clinic and later completed the SRS-22 questionnaire as young adults (range 18-25 years). Table 1 contains descriptions of the subjects.

All subjects attended the pediatric scoliosis service between 14 and 16 years of age. They received radiographs and surface topography examinations during their routine clinical visit. These subjects returned as young adults, at their request, to see an adult spine orthopedic surgeon. They received radiographs and surface topography as well as completed the SRS-22 questionnaire at this examination.

Table 2 shows the SRS-22 pain domain questions and the extreme anchor points. The full SRS-22 questionnaire is available on-line [8].

The number of features chosen to predict adult back pain was limited to 3 to have approximately 10 subjects per predictor variable. The largest Cobb angle was selected because it is the most common radiographic measure to describe scoliosis severity. Decompensation may be reflective of undesirable loading patterns and thus may be a predictor of future pain. Trunk twist is a noticeable visible deformity to the subject and may also be related to an undesirable loading pattern. The relationships between largest curve size, decompensation and trunk twist at baseline and pain as measured by the SRS-22 pain domain as young adults were studied using Pearson's correlation coefficient. Statistical analysis was carried out using Microsoft Excel with an alpha level of 0.05.

The SRS-22 has higher scores for more desirable outcomes whereas for the measured features higher scores represent more deformity, or less desirable outcomes. Correlations near zero represents minimal relationships, negative correlations reflect poorer scores with increasing deformity and positive correlations reflect better scores with increasing deformity.

Table 1. Subject Description

Diagnosis:	N=27 with Adolescent Idiopathic Scoliosis
Gender:	100% Female
Baseline:	
Age:	15.6 $\pm$ 0.9 years
Curve Type:	12 Rt main thoracic, 5 Lt Thoracolumbar, 9 Lt Lumbar, 1 Rt lumbar
Treatment status:	19 observation only, 8 other conservative treatments
Follow-up:	
Age:	20.9 $\pm$ 1.9 years
Time baseline to follow-up:	5.3 + 1.9 years
Treatment status:	13 non-surgery (2 physical therapy, 3 contemplating surgery, 8 observation only); 14 surgery

Table 2. SRS-22 Pain Domain Questions

1. Which one of the following best describes the amount of pain you have experienced during the past 6 months? 1 = Severe; 2= Moderate to severe; 3 = Moderate; 4 = Mild; 5 = None
2. Which one of the following best describes the amount of pain you have experienced over the last month? 1 = Severe; 2 = Moderate to severe; 3 = Moderate; 4 = Mild; 5 = None
8. Do you experience back pain when at rest? 1 = Very often; 2 = Often; 3 = Sometimes; 4 = Rarely; 5 = Never
11. Which one of the following best describes your medication usage for your back? 1 = Narcotics daily; 2 = Non-narcotics weekly or less (e.g., aspirin, Tylenol, Ibuprofen); 3 = Non-narcotics daily; 4 = Narcotics weekly or less (e.g. Tylenol III, Lorocet, Percocet); 5 = None
17. In the last 3 months have you taken any sick days from work/school due to back pain and if so how many? 1= 4 or more; 2 = 3; 3 = 2; 2 = 1; 5 = 0

4. Results

At baseline (Table 3), the mean Cobb angle of the major curve was 47 ± 15 degrees and ranged from 20 to 90°, decompensation was 18 ± 14 mm and trunk twist was 14 ± 6°. At follow-up, the SRS-22 scores were generally well distributed, except for questions 11 and 17 which tended to be clustered near the top of the scale.

Table 3. Outcome measures from subjects

Baseline:	
Largest curve (Cobb):	47 ± 15 degrees
Decompensation:	18 ± 14 mm
Trunk Twist:	14 ± 6 degrees
Follow-up:	
SRS-22 total score	3.9 ± 0.3
SRS-22 Pain Domain	3.9 ± 0.7
Pain Domain Question 1	3.4 ± 1.1
Pain Domain Question 2	3.6 ± 0.9
Pain Domain Question 8	3.6 ± 1.0
Pain Domain Question 11	4.5 ± 0.7
Pain Domain Question 17	4.4 ± 1.2

There were minimal floor effects of less than 10% for all questions and domain (Table 4). Two of the five questions (11 and 17) had high ceiling effects (>50%) which may limit correlations. The other 3 questions and the pain domain had acceptable ceiling effects.

The deformity features measured at baseline had low correlations with the SRS-22 total score, the pain domain and individual SRS-22 questions at follow-up (Table 5). The largest curve and decompensation had non-significant positive and negative correlations with pain measures. Only trunk twist had consistently a negative but also non-significant correlation with SRS-22 pain measures.

Table 4. Ceiling and floor effects (%) for SRS questionnaire

	SRS-22 total score	Pain Domain	Q1	Q2	Q8	Q11	Q17
Ceiling	0	11	11	15	22	56	78
Floor	0	0	4	0	0	0	7

Table 5. Correlations between features and questionnaire scores

Deformity feature	SRS-22 Total	Pain Domain	Q1	Q2	Q8	Q11	Q17
Largest Curve	-0.05	0.17	0.01	0.05	0.15	0.38	.20
Decompensation	0.30	-0.11	-0.23	-0.10	-0.09	0.18	0.01
Trunk Twist	-0.21	-0.25	-0.25	-0.03	-0.11	-0.02	-0.26

All correlations non-significant ($p>0.05$)

5. Discussion

The hypothesis was that subjects with the most severe scoliosis would be at highest risk of developing future back pain. Contrary to our hypothesis, spinal deformity measures during teenage years were not predictive of pain complaints in young adulthood. The follow-up period may need to be extended, as possible future back pain may not yet be evident in the young adult. There was also selection bias. Adult subjects consulted their spine surgeon at their request. These subjects had significant scoliosis at baseline. The majority of subjects who attend the pediatric spine service as teenagers do not routinely see an orthopedic surgeon as young adults. Subjects who did not consult the spine surgeon as adults either moved from the area or did not feel they required follow-up. Pain may be the reason justifying an adult consultation as young adults. A longitudinal study including subjects with a wider range of deformity severity at baseline followed as young adults without regard to their seeking further care would help clarify whether adult pain can be predicted from deformity levels in the teenage years. Recent work also suggests that the association between deformity and pain may not be linear [9].

Lack of association between baseline measures of deformity and pain at follow-up may also be due the intervening surgery in many of the subjects. Corrective surgery may affect the relation between deformity measures and pain. Surgery hopefully would have reduced the severity of back pain. The sample size did not allow examining the association in the subset of subjects who did or did not have surgery.

6. Conclusion

Even though the sample represented a wide range of scoliosis severity at baseline and a wide range of pain scores (2.4 to 5) at follow-up, baseline scoliosis deformity parameters of largest curve size, decompensation and trunk twist did not predict scoliosis-related pain in young adulthood.

7. Acknowledgments

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A Machine Learning Approach to Assess Changes in Scoliosis

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Abstract. This paper presents a machine learning approach that can be used to evaluate the validity of the results obtained with an automated system to measure changes in scoliotic curves. The automated system was used to measure the inclinations of 141 vertebral endplates in spine radiographs of patients with scoliosis. The resulting dataset was divided into training and test set. The training set was used to configure three classifiers: a support vector classifier (SVC), a decision tree classifier (DT) and a logistic regression classifier (LR). Their performance was evaluated on the test set. The SVC had an accuracy of 86% discriminating Good Results (those in which the error was less than 3°) from Bad Results. This accuracy was better than that of the LR (76%) and DT (68%). The differentiation between Good and Bad Results using the proposed machine learning approach was achieved successfully.

Keywords. Scoliosis, image registration, machine learning

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, a machine learning approach that can be used to automatically assess the quality of the results obtained with an automated system to measure changes in scoliotic curves is presented. Since the clinical focus was on spinal deformities, the main interest was on measuring the inclinations of vertebrae in spine radiographs.

Machine learning is concerned with the design and development of techniques that allow computers to learn from datasets. Among machine learning techniques, classification strategies can be used to discriminate between groups. In this work, a classification strategies is proposed to discriminate Good Results (those in which the inclination measurement had an error greater than 3 degrees) from Bad Results. The proposed classification strategy is based on Support Vector Classifiers (SVC) [5]. The main goal was to determine whether SVC could predict results quality sufficiently well to be used in clinical practice. SVC were chosen because they usually outperform techniques such as Artificial Neural Networks when trained using small datasets as is usually the case in scoliosis research. Moreover, unpublished preliminary studies comparing the performance of radial basis function neural networks [6] and SVC indicated the superiority of the latter in our datasets of scoliosis patients. Finally, the results of applying a SVC to the dataset of scoliosis patients are compared to those obtained by applying logistic regression [7] and classification decision trees [8] to the dataset.

2. Methods

Retrospectively, radiographs of patients with scoliosis from the database of the scoliosis clinic at the Glenrose Rehabilitation Hospital (Edmonton, Canada) were examined, after getting Ethics Approval, to select patients for the study. The following inclusion criteria were used: 1) having available a posterior-anterior standing radiograph with a maximum Cobb angle of less than 75°; 2) not having undergone surgery; and 3) having at least a visually identifiable vertebral endplate. Eighteen patients and a total of 141 vertebral endplates satisfied the inclusion criteria. Patients had a variety of spinal curvatures, with an average of maximum Cobb angle of 39° ± 18° (range 8°-74°). There were 7 (39%) patients with double curve and 11 (61%) patients with single curves. All images were carefully annotated to create the “ground truth”. A graphical user interface was used to allow the user to select two vertebral endplates to be analyzed (Figure 1). Based on the user selection, two regions of interest (ROIs) were created (Figures 2 and 3). A model (Figure 4) was then registered to the ROIs, using custom-made software, to find the location and orientation of the endplates under study (See Figure 5 for two unsuccessful registrations and Figure 6 for two successful registrations). The process was repeated for an average of 8 vertebrae per radiograph creating a database of 141 registration solutions.

The data set for the experiments was divided into training and test set according to the time in which the data became available. The training set consisted of 14 radiographs from which 104 vertebral endplates were selected using the selection criteria previously discussed. The test set consisted of 4 radiographs that became available after the first group. From the second group of radiographs, 37 vertebral endplates were selected following the inclusion criteria previously discussed. Once the endplates were selected, model-to-image registrations were performed. After registration, each solution was evaluated with respect to the ground truth. If the difference in the rotation angle was greater than 3° the solution was labeled as a Bad Solution. Otherwise, the location of the registered model was assessed visually to assign one of two possible labels: Bad Results (BR) or Good Results (GR). For the training set there were 54 registration solutions labeled as BR and 50 registration solutions labeled as GR. For test set there were 25 registration solutions labeled as BR and 12 registration solutions labeled as GR. The training set was used to build three classifiers: a Support Vector Classifier (SVC), a Decision Tree Classifier (DT), and a Logistic Regression Classifier (LR). The performance of the classifiers was assessed using the test set.

Figure 1. Spine radiograph with user-entered landmarks (indicated with a *)

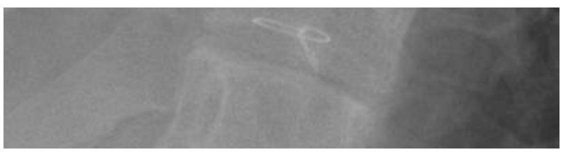

Figure 2. Region of interest around top landmark

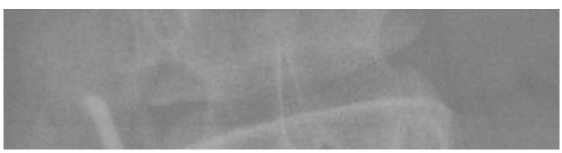

Figure 3. Region of interest around bottom landmark

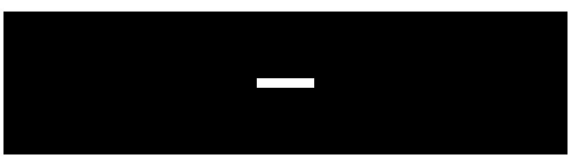

Figure 4. Model used for registration

Figure 5. Two un-successful registrations (indicated with straight lines)

Figure 6. Two successful registrations (indicated with straight lines)

3. Results

This section compares the results, in testing, of the Support Vector Classifier (SVC) with those of the Decision Tree (DT) and Logistic Regression (LR) classifiers and evaluates their performance. The results of classifying the cases into Good Results (GR) and Bad Results (BR) (using the test data set) are summarized in Table 1. In terms of accuracy, the SVC outperformed the DT and LR classifiers with accuracy of 86% compared to 68% and 76%, respectively, for the DT and LR. Moreover, the SVC detected the largest percentage of cases with BR: 96%, compared to 64% of the LR and only 52% of the DT.

Table 1. Classification problem: Bad Results versus Good Results. Test results with the SVC, DT, and LR classifiers on the test set. TO: True Output. CO: Classifier Output. BR: Bad Results. GR: Good Results.

TO\CO	SVC		DT		LR	
	BR	GR	BR	GR	BR	GR
BR	24(96%)	1(4%)	13(52%)	12(48%)	16(64%)	9(36%)
GR	4(33%)	8(67%)	0(0%)	12(100%)	0(0%)	12(100%)
Accuracy	86%		68%		76%	

4. Discussion

Results obtained from comparing classifiers with a test set showed that the support vector outperformed a decision tree and logistic regression classifiers. The classification accuracy for the SVC was 86% in testing. The classification accuracy for the DT was 68% in testing. The classification accuracy for the LR was 76% in testing. Even though, the SVC achieved a high discriminatory power to Bad Results, work on improving its discriminatory power continues because improvements in it will translate to early detection of Bad Results guaranteeing a high level of care for the patients. It was observed that 1 record in the test set was misclassified by all the classifiers. This may suggest that the misclassified record was an outlier present in the data set.

Although the SVC-based method was designed for estimating the quality of model-to-image registrations of spine radiographs, the proposed approach may be useful in other contexts as well.

5. Conclusion

In conclusion, it is possible to differentiate Good Results from Bad Results by using the proposed support vector classifier. This finding may be useful in identifying when an application for automatically measuring scoliosis severity requires domain expert intervention to provide new configuration settings that could improve the results

6. Acknowledgement

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Chapter 6

Mathematical Modelling

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The posterior skeletal thorax: rib-vertebral angle and axial vertebral rotation asymmetries in adolescent idiopathic scoliosis

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Abstract. The deformity of the ribcage in thoracic adolescent idiopathic scoliosis (AIS) is viewed by most as being secondary to the spinal deformity, though a few consider it primary or involved in curve aggravation. Those who consider it primary ascribe pathogenetic significance to rib-vertebra angle asymmetry. In thoracic AIS, supra-apical rib-vertebra angle differences (RVADs) are reported to be associated with the severity of the Cobb angle. In this paper we attempt to evaluate rib and spinal pathomechanisms in thoracic and thnoracolumbar AIS using spinal radiographs and real-time ultrasound. On the radiographs by costo-vertebral angle asymmetries (rib-vertebral angle differences RVADs, and rib-spinal angle differences RSADs), apical vertebral rotation (AV) and apical vertebral translation (AVT) were measured; and by ultrasound, spine-rib rotation differences (SRRDs) were estimated. RVADs are largest at two and three vertebral levels above the apex where they correlate significantly and positively with Cobb angle and AVT but not AVR. In right thoracic AIS, the cause(s) of the RVA asymmetries is unknown: it may result from trunk muscle imbalance, or from ribs adjusting passively within the constraint of the fourth column of the spine to increasing spinal curvature from whatever cause. Several possible mechanisms may drive axial vertebral rotation including, biplanar spinal asymmetry, relative anterior spinal overgrowth, dorsal shear forces in the presence of normal vertebral axial rotation, asymmetry of rib linear growth, trunk muscle imbalance causing rib-vertebra angle asymmetry weakening the spinal rotation-defending system of bipedal gait, and CNS mechanisms.

Keywords. Idiopathic scoliosis, pathogenesis, spine, ribs vertebral rotation

1. Introduction

The deformity of the ribcage in thoracic adolescent idiopathic scoliosis (AIS) is viewed by most as being secondary to the spinal deformity, though a few consider it primary [1-9] or involved in curve aggravation [10-11]. In terms of the pathogenesis of AIS, Grivas and colleagues ascribed *pathogenetic significance to rib-vertebra angle asymmetry* [5-9] a concept that was incorporated in the Nottingham concept of pathogenesis for AIS [6,7] and its subsequent developments [12-14]. More recently, Castelein et al [15] hypothesized that it is not the thoracic lordosis itself but the sagittal orientation of vertebrae in humans which, in the presence of normal vertebral axial rotation asymmetry [16,17], contributes to the initiation and progression of AIS.

Unlike infantile idiopathic scoliosis where apical rib-vertebral angle difference (RVAD)[18] and apical convex rib-vertebra angle (convex RVA) [19] are prognostic, RVAD is not prognostic for AIS. Supra-apical RVADs (Figure 1) are reported to be associated significantly with the severity of the Cobb angle [20,21]. In this paper we attempt to evaluate rib and spinal pathomechanisms of AIS using 1) spinal radiographs using costo-vertebral angle asymmetries and apical axial vertebral rotation, and 2) real-time ultrasound using the spine-rib rotation difference (SRRD) [13]. The costovertebral angle asymmetries studied include segmental rib-vertebra-angle difference (RVAD)[18,19] and segmental rib-spinal angle difference (RSAD)[22](Figure 2).

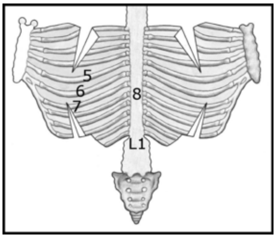


Figure 1. Drawing of an opened thoracic cage labeled to show a T8 apical vertebra and the longest true ribs at 5-7 situated above T8 of right thoracic AIS.

2. Left-right asymmetries of the posterior skeletal thorax: do costo-vertebral pathogenic mechanisms contribute to the initiation and progression of right thoracic adolescent idiopathic scoliosis?

2.1. Methods and subjects

Anteroposterior spinal radiographs of 30 subjects with right thoracic curves (mean Cobb angle 20.3º, apex T7-11, mean AVR 15.7º, girls 20 postmenarcheal 17, boys 10, .mean age 15.1 years) were measured by one observer (RGB) for each of: Cobb angle (CA), apical vertebral rotation (AVR)[23], apical vertebral translation (AVT) and vertebral tilt in relatikon to the horizontal; rib-vertebral angles (RVAs to each vertebral endplate [18,19], rib-spinal angles (RSAs to T1-S1 line [22]) and their asymmetries (RSADs)(Figure 2).

RVADs (a local system of spinal control) and RSADs (a spinal system of spinal control) were each calculated as concave *minus* convex (cc-cx) at six vertebral levels, at the apex, three above and two below the apex.

2.2. Results (Table)

A preliminary account of the findings has been published [24].

Figure 3 shows that RVADs are largest above the apex where at two and three levels above the apex they correlate significantly and positively with each of CA and AVT but not AVR. (In a separate study these associations with Cobb angle and AVT were found to relate to concave RVAs and not convex RVAs [14]).

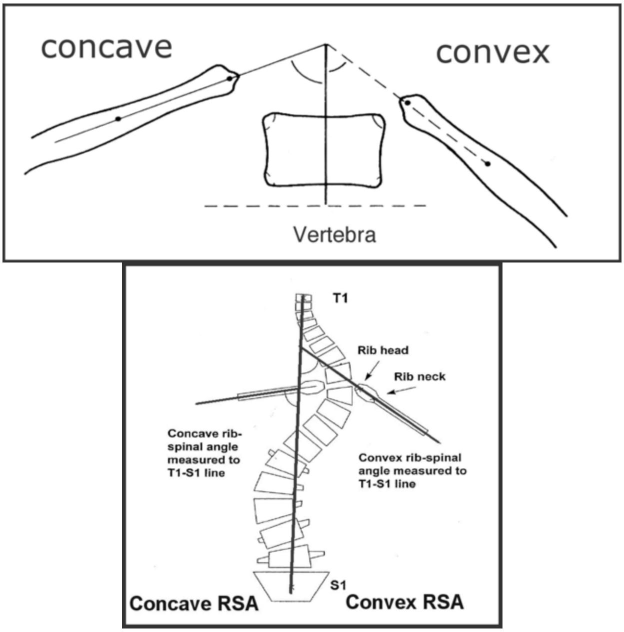


Figure 2. Left: concave and convex rib-vertebral angles from which to calculate the RVAD [18,19]. Right: Concave and conxex rib-spinal angles to T1-S1 line from which to calculate rib-spinal angle difference [22].

Supra-apical cxRVAs have low mean values similar at all levels at about 64º, and smaller relative to supra-apical ccRVAs decreasing by level supero-inferiorly to 60º. Two levels below the apex RVADs correlate significantly and negatively with CA, AVR and AVT. The RSADs do not correlate significantly with any measured paraameter of the spinal deformity showing the importance of vertebral tilt in the statistically significant correlations; vertebral tilt of the end vertebrae are the components of the Cobb angle and also of the RVADs, and are not contained in the RSA differences.

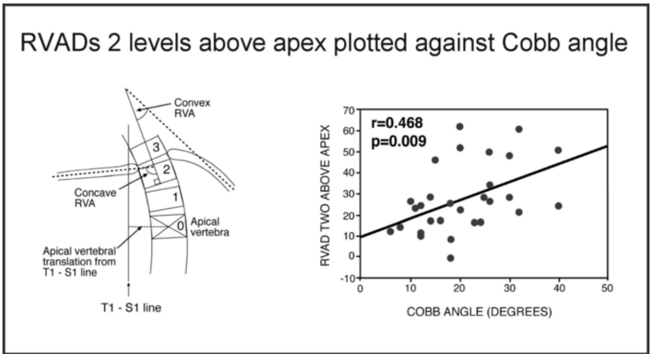
2.3. Conclusions

1) RVADs are largest at two vertebral levels above the apex where, in a supra-apical position, they correlate significantly and positively with Cobb angle confirming earlier findings [20,21], and showing a correlation with AVT but not AVR.

2) Supra-apical ribs at and above rib 7 are sternally-stabilized between the sternum and the spine forming a *'fourth column of structural thoracic spine support'* [25] with the longest ribs about 5-7.

3) The cause(s) of the RVA asymmetries is unknown. The asymmetries may result from:

- a) ribs adjusting passively within the constraint of the *fourth column of the spine* to increasing spinal curvature from whatever cause [21], and/or
- b) trunk muscle imbalance [4-9] associated with upright posture and bipedal gait contributing to the rib-vertebra angle asymmetries by weakening the spinal rotation-defending system in bipedal gait [4-9], initiate right thoracic AIS [5-9] in association with trunk movements [26].



RVADs/level	RVAD	VT	CA	AVR	AVT
3 above apex	30	9	**+	ns	*+
2 above apex	27	7	**+	ns	*+
1 above apex	18	2.5	ns	ns	ns
Apex	8	-2.3	ns	ns	ns
1 below apex	1	-5.9	ns	ns	ns
2 below apex	- 4	-8.1	*-	**-	**-

RSADs/level	RSAD	VT	CA	AVR	AVT
3 above apex	11	9	ns	ns	ns
2 above apex	12	7	ns	ns	ns
1 above apex	13	2.5	ns	ns	ns
Apex	13	-2.3	ns	ns	ns
1 below apex	13	-5.9	ns	ns	ns
2 below apex	12	-8.1	ns	ns	ns

Figure 3. Left: The method of measuring the RVA to the vertebral end plate [18]; and RVADs two levels above curve apex plotted against Cobb angle (r=0.468, p=0.009).
Right Table showing RVADs (above) and RSADs (below): correlations and statistical significances by spinal level against vertebral tilt, Cobb angle, AVR and AVT (*=0.01<p<0.05, ** 0.001<p<0.01, NS=not significant).

4) Asymmetric rib drooping may lead to a lateral spinal curvature by thoracic vertebrae tilting towards a drooping rib as a reflex neuromuscular adaptation to elevate the drooping rib and re-establish symmetry of the costal basis for longitudinal muscle function in the trunk [14].

3. Does vertebral axial rotation asymmetry in normal and AIS subjects determine curve laterality and mediate curve progression?

3,1. Methods and subjects

Radiological and ultrasound evidence from 57 scoliosis school screening subjects selected by a routine quantitative protocol during 1993-99 with thoracic (T, 24) or thoracolumbar (TL, 33) AIS was examined by one observer (RGB)(girls 44, post-menarcheal 37, boys 13, mean age 14.9 years, right curves 37, left curves 20, mean Cobb angle 19 degrees (6-42 degrees), mean AVR 15 degrees (0-39 degrees [23]), apical vertebral translation -37 to +38mm). The ultrasound method used was briefly described previously [12].

3.2. Results.

A preliminary account of the findings has been published [27]

The findings show that apical vertebral rotation (AVR) and spine-rib-rotation difference (SRRD, each transverse plane) and apical vertebral translation (AVT, frontal plane) are related components of curve progression Partial correlation coefficient analysis reveals:

(1) after controlling for AVT, AVR/SRRD is significant for TL (p=0.015) but not T AIS, and

(2) after controlling for AVR AVT/SRRD, is not significant for either T or TL curves.

3.3. Conclusions

1) The findings confirm axial vertebral rotation as an important component of curve progression in both thoracic and thoracolumbar AIS.

2) The cause(s) of the AVR asymmetry is unknown. Axial vertebral rotation in AIS may be driven by biplanar spinal asymmetry [28], relative anterior spinal overgrowth and torque forces created by posterior spinal soft tissues [29], dorsal shear forces [15] in the presence of normal axial vertebral rotation [16,17], asymmetry of rib linear growth [1,2], trunk muscle imbalance causing rib-vertebral angle asymmetry and weakening the spinal rotation-defending system of bipedal gait [4-9,14](see Figure 2 of [26]), and CNS mechanisms [30-33]. Grivas [8] advocates the hypothesis that the deformity of the thorax develops first and then the deformity of the spine follows.

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Prediction of the T2-T12 Kyphosis in Adolescent Idiopathic Scoliosis using a Multivariate Regression Model

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Abstract. The paper presents a nonlinear regression model built on the coronal thoracic curvature, the lumbar lordosis and the slope of the first lumbar vertebra in order to estimate the thoracic kyphosis measure between T2 and T12. To train the proposed model, a large database containing scoliotic spines demonstrating several types of scoliotic deformities was used to train the proposed system by a cross-validation method. Validation was performed on patients exhibiting three different types of sagittal thoracic profiles: normal, hypo-kyphotic, and hyper-kyphotic. Results show that a multivariate regression model based on dependent variables is able to predict with a reasonable accuracy the sagittal thoracic kyphosis for the automatic assessment and classification of the spinal curve.

1. Introduction

Analyzing the coronal and sagittal profile of a scoliotic spine on X-ray images is necessary for evaluating and assessing the patient's preoperative deformity or postoperative correction in adolescent idiopathic scoliosis. However due to several anatomical structures overlapping in the thoracic region of the spine, increased body fat and irregular dosage of the X-ray beam, it is not uncommon to have the vertebrae in the upper thoracic region of the spine occluded on the sagittal X-ray image. This makes the automatic identification and classification of the sagittal kyphotic curve at times quite difficult. However several other global or local clinical indices may be able to give an indication of the tendency for the kyphosis measurement. Jansen *et al.* have found that significant correlations were present between preoperative kyphosis and lordosis ($r = 0.421$; $p = 0.021$), while postoperative correlations were even stronger ($r = 0.591$; $p = 0.001$) [1]. These results were confirmed by Jang *et al.* who also found that significant preoperative correlations existed between kyphosis and lordosis ($r = 0.628$; $p = 0.0003$), as well as in postoperative measurements [2]. Furthermore, a well known correlation exists between the thoracic curvature measurements in the coronal and sagittal plane. Previous studies have therefore attempted to predict the thoracic kyphosis using the main thoracic Cobb angle between T4 and T12 and the Debrunner kyphometer using linear regression analyses [3].

Contrary to linear analyses, nonlinear regression models are a form of regression analysis where observational data are modeled by a nonlinear function combining various model parameters and depend on multiple variables. The objective of this study is to evaluate the feasibility of a multivariate nonlinear predictor based on the visible information collected from the X-ray images in order to estimate the thoracic kyphosis measurement between the T2 and T12 vertebrae on the sagittal image plane. This work is made towards an automatic classification of the sagittal spinal curve.

2. Materials and methods

2.1. Identification of prior information

The spinal curve going from T1 to L5 is first identified semi-automatically on the coronal X-ray image using a 2D cubic B-spline to ease user adjustments on a graphical interface [4]. The curve passes through the centers of the vertebral bodies and its inflexion points, computed by the 2nd derivative of the curve, are able to distinguish three different spinal regions: the upper thoracic, main thoracic (C_{MT}) and lumbar curve. A similar method is used to determine the lumbar curve on the sagittal X-ray from L1 to L5 in order to subsequently compute the lumbar lordosis angle ($L_{TL/L}$). The perpendicular line to the sagittal lumbar curve at the location of L1 is used to determine the orientation θ_{T12} of the caudal endplate vertebra of T12 (Figure 1).

2.2. Multivariate regression model

The main thoracic Cobb angle (C_{MT}) taken on the coronal X-ray image as well as on the lumbar lordosis ($L_{TL/L}$) computed on the sagittal image is then used to built a reliable predictor of the constrained thoracic kyphosis angle between T2 and T12 (K_{T2-T12}) by training a nonlinear multi-variant regression model by cross-validation. In order to take into account sagittal balance and the orientation of the lumbar curve, the slope of T12 was also integrated in the model. The nonlinear regression model is defined by Eq(1):

$$\mathrm{K}^{i}_{T2-T12} = \alpha + f(\{C^{i}_{MT}, L^{i}_{TL/L}, \theta_{T12}\}; \beta) + \varepsilon_i \tag{1}$$

where α is the intersect, f the nonlinear regression function and β the variable parameters. The residual error term ε_i is:

$$\varepsilon_i = \mathrm{K}^{i}_{T2-T12} - f(\{C^{i}_{MT}, L^{i}_{TL/L}, \theta_{T12}\}; \beta) \tag{2}$$

and the empirically determined regression function is defined as:

$$f(\{C^{i}_{MT}, L^{i}_{TL/L}, \theta_{T12}\}; \beta) = \beta_0 \exp^{-\beta_1 * L^{i}_{TL/L} - \beta_2 \theta^{i}_{T12}} + \beta_3 \exp^{-0.1 * C^{i}_{MT}} \tag{3}$$

A database containing 732 scoliotic spines demonstrating several types of scoliotic deformities was used to train the proposed system. The database was separated into two parts, with training and testing subset of 366 scoliotic spines. Training of the model was performed by cross-validation which consists in dividing the training data into N disjoint parts of equal size. For each part, a model is built from the N-1 other folds, and evaluated on the remaining fold. This procedure was repeated for all N folds. In our case, N = 5. The final model was obtained using the entire data.

2.3. Constrained kyphosis measurement

Once the angular value of the kyphosis measurement $K_{T2\text{-}T12}$ is obtained from the regression model, the measurement is constrained between the orientation θ_{T12} at T12 and the 2D position of the T2 vertebra on the sagittal image. The position of T2 is obtained by the epipolar line corresponding to the location of T2 identified on the coronal X-ray. In the current work, the epipolar geometry can be computed since the calibration of the radiographic acquisition scene is known [5]. Figure 1 illustrates the proposed methodology.

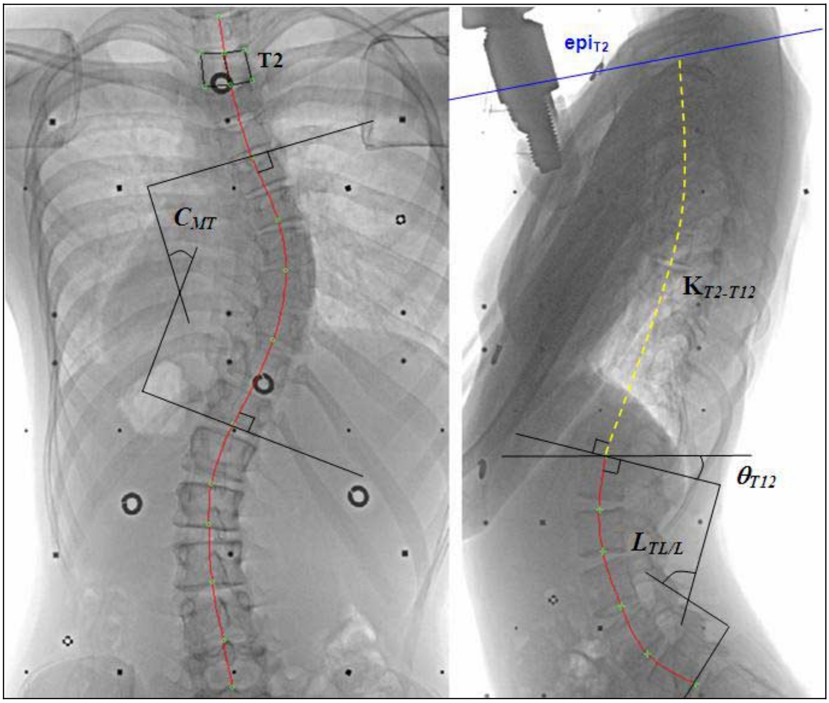

Figure 1. Prior information collected on the coronal and sagittal X-ray images.

3. Results

The parameters of the non-linear predictive model were determined by minimizing the residual errors obtained from the training dataset (366 models). The multivariate model was subsequently tested on three types of scoliotic patients in order to evaluate its accuracy: (1) normal; (2) hypo-kyphotic; (3) hyper-kyphotic. Table 1 presents the accuracy results obtained from the different experiments. The cross-validation accuracy (ratio of correctly predicted angle within 5°) computed from the training dataset on 366 scoliotic spines was of 0.98. The accuracy on the testing datasets is presented for hypo-kyphotic curves (40 spines, kyphosis range 0–10°), for normal kyphotic curves (257 spines, kyphosis range 10–40°) as well as for hyper-kyphotic curves (69 spines, kyphosis > 40°).

Table 1. Accuracy results for the nonlinear multivariate regression model.

	Training	**Hypo-kyphotic**	**Normal**	**Hyper-kyphotic**
Sample size (*N*)	366	40	257	69
Accuracy (°)	0.98	0.78	0.89	0.76

4. Discussion

The regressed best-fit model obtained from the exponential-based equation is able to replicate various types of kyphotic profiles in the scoliotic population. When comparing the results obtained from the different groups, the predictive model seems to estimate more accurately normal kyphotic curves to hypo or hyper-kyphotic profiles. This can be explained by the significantly lower number of training data available for these two extreme types of patients.

This paper presents promising results for a multivariate regression model which is able to predict the sagittal thoracic kyphosis between T2 and T12 built on the thoracic Cobb and lumbar lordosis measures. Although the estimate is not perfectly accurate, it falls within a reasonable range to adequately assess the sagittal curve of the spine. Future development includes building the predictive model from an automatic detection of the coronal spinal curve and using support vector machines (SVM) for training the predictive model [6].

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Intervertebral disc changes in an animal model representing altered mechanics in scoliosis

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Abstract: The intervertebral discs become wedged and narrowed in a scoliosis curve, and this may be due in part to altered biomechanical environment. To study this, external rings were attached by percutaneous pins transfixing adjacent vertebrae in 5-week-old Sprague-Dawley rats and four permutations of mechanical conditions (4 groups of animals) were compared: (A) 15 degrees Angulation, (B) Angulation with 0.1 MPa Compression, (C) 0.1 MPa Compression, and (D) Reduced mobility. These altered mechanical conditions were applied for 5 weeks. After 5 weeks, disc narrowing at the intervention levels was evident in micro-CT images. Average disc space loss as a percent of the initial values over the 5 weeks was 19%, 28%, 22% and 20% four groups listed above. Increased lateral bending stiffness relative to within-animal controls was also observed at all groups. The minimum stiffness was recorded at an angle close to the *in vivo* value, indicating that angulated discs had adapted to the imposed deformity. In the angulated and compressed discs there was a small difference in the amount of collagen crimping in the disc annuli between concave and convex sides. All experimental interventions produced substantial changes in the intervertebral discs of these growing animals. 'Reduced mobility' was present in all interventions, and the changes in the discs with reduced mobility alone were comparable with those in loaded and angulated discs. This suggests that imposed reduced mobility is the major source of disc changes, and may be a factor in disc degeneration in scoliosis. Further studies are in progress to characterize gene expression, matrix protein synthesis and composition in these discs.

Keywords: Intervertebral disc; In vivo; Growth, Deformity; Rat model, Biomechanics

1. Introduction

A scoliosis deformity, as measured by the Cobb angle, consists of wedging asymmetry of the vertebrae and of the intervertebral discs in approximately equal proportions. The wedging and narrowing of the discs in a scoliosis curve may be due in part to altered biomechanical environment. The pathomechanism of the progressive deformity of both the vertebrae and the discs is poorly understood. The eventual aim of this study is to determine how immature intervertebral discs respond morphologically, mechanically and biologically to components of the altered mechanical environment that occurs in scoliosis. The purpose of the present study is to document morphological,and biomechanical changes in four different models of altered mechanical environment in intervertebral discs of growing rats.

2. Methods

External rings attached by percutaneous pins transfixing adjacent vertebrae in 5-week-old Sprague-Dawley rats were applied for 5 weeks, using a modification of the apparatus described by MacLean et al. [1] Four permutations of mechanical conditions (4 groups of animals) were compared: 15 degrees Angulation (Group A), 0.1 MPa Compression (Group C), both Angulation and Compression (Group B), and Reduced mobility (Group D). Angulation in Groups A and B was achieved by installing the rings each at 7.5 degrees to the transverse plane of adjacent tail vertebrae, then using connecting rods and springs to align the rings parallel to each other. Compression was achieved by compressing the springs to produce a force corresponding to the desired amount of stress [2].

The alignment of the rings and the lengths of springs were checked and adjusted if needed every week. In vivo micro-CT imaging (Explore Locus volumetric conebeam MicroCT scanner (GE Medical Systems, London, Ontario) of the tails of anaesthetized animals was done at week 1 and week 5. After semi-automated edge detection to identify the disc-vertebra margins, the mean disc space and the disc wedge angle of each disc was determined from a straight line fit though the points on the disc-vertebra margin.

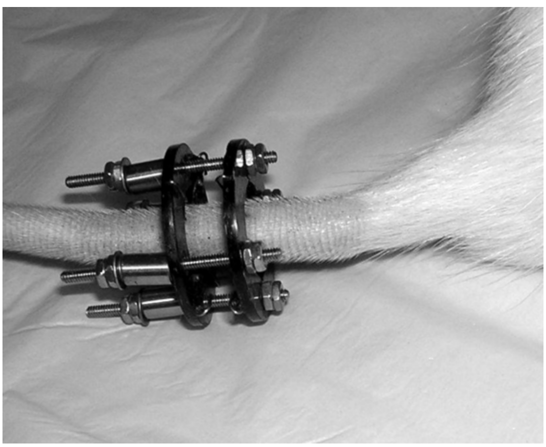

Figure 1: Photograph of rat tail with apparatus installed to produce both Angulation and Compression (Group B) at the instrumented intervertebral disc. Note: The rings were initially installed on a straight tail with a relative angulation of 15 degrees.

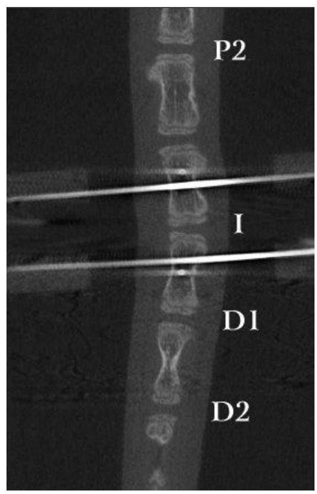

Figure 2: Coronal plane section through micro-CT image of rat tail in Group B, two days after installation of the apparatus. These images were used to measure the disc wedging and disc space. Labelled discs: I=Interventaion level, P2: proximal control; D1, D2 Distal controls

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Animals were euthanized after 5 weeks. Sections of the tail including three vertebrae and 2 discs (the intervention level and the adjacent-distal control) were removed for mechanical testing,, and a disc two levels proximal to the intervention level, and the two discs distal to the intervention level were removed for histology and also (data not presented here) for gene expression and compositional studies, (Figure 2). The loaded and distal-adjacent intervertebral discs were tested mechanically to obtain curves for angle-rotation in lateral bending, using a custom four-point bending apparatus. The moment-rotation recordings were used to identify the angle at which stiffness was a minimum (degrees), the value of the minimum stiffness (mN/degree), and the 'finite-range' stiffness (measured over a range of +/- 5 degrees from the angle at which stiffness was a minimum.

Tail sections were then fixed in 10% formalin with glutaraldehyde with the loading apparatus in place, and decalcified. Frozen sections were imaged under polarized light to demonstrate collagen crimping, which was quantified by crimp angle and crimp period [3]. These crimp measurements were made at three radial positions of the annulus – inner, middle and outer.

3. Results

3.1 *Geometrical:*

Disc narrowing at the intervention levels was evident in micro-CT images. Compressed discs (groups B and C) had slightly reduced disc space at the initial measurement, relative to other groups (Table 1), and there was subsequent loss of disc space in all groups over the 5-week duration of the loading. Average disc space loss as a percent of the initial values over the 5 weeks was 19%, 22%, 28% and 20% four groups (Table 1). The amount of disc narrowing did not differ significantly between groups.

Table 1: Disc space and loss of disc space (mm) at the intervention l intervertebral disc level in four groups of animals. Group A (Angulation), Group B (both Angulation and Compression, Group C (0.1 MPa Compression) and Group D (Reduced mobility).

	Initial (after 2 days)	Final (week 5)	Difference
Group A (N=9)	0.69 (0.12)	0.55 (0.13)	-0.13 (0.16)
Group B (N=31)	0.64 (0.14)	0.47 (0.14)	-0.18 (0.21)
Group C (N=8)	0.50 (0.16)	0.39 (0.14)	-0.11 (0.25)
Group D (N=11)	0.60 (0.15)	0.48 (0.08)	-0.12 (0.18)

3.2 *Mechanical*

Increased lateral bending stiffness relative to within-animal controls was observed at all groups. Trends were similar for both group-wise mean values of stiffness, as measured at minimum stiffness, and as measured over the finite range of displacement (+/- 5 degrees). (Table 2) The minimum stiffness was recorded at an angle close to the *in vivo* value, indicating that angulated discs had adapted to the imposed deformity.

Table 2: Average lateral bending stiffness (mN/degree) at intervention levels, and at distal control levels of four groups: Group A (Angulation), Group B (both Angulation and Compression), Group C (0.1 MPa Compression) and Group D (Reduced mobility).

	Group A	Group B	Group C	Group D
Minimum stiffness (intervention level)	12.6 (n=6)	60.0 (n=8)	15.2 (n=9)	61.7 (n=7)
Minimum stiffness (distal-adjacent level)	16.9 (n=4)	21.1 (n=6)	16.9 (n=3)	0.34 (n=6)
Finite-range stiffness (intervention level)	55.0 (n=6)	210 (n=8)	50.7 (n=9)	129 (n=7)
Finite-range stiffness (distal-adjacent level)	47.3 (n=4)	54.1 (n=6)	39.7 (n=3)	38.1 (n=6)

3.3 *Histology (Collagen crimping)*

At the intervention levels of the Group B (angulated and compressed) discs there was a small non-significant difference in the amount of collagen crimping in the disc annuli between concave and convex sides. This was consistent with the collagen having remodeled to a similar strain condition on each side of these angulated discs. The crimp periods at these levels was significantly less than at the within-animal control discs. This is consistent with the fact that the intervention level discs were fixed with the apparatus in place (angulation and compression present).

Table 3: Mean (and Standard Deviation) of collagen crimp length (arbitrary units) and crimp angle (degrees) in 4 groups of animals: Group A (Angulation), (Group B) both Angulation and Compression, Group C (0.1 MPa Compression) and Group D (Reduced mobility) at the intervention, proximal adjacent and two-distal discs. *Note:* more crimped collagen has shorter crimp period, and greater crimp angle.

	Proximal		Intervention level disc		Two-Distal	
	Convex	Concave	Convex	Concave	Convex	Concave
Crimp Length (arbitary)	93.4 (11.7)	87.2 (11.9)	69.6 (27.8)	66.5 (35.3)	93.8 (16.1)	93.5 (21.3)
Crimp Angle (degrees)	23.8 (8.5)	24.0 (8.7)	23.1 (16.4)	26.9 (7.2)	22.5 (8.17)	19.6 (4.9)

4. Discussion and Conclusion

All experimental interventions produced substantial changes in the intervertebral discs of these growing animals over the five-week period. This five-week period corresponded to a large proportion of the post-natal growth of the animals (bodyweight typically increased from 125 to 400 g). The changes included narrowed disc space and increased lateral bending stiffness, and there was evidence of collagen remodeling to accommodate the deformed position, also compatible with the observation that minimum lateral bending stiffness was measured close to the *in vivo* ‘bent-tail’ configuration in angulated discs.

The discs at the level immediately distal to the experimental intervention level, as well as discs two distal and proximal to the experimental intervention levels were used as within-animal controls. It should be noted that in the angulated tailed (Groups A and B) there were compensating curves (Figure 2) that could result in some wedging of these discs, especially at the adjacent-distal level.

'Reduced mobility' was present in all interventions, and the changes in the discs with reduced mobility alone were comparable with those in loaded and angulated discs. This suggests that reduced mobility is the major source of disc changes, and may be a factor in disc degeneration in scoliosis. Further studies are in progress to characterize gene expression, matrix protein synthesis and composition in these discs.

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Chapter 7

Education

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Knowledge about Idiopathic Scoliosis Among Students of Physiotherapy

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Abstract. The aim of the study was to determine the level of basic knowledge about idiopathic scoliosis (IS) among students of physiotherapy. The study included 37 students of Medical University of Silesia (17F and 20M aged 22-25, mean 22.6), attending the 3rd year of a 1st degree of physiotherapy. All students had credits in kinesiotherapy, including methods of conservative treatment of IS. Students were examined using a questionnaire, comprising general knowledge of IS, questions related to sagittal plane correction, influence of various physical activities on IS and known methods of conservative treatment. 81% of students considered IS as 3-D deformity. 62.2% of those questioned would diagnose IS when the Cobb angle reaches 10°. All students agreed that the aetiology of IS remains unknown. 54.1% considered forcible extensory exercises of back as favourable in IS. Questioned students mostly preferred swimming (94.6%), yoga (73.0%) and martial arts (32.4%) as beneficial to IS. The methods of conservative treatment which were known best were: Lehnert-Schroth-Weiss (94.6%), Klapp (91.9%), Majoch (89.2%) and Dobosiewicz (78.4%). The conclusions indicate that the average level of knowledge of idiopathic scoliosis among students of physiotherapy is unsatisfactory, despite the education programme including the SOSORT guidelines. Education in the field of scoliosis should be comprehensive and meet contemporary guidelines and standards.

Keywords: *idiopathic scoliosis, education, conservative treatment*

1. Introduction

Scoliosis, a three-dimensional deformity of the spine, is one of the most common diseases of contemporary society. Idiopathic scoliosis (IS), the most common type of scoliosis, affects humans from infancy to after puberty, imprinting their health and quality of life for the rest of their life. Adequate early diagnosis and treatment of IS can often mitigate its course and further after effects. Despite the still poorly understood aetiology, the pathomechanisms of IS have been thoroughly researched. Successful conservative therapy of idiopathic scoliosis should be based on three-dimensional correction of developing deformity and requires an in-depth understanding of the aetiology and pathology of the scoliotic growing spine by both patients and therapists [1,2,3].

2. Aim of the study

The purpose of the study was to determine the level of basic knowledge about idiopathic scoliosis among students of physiotherapy.

3. Material and method

The study included 37 students at the Medical University of Silesia (17F and 20M aged 22-25, mean 22.6), randomly selected, and in the 3rd year of the 1st degree of physiotherapy studies. All students were credited in kinesiotherapy, including methods of conservative treatment of IS. Students were examined with a proprietary, anonymous questionnaire, comprising:

- general knowledge of IS
- sagittal plane correction in IS
- influence of various physical activities on IS
- known methods of conservative treatment of IS (open question)

4. Results

4.1 General knowledge of idiopathic scoliosis

81% of students considered IS as a 3-D deformity, 16.2% as lateral bending in the frontal plane and 2.7% as sagittal plane deformation. 62.2% of questioned would diagnose IS when Cobb angle reaches 10°, 29.7% considered 5° and 8.1% chose 20° as indicative. All students agreed with yet unknown aetiology of IS.

4.2 Sagittal plane importance in idiopathic scoliosis

54.1% of trainee physiotherapists considered forcible extensory exercises of the back as favourable in IS.

4.3 Oriented physical activity and its influence on idiopathic scoliosis

Questioned students mostly considered swimming (94.6%), yoga (73.0%) and martial arts (32.4%) as being beneficial in IS. In contrast, they indicated cycling (51.4%), long jump (48.7%), martial arts, jogging and skiing (46%) as potentially dangerous in IS. Details are presented on the Figure 1.

Regarding physical education (PE), 59.5% of questioned would advise full activity during athletics, but 27% complete avoidance of PE. 8.1% of students would recommend PE with exclusion of extensory exercises and 5.4% would eliminate flexion movements.

4.4 Known methods of conservative treatment of idiopathic scoliosis

Most known methods were Lehnert-Schroth-Weiss (94.6%), Klapp (91.9%), Majoch (89.2%) and Dobosiewicz (78.4%). Most preferred methods were Lehnert-Schroth-Weiss (32.4%), Dobosiewicz (24.3%) and Nowotny (18.9%). Detailed results are presented on the Figure 2.

Apart from the questionnaire, surveyed students complained about problems with the availability of Polish translations of the specialist foreign literature.

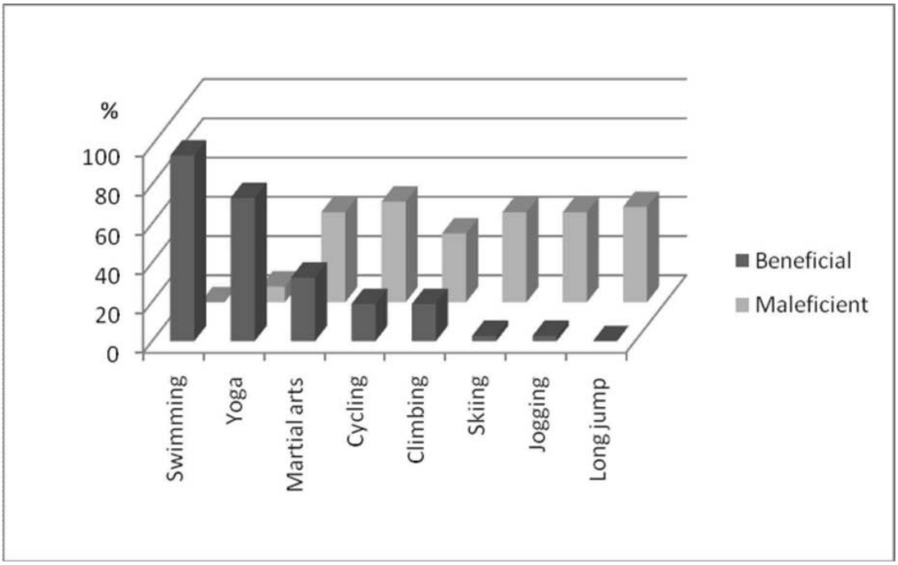

Figure 1. Preference of sports in management of IS.

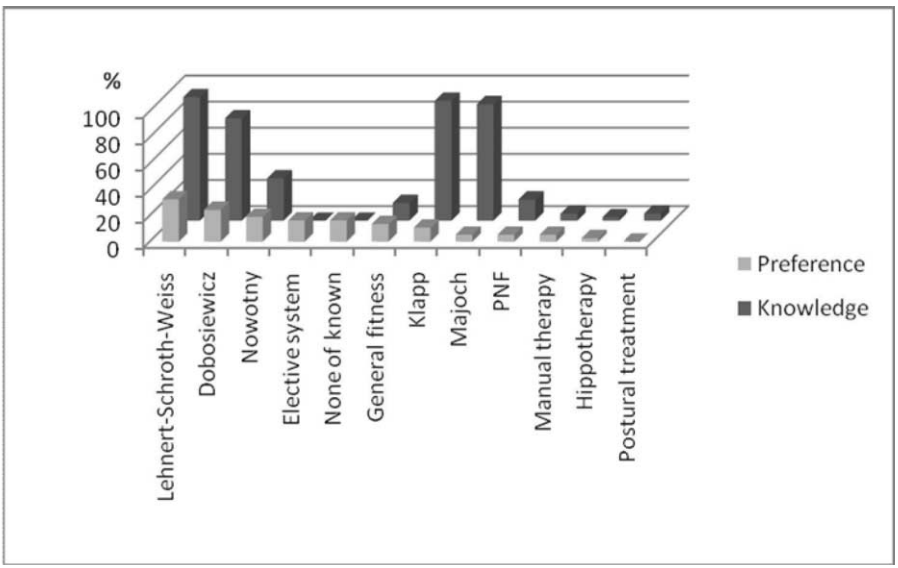

Figure 2. Known and preferred methods of conservative treatment in IS.

5. Discussion

The current survey revealed that the physiotherapy students questioned do have a basic, if incomplete, inconsistent and often incorrect knowledge of idiopathic scoliosis. Most of them complained about lack of native language translations of topical expert literature. Nowadays, in age of globalisation with common access to internet and original specialist literature, mostly written in English, these findings suggest there are bad habits adopted to collect a personal knowledge base. However, translation of recent literature would probably target a wider spectrum of interested students, therapists and to some extent – patients and parents. Furthermore, more widely accessible popular literature of subject would be highly appreciated.

As general knowledge, most students agreed with the 3-D nature of scoliotic deformity. However, more than one third of questioned did not know the correct criterion of diagnosis of scoliosis. The SRS recommendation of 10° of Cobb angle is considered as an international standard and should be known to any physiotherapist [4].

Examining the students about prevalence considered forcible extension exercises of the back as an activity which supports correction of IS. At present most authors agree that this kind of training not only does not help to overcome scoliosis, but may aggravate curve progression and should be avoided. Pathomechanisms of the development of IS points out that an initial thoracic curve is induced at the apex by local lordotisation caused by disproportion between the anterior and posterior column of the spine. This point of view emphasizes the importance of sagittal plane correction and preservation or rebuilt of normal thoracic kyphosis [5].

In a question regarding the influence of various sporting activities on idiopathic scoliosis resulted in substantial difference of opinion. Only swimming was considered as harmless and positively affecting scoliosis. Interestingly enough, review of the literature reveals the need of consensus regarding the effect of swimming and other sports on sagittal plane [6,7,8,9]. Nowadays, when sedentary style of life takes on the proportions of civilisation issue, therapists cannot afford such a dissonance in recommendations. Guidelines concerning various sport activities should be specified in view of scoliosis and then individually modified in respect of particular patient. Physical activity and maintenance of general fitness is important either for scoliotics and healthy people.

Methods of conservative treatment of scoliosis mentioned by questioned students reflected the program of education, then again general availability of contemporary literature on the subject. Students seem to know about a variety of treatment methods, but only a small proportion of these therapies had proven radiological evidence. It should be recognised as a favourable point that the most popular of preferred therapies used methods based on the 3-D correction of the spine: Lehnert-Schroth-Weiss and Dobosiewicz. Ignorance of knowledge of the Methode Lyonaise, Side-Shift and SIR is striking, especially in view of their recommendation by SOSORT guidelines [3].

The questionnaire did not include any questions relating to brace treatment, which requires further investigation.

6. Conclusions

1. The average level of knowledge of idiopathic scoliosis among students of physiotherapy is unsatisfactory despite the education programme including SOSORT guidelines.

2. Education in the field of scoliosis should be both wide ranging and consistent with contemporary standards.

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Chapter 8

Treatment of Scoliosis

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Thoracoplasty in the Surgical Treatment of Adolescent Idiopathic Scoliosis

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Abstract. A consecutive series of 40 adolescents surgically treated between 1998-2001, by posterior spinal fusion and thoracoplasty were compared with a similar group of 40 adolescents treated in the same period by posterior only segmental fusion. Clinical and radiographic analysis was performed, including the SRS-30 questionnaire and Pulmonary Function Tests (PFT). Minimum five years follow-up was requested. No statistical differences were found between the two groups in PFT's both pre-operatively and at latest follow up. Our findings suggest that thoracoplasty did not adversely affected long-term PFT's in AIS patients treated by posterior spinal fusion alone.

1. Introduction

The primary goal of surgical treatment in adolescent idiopathic scoliosis (AIS) remains the arrest of further curve progression by obtaining a solid arthrodesis mass, long-term balance of the spine in both the sagittal and coronal planes, and preservation of the maximum number of motion segments. Several additional factors, e.g., safety, cost, and morbidity, are important in the surgical decision-making. In recent years, with the advent of modern third-generation segmental posterior instrumentation, in particular pedicle screws only constructs, a significant deformity correction is also desired by both the physician and the patient, whereas preservation or enhancement of pulmonary function is a strong consideration for thoracic curves [1-5].

The association between a spinal deformity and pulmonary impairment has been widely reported [6-13], with more severe curves (>100°) considered to be responsible for a significant decrease in clinical pulmonary function. A recent multicenter study on 631 AIS patients found a moderate or severe pulmonary impairment in association with thoracic curves of <50°, showing that some patients with adolescent idiopathic scoliosis may have clinically relevant pulmonary impairment that is out of proportion with the severity of the spinal deformity [14].

Posterior spinal arthrodesis with thoracoplasty and an open anterior approach, with respect to a posterior only fusion, were found to have a deleterious effect on pulmonary function for as long as five years postoperatively and chest cage preservation was recommended to maximize both absolute and percent-predicted pulmonary function values after surgical treatment of adolescent idiopathic scoliosis [15]. More recently, both anterior open approaches and thoracoplasty were the only variables found to be related to a clinically significant reduction in the predicted 2-year pulmonary function in surgically treated AIS patients. The magnitude of the effects of both these variables, however, was considered modest [16].

The aim of the present study was to compare two similar groups of adolescents surgically treated for their spinal deformity, the first by means of posterior only segmental fusion (PSF), the second by posterior spinal fusion and thoracoplasty (PSF+T), focusing on the long-term effects of thoracoplasty in the surgical treatment of adolescent idiopathic scoliosis.

2. Materials and Method

A consecutive series of 40 patients with main thoracic AIS curves (Lenke type 1, 2, 3, and 4), surgically treated between 1998 - 2001 at one institution by PSF+T were compared with a similar group of 40 adolescents treated in the same period by PSF alone. Inpatient and outpatient charts were used for the collection of demographic data, and annotation of any medical and surgical-related complications, including revision surgeries. The Lenke surgical classification of AIS [17] was used to describe curve patterns. Radiographic evaluation on standing postero-anterior and lateral films on long-cassette (90x30 cm) was performed, including Cobb measurements [18] of the major thoracic (MT) curve, and thoracic kyphosis (T5–T12), both preoperatively and postoperatively, and at the latest follow up visit. A radiographic Rib Hump (RH) assessment (Fig.1), as proposed by Potter [19], was also performed. On the final visit, the SRS-30 questionnaire was administered, and a Pulmonary Function Test (PFT) evaluation was performed. A minimum five years' follow-up was requested for inclusion in the study. During the period considered for the current investigation the same surgical team (three different surgeons) performed all surgeries, with indication for thoracoplasty being a clinically relevant rib hump (i.e > 15° on the scoliometer measurement), or a particular concern of such deformity from the patient or family.

Statistical analysis was performed using the *t*-test (paired and unpaired), the Wilcoxon test for non-parametric paired analysis, and the Mann-Whitney test for non-parametric unpaired analysis. Results are expressed as the mean (SD), with a P value < 0.05 considered as being statistically significant.

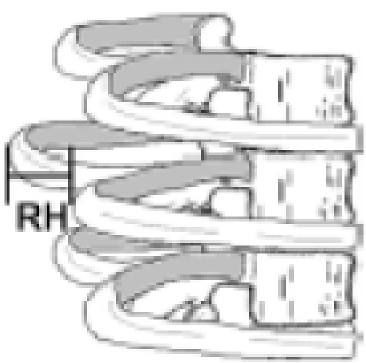

Fig. 1 Diagram showing the measurement technique for assessing the RH deformity. The RH is the linear distance between the left and right posterior rib prominences at the apex of the rib deformity on a lateral radiograph.

3. Results

We were able to review the entire series at an average clinical follow of 6.2 years (1.3). There were no statistically significant differences between the two groups concerning gender, age (PSF+T:16.3 years vs PSF: 15.2 years), Lenke's curve type distribution, and Cobb's preoperative main thoracic (MT) curve magnitude (PSF+T: 66° vs PSF: 63°), whereas both final MT percent correction (PSF+T: 53.03% vs PSF: 51.35%; $p<0.03$) and RH absolute correction (PSF+T: -2.1 cm vs PSF: -1.5; $p<0.01$) were superior in the thoracoplasty group (Table 1). We found no statistically significant differences between the two groups in terms of sagittal contour, with thoracic kyphosis (T5–T12) angle similar in each group before surgery (PSF+T 35.32° vs PSF 35.22°), immediate postoperative (26° vs 29.3°), and at final follow-up evaluation (28.4° vs 32.4°).

Table 1

	PSF+T group	PSF group	*P*
Gender (M/F)	6M/34F	5M/35F	n.s
Age (years)	16.3 (2)	15.2 (1.9)	n.s
Lenke's distribution	25 "**1**"/10 "**2**"/5 "**3**"	29 "**1**"/8 "**2**"/3 "**3**"	n.s
Preoperative main thoracic Cobb	66 (14)	63 (13)	n.s
Follow-up main thoracic Cobb	31 (11.2)	35 (13)	n.s
Percent overall correction	53.03 (12.6)	51.35 (12.8)	n.s
Preoperative kyphosis (T5-T12)	35.32 (10.1)	35.22 (12.5)	n.s
Follow-up kyphosis (T5-T12)	28.4 (9.8)	32.4 (10.6)	n.s
Preoperative Rib hump (cm)	3.45 (0.44)	2.96 (0.63)	n.s
Postoperative Rib hump (cm)	1.69 (0.77)	1.91 (0.4)	n.s
Overall Rib hump correction (cm)	-2.1 (0.9)	- 1.5 (1.1)	< 0.01

With regards to PFT's, in the PSF+T group both the absolute values of forced vital capacity was unchanged, from 2.87 to 3.1 L ($p = 0.16$), and those of forced expiratory volume in one second from 2.39 to 2.60 L ($p = 0.36$), in the pre-operative and last follow-up evaluation. In the PSF group the forced vital capacity increased from 2.83 to 3.34 L [$p < 0.0001$] and forced expiratory volume in one second increased from 2.41 to 2.84 L [$p < 0.0001$]), showing nevertheless no statistical differences both pre-operatively and at latest follow up when the two groups were compared (Table 2). At the latest follow-up visit, SRS-30 scores did not show any statistical differences between the two groups (total score PSF+T: 4.1 vs PSF:4.3; n.s) (Table 2).

Table 2

	PSF+T group	PSF group	*P*
Preoperative FVC (L)/ FVC %	2.87 (0.75) / 85% (15)	2.83 (0.8) / 84% (14)	n.s
Preoperative FEV1 (L)/ FEV1 %	2.39 (0.48) / 82% (12)	2.41 (0.7) / 80% (13)	n.s
Follow-up FVC (L)/ FVC %	3.1 (0.6) / 83% (14)	3.34 (0.5) / 87% (18)	n.s
Follow-up FEV1 (L)/ FEV1 %	2.60 (0.36) / 80% (11.5)	2.84 (0.4) / 83% (17)	n.s
Follow-up vs Pre-operative FVC (L)/ FVC %	-	< 0.0001	n.a
Follow-up vs Pre-operative FEV1 (L)/ FEV1 %	-	< 0.0001	n.a
SRS pain	4.16 (0.65)	4.23 (0.54)	n.s
SRS self-image	3.84 (0.53)	3.46 (0.71)	n.s
SRS function	3.54 (0.71)	3.25 (0.36)	n.s
SRS mental health	4.02 (0.35)	3.63 (0.46)	n.s
SRS satisfaction	4.3 (0.75)	4.5 (0.29)	n.s
SRS total score	4.1 (0.25)	4.3 (0.30)	n.s

No fatal complications or neurologic injuries, either acute or delayed deep wound infections were observed in this case series. In the PSF+T group 3 surgery-related complications (proximal hook disengagement) in 3 patients (7.5%) required 2 revision surgeries in 2 patients (at 3 ½, and 5 years respectively from the index procedure), whereas post-operative thoracoplasty-related pulmonary complications were encountered in 10 patients (moderate pleural effusion in 7, pneumonia secondary to moderate atelectasis in 2, pneumothorax in 1), requiring chest tube placement in 3 patients. In the PSF group a revision surgery with complete removal of the instrumentation was performed in a 19-year-old female patient due to persistent late operative site pain; intra-operative cultures were negative, 4 years after the index procedure. Three post-operative medical complications were observed in this latter group (1 acute cholecistitis, a superior mesenteric artery syndrome, a moderate pneumonia in 1) that did not require any invasive procedure and healed uneventfully by conservative treatment.

4. Conclusions

According to our findings thoracoplasty did not adversely affect long-term PFT's in AIS patients treated by posterior spinal fusion alone, as suggested by previous reports. A relatively high incidence of peri-operative complications were observed in the thoracoplasty group when compared to the posterior only fusion group. A trend towards better coronal plain correction and rib hump amelioration was found, not clearly reported by a self-assessment disease specific questionnaire.

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Preliminary Validation of Curve Progression Model for Brace Treatment

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Abstract. Brace treatment is the most commonly used non-surgical treatment for adolescent idiopathic scoliosis (AIS). A brace compliance monitoring system consisting of a microcomputer and a force transducer was used to monitor how brace candidates used their braces during daily activates. A prediction model of the brace treatment outcome was developed based on 20 AIS subjects. Six subjects (1M, 5F) with AIS who had worn their braces for six weeks participated into this study. One month data was recorded during the study period. Knowing the risk progression at the beginning of brace treatment plus how brace subjects used their braces in terms of brace tightness and wear time during brace treatment yielded a predicted outcome which was compared to the final treatment outcomes with 2 years followed-up. This preliminary result demonstrated that the prediction model was able to predict the treatment outcome within ±3 .5 degrees.

Keywords. Brace management, scoliosis, instrumentation, quality and quantity of brace usage

1. Introduction

Scoliosis is a three-dimensional deformity caused by lateral curvature of the spine with vertebral rotation within the curve. Adolescent Idiopathic Scoliosis (AIS), which appears before the onset of puberty and skeletal maturity, accounts for about 80% of all scoliosis cases. Severity of scoliosis is usually described by a Cobb angle. Although the Cobb angle measurement cannot truly describe the three-dimensional deformities of spine, it is still the gold standard to assess and evaluate treatment outcome. Treatment modalities are based on patient's skeletal maturity, Cobb angle measurement, patient's motivation, and the risk of progression [1]. In North America, curves less than 25°are generally not treated, but monitored until skeletal maturity. According to Scoliosis Research Society, curves of 25° to 40° in a growing child are considered for orthotic bracing. The goal of brace treatment is to stop curve progression. Surgery is the final option for treating scoliosis. To be effective, surgeons and orthotists suggest the brace must be worn for up to 23 hours per day [2]. However, the wear hour is not based on experimental data, it is based on researchers' reports [3] that the more the patient wears the brace, and the better is the result.

A typical brace candidate is a 12 year-old girl who is at a stage that she pays close attention to her appearance and does not want to be different than her peers. However, wearing a brace is restrictive, uncomfortable and draws unwanted attention; it affects patients' physical function and social activities [4]. Family, peer support, encouragement and scientific data to show bracing is effective are important to motivate patients to follow treatment regimens.

Although bracing for scoliosis has been used for more than fifty years, its effectiveness is still controversial [5-8]. The controversial results may be due to non-consistent inclusion criteria and different definitions of brace effectiveness as well as the unknown brace usage by patients. Recently, standardization of criteria for AIS brace studies has been set out by the Scoliosis Research Society Committee on Bracing and Nonoperative Management [9]. Recommended inclusion criteria for future AIS brace studies consist of: age 10 years or older when brace is prescribed, Risser 0-2, primary curve angles 25°-40°, no prior treatment, and, if female, either premenarchal or less than 1 year postmenarchal. Assessment of brace effectiveness should include: (1) the percentage of patients who have $\leq 5°$ curve progression and the percentage of patients who have > 6° progression at maturity, (2) the percentage of patients with curves exceeding 45° at maturity and the percentage who have had surgery recommended/undertaken, and (3) 2-year follow-up beyond maturity to determine the percentage of patients who subsequently undergo surgery. All patients, regardless of compliance, should be included. Some studies have investigated brace wear compliance by using temperature or humidity sensors and force switches [10-15]. However, these studies did not measure how tightly the brace was worn. It may not be able to truly conclude whether the brace is effective or not.

To measure the quality and quantity of brace usage, a low-powered portable load monitoring system has been developed [16]. The latest version of the monitoring system [17] is able to log wear pattern during daily activities over a 4 month period without requiring patient's attention. However, during this study, our monitor system was only able to log 1 month data without patients' interaction. Since brace treatment is a long term commitment, early prediction of treatment outcome may help surgeons to change treatment protocol more appropriately. A prediction model of brace treatment outcomes has been developed [18] based on 20 AIS patients (13.4 $\pm$ 1.8 years).

The curve progression model is:

Curve Progression (degrees) = 33 + 0.12*Peterson Risk(%) - 0.48*Quality(%) - 0.52*Quantity (%) +0.0066*Quantity*Quality.

The risk score was calculated based on Peterson's risk of progression formula when the brace was prescribed. The age threshold for males was increased by 2 years over the female threshold in Peterson's risk score as males physically mature later than females. The quality of brace wear was assessed as a continuous variable relative to the prescribed load levels and 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.

2. Objective

This study was to evaluate the accuracy of the prediction model of the brace treatment outcomes based on the risk progression and brace usage.

3. Materials & Methods

Six new brace subjects (5F, 1M), age 12.7 ± 2.0 years, Cobb 33 ± 6 who were prescribed a TLSO type of brace were recruited into this study. All subjects signed the consent form before they participated into this study. The selection criteria followed the SRS brace study guidelines. The Cobb angle of the treated curve at pre-brace and in-brace at time of monitoring were 33±6^{o} and 22 ± 5^{o}, respectively. The prescribed wear time was 22 hours per day. A monitor system consisting of a data logger and a force sensor (Figure 1) was installed into a brace (Figure 2) 6 weeks after the in-brace follow-up checking session. Each monitor collected data for a month without requiring recharge. 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 a 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 the force level recorded at each sample. The quality of brace wear was assessed as a continuous variable using the actual load levels during the monitor time. 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.

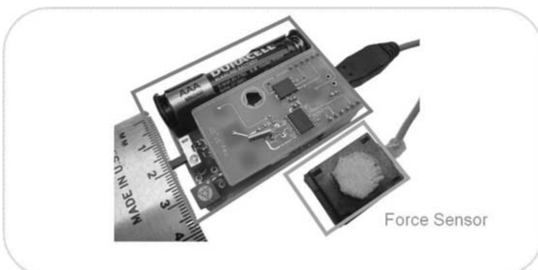

Figure 1. Brace Monitor System

Figure 2. Brace Monitor embedded inside a brace without patient interaction.

4. Results

All subjects were followed for a minimum of 2 years beyond finishing brace treatment or until surgery. The Peterson risk, the quality and quantity of the brace usage of each subject during monitor was shown in table 1.

Subject	Gender	Peterson risk (%)	Quality	Quantity
1	F	87	23	43
2	F	73	83	44
3	F	87	70	65
4	M	73	51	72
5	F	38	72	83
6	F	22	26	68

Table 1. Summary of the risk of progression, quality and quantity measurement.

Table 2 showed the prediction results and the actual brace treatment outcomes after the treatment. Among these 6 subjects, subject 1 had had a surgery when her curve reached 53 degrees. The maximum difference between the model and the actual values were 3.5 degrees.

Subject	Initial Cobb angle	In brace Cobb angle	Predicted Curve progression	Actual curve changes
1	33	26	16	20
2	25	15	3	2
3	38	22	6	7
4	35	25	4	2
5	27	18	-1	1
6	40	26	0	1

Table 2. The prediction results versus the actual curve changes

5. Discussion

The purpose of brace treatment is to stop curve progression during the high-risk growth period of early adolescence, minimizing the permanent deformities and to reduce the need for surgeries. Brace treatment results in successful outcomes in only a subset of patients. Is this because of the variable underlying causes of scoliosis, timing of brace usage, curve responsiveness, brace design, how the brace is worn (quality), how often the brace is worn (quantity) or more likely a complex combination of these and other factors? Many patients are distressed as the brace is seen as a major life altering event, when they are told to wear a brace. The most appropriate brace protocol can be provided with the best likelihood of success if the brace treatment can be predicted at the first follow-up clinical visit, alleviating some of this anxiety.

6. Conclusions

The prediction model demonstrated that it is possible to predict brace treatment outcome using quality, quantity of brace usage and a risk progression factor.

7. Acknowledgments

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BRACE MAP, a proposal for a new classification of braces

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Abstract. Braces today are named according to the author's name or town. The existing classification of braces considers only the anatomical spinal section involved (C: cervical; T: thoracic; L: lumbar; S: sacral; Orthosis). The absence of a more detailed classification do not allow to really distinguish between the different braces and to have a common language between the conservative treatment experts. Our aim was to propose and verify a new classification of braces. We developed the classification and applied it to 13 different braces (Boston, Charleston, Cheneau 2000, Lapadula, Lyonese, Maguelone, Milwaukee, PASB, Providence, Sforzesco, Sibilla, SpineCor, Triac). We considered the following items (acronym BRACE MAP): Building, Rigidity, Anatomical classification, Construction of the Envelope, Mechanism of Action, Plane of action. Each item is composed by 2 to 7 classificatory elements defined using one or maximum two letters, so that from the classification it is possible to come back to the brace characteristics. Out of the 13 braces considered, BRACE MAP did not allow to differentiate only two. This first proposal needs to be refined through Consensus and discussions that are already underway in the international Society On Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT); nevertheless, BRACE MAP appears to be useful in distinguishing between the existing braces.

Keywords Idiopathic scoliosis, Brace, Classification.

1. Introduction

Classifications in medicine are key elements to understand both pathologies and all the other health related issues [1, 2]: moreover, they offer a common language to physicians and allied health professionals as well as, in many cases, real clues to understand the phenomenon described by the classifications itself [3]. In some way, our way of thinking is driven by a classification and the measurement systems we use.

In the field of scoliosis classifications on the pathology have been proposed, even though they are not totally satisfying until now [3-7]. In fact, some other classifications has been attempted or to better describe scoliosis in 3D [3, 8-11] or with therapeutic aims: surgical [4, 12] or conservative according to single type of braces [13, 14].

The classical existing classification of braces most widely used today considers only the anatomical spinal section involved (C: cervical; T: thoracic; L: lumbar; S: sacral; Orthosis). The absence of a more detailed classification do not allow to really distinguish between the different braces and to have a common language between the conservative treatment experts.

On the other hand, the existing situation is that braces are named by their developers, using their own or their town names, or others. The possibility that same braces are continuously re-created with different names by different people is real and not verifiable. This situation at least do not allow to increase our knowledge in the field, while personalisms progressively develops that contrast with science; moreover the possibility to understand braces actions and usefulness is reduced [15].

The aim of this paper is to propose for the first time, and initially verify a new classification of braces.

2. Materials and Methods

We theoretically developed the classification and applied it to 13 conveniently chosen braces (European and American) to preliminarily verify if it was possible to distinguish between all of them. The braces considered in this study come from (and are used mainly in) different countries and include: Boston (US), Charleston (US), Chêneau 2000 (Ch), Lapadula (I), Lyonese (F), Maguelone (I), Milwaukee (US), PASB (I), Providence (US), Sforzesco (I), Sibilla-Chêneau (I), SpineCor (Ca), Triac (D).

2.1 Classification

Due to the fact that a complete, but not anatomic classification will always be difficult to remember, and to avoid the difficulties encountered in other experiences where numbers have been used [13, 14], for memorization purposes we choose the classificatory items in a way to make an acronym (BRACE MAP). Each item is composed by 2 to 7 classificatory elements (Table 1) defined using one or maximum two letters, so that from the classification, remembering the acronym BRACE MAP, it is possible to come back to the brace characteristics.

The classificatory items proposed for BRACE MAP are:

- B: Building (C: Custom made, Cp: Custom positioning, P: prefabricated envelope)
- R: Rigidity (S: Soft; E: Elastic; R: Rigid; V: Very rigid)
- A: Anatomical classification (C: CTLSO; T: TLSO; L: LSO)
- CE: Construction of the Envelope (S: Symmetric; A: Asymmetric)
- MA: Mechanism of Action (T: Three Point; E: Elongation; P: Push; M: Movement)
- P: Plane of action (3: 3D; F: 2D Frontal; H: 2D Horizontal; S: 2D Sagittal; Fh: Combined Frontal horizontal; Fs: Combined Frontal sagittal; Hs: Combined Horizontal sagittal).

3. Results

Out of the 13 braces considered, the BRACE MAP classification did not allow to differentiate only two of them: the Charleston and Providence (Table 1).

4. Discussion

The proposed classification proved to be able to differentiate 12 braces one from the other, and only two were similarly classified.

The first point to be discussed is: do we need a classification in this field ? We think that if we continue with the actual names we cannot compare different braces; same braces with same principles can have different names, and same braces with same names are applied by different physicians according to different principles [15]. Moreover, to understand what we are doing we need to compare the different braces starting from a common basis: a classification offers such a common language, and we definitively need it.

Table 1. Classification of the 13 braces considered. Only Charleston and Providence brace have not been distinguisched by the proposed classification.

	B	R	A	CE	MA	P
	Building	**R**igidity	**A**natomical classification	**C**onstruction of the **E**nvelope	**M**echanism of **A**ction	**P**lane of action
Boston	P	R	L	S	T	3
Charleston	C	R	T	A	T	F
Cheneau 2000	C	R	T	A	T	3
Lapadula	C	R	L	S	P	3
Lyonese	C	V	T	A	T	Fh
Maguelone	C	V	T	S	T	S
Milwaukee	C	R	C	S	E	Fh
PASB	C	R	L	A	M	Fh
Providence	C	R	T	A	T	F
Sforzesco	C	V	T	S	P	3
Sibilla	C	R	T	S	P	3
SpineCor	Cp	E	T	A	M	3

It's possible that this first proposal is not the best one, but it could at least serve as a basis for discussion.

The BRACE MAP classification has some limits. The acronyms resulting from the classification are difficult (Table 1), but this is presumably unavoidable because of the inherent difficulty of this field; moreover, this can be overcome using the acronym BRACE MAP to come back from the classification to its meaning. The classifications of Table 1 could not be totally accurate, because we do not have a direct experience on all these braces: it should be given by braces developers, even if some of these braces are used differently by different physicians [15]. In any case this classification is a first proposal and need refinement, that is already underway in the SOSORT (international Society On Scoliosis Orthopaedic and Rehabilitation Treatment – www.sosort.org).

In conclusion, we need to better understand braces action; and, to understand we need to compare the different orthosis; but, to compare we need to have a common background, and a classification is the possible starting point. If BRACE MAP will not be the right classification, it could be changed. Nevertheless we need to a point to start.

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Clinical and postural behaviour of scoliosis during daily brace weaning hours

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Abstract. What happens to scoliosis when the brace is daily weaned is not described in the literature, even if this can have a significant clinical impact. Our aim was to evaluate the postural and clinical changes at brace weaning. We developed a pre-post trial in 10 adolescent idiopathic scoliosis female patients 12.6 years old, with 42.8±7.4° Cobb curves. Inclusion criteria: more than 30° Cobb; TLSO worn at least 20 hours/day. Patients have been divided according to the hours of brace wearing per day: group 23H (6 patients, 23 hours per day) and group 20H (20-21 hours per day). We evaluated the patients at brace weaning and every hour per 4 hours, clinically (Bunnell degrees, hump and plumbline distances through usual clinical instruments) and posturally (scoliosis degree), by means of a non-ionising instrument that allow a 3D reconstruction of the spine. Paired ANOVA and t-test were used for statistical analysis. Group 23H showed statistically significant variations in 1 to 3 hours in all clinical parameters, and a tendency to progression of scoliosis. Group 20H did not show any statistically significant variation in 4 hours, a part from slight improvements. These results could be explained in terms of scoliosis reactions to usual/unusual daily load on the spine. Moreover, these data show the possible existence of the “concertina effect” due to brace weaning, and the importance of standardizing clinical examination with respect to the daily brace weaning hours.

Keywords Idiopathic scoliosis, Brace tretment, Evaluation.

1. Introduction

During brace treatment, everyday the patient wean the brace for a more or less long period of time. This brace weaning time is directly related to the final results: in fact, braces work when prescribed full time [1], and when compliance is high [2]. In any case, what happens to scoliosis when the brace is weaned is not described in the literature, even if this have a clinical impact. The question relate both to assessment (i.e.: what happens to the clinical signs we evaluate ?) and results (i.e. what happens to scoliosis ?).

In the past we hypothesized a possible “concertina effect” (Figure 1) [3] that could explain the importance of patient’s compliance. According to this hypothesis, each time a brace is weaned the deformity gradually moves back from the maximal in-brace correction to the original out-of-brace situation; this reversal is due to a postural collapse [4-6], that is correlated to the length of brace weaning and the rigidity (flexibility) of the spine [5] (itself correlated to the stage of growth, the bone age, the muscular endurance and the usual brace wearing). According to the “concertina effect” hypothesis, the deformity reached at the end of daily brace weaning gives the allowed compression of the wedged vertebrae, and consequently the final results.

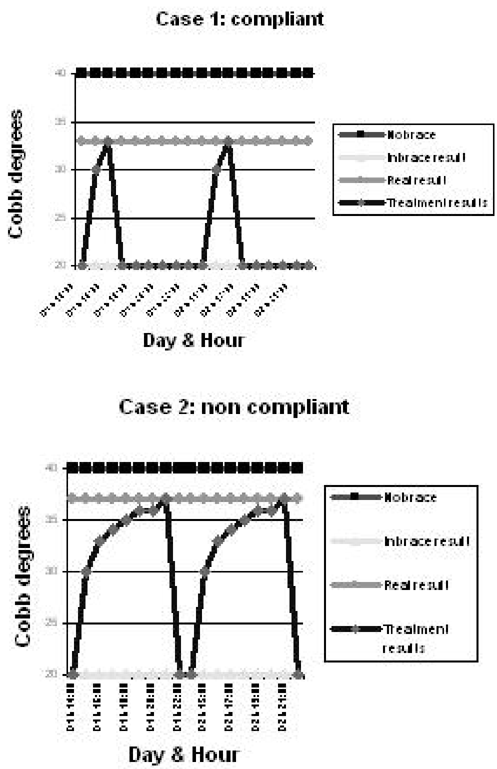

Figure 1

To verify what happens during daily weaning time, and to verify if the concertina effect is possibly real, we developed a study to evaluate scoliosis postural and clinical changes at brace weaning.

2. Materials and Methods

This is a pre-post trial on 10 adolescent idiopathic scoliosis female patients 12.6 years old, with 42.8±7.4° Cobb curves. Inclusion criteria were: more than 30° Cobb curves; TLSO worn at least 20 hours/day. Patients have been divided according to the hours of brace wearing per day into two groups: 23H group included 6 patients who used the brace 23 hours per day, and 20H group consisted of the 4 patients who used the brace 20 or 21 hours per day.

We evaluated all patients at brace weaning and every hour per 4 hours. The evaluations performed were clinical (Bunnell degrees, prominence height and plumbline distances) and postural, by means of GOALS (Global Optoelectronic Approach for

Locomotion and Spine), a non-ionising instrument that allow a 3D reconstruction of the spine [7]. Paired ANOVA and t-test were used for statistical analysis.

3. Results

Main results are reported in Figure 2. The 23H group showed a statistically significant ($P<0.05$) worsening of 2° of the ATR in 3 hours, 3 mm of the prominence in 1 hour and 6 mm of the Sagittal Index in 3 hours; in the meantime we had a scoliosis worsening in 4 hours, but not significant. On the contrary the group 20H did not show any statistically significant change in 4 hours. Although not statistically significant, GOALS variation (Figure 2D) suggest a positive postural reaction in Group 20H and stability/slight worsening in 23H.

4. Discussion

Group 23H showed variations in 1 to 3 hours in all clinical parameters and presumably in scoliosis Cobb degrees as could be hypothesized from a surface topographic measurement. The variations observed were bigger than the measurement errors of the considered parameters [8-10].

Inside the everyday brace weaning time (group 20H) there were no variations (perhaps positive slight straightening reactions), while when overcoming it (group 23H), and in the

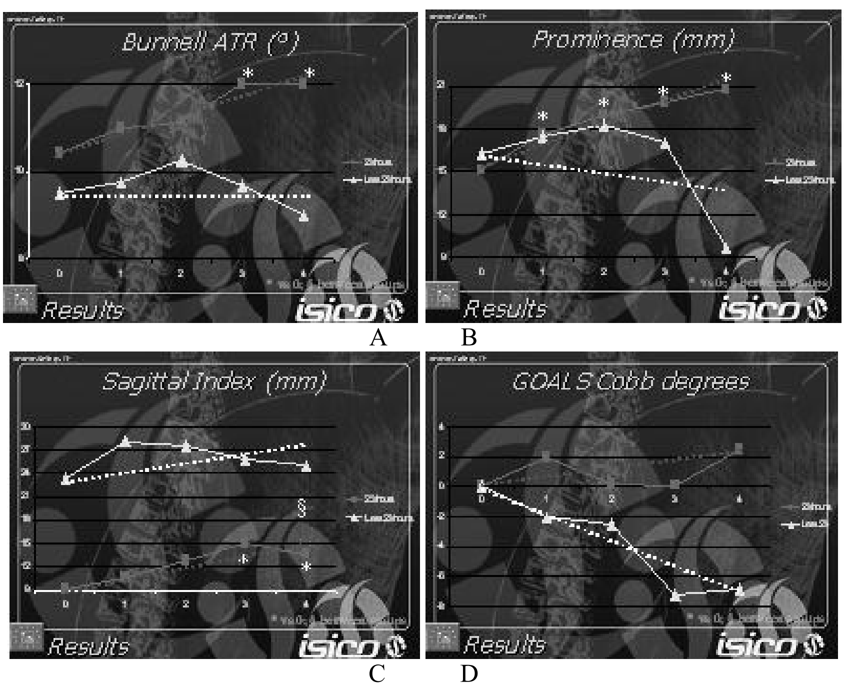

Figure 2

case of prominence (that already changed after 1 hour only) simply reaching this time, we observed statistically and clinically significant worsening of clinical parameters; scoliosis could change, but the reduced sample did not allow to reach definitive results. According to these results it's possible that the "concertina effect" (Figure 1) exist, because the correction is gradually loosen, even if more studies should be carried out in this respect.

To our knowledge, this is the first study on the topic. The limitations of the study included the reduced sample, due to the difficulties of recruiting patients and to the time required to carry on all the evaluations. We did not have any evaluation at immediate brace weaning, due to the characteristics of the system used, that required 10 to 15 minutes for markerization. Another limitation has been the use of an optoelectronic instrument, but obviously for ethical reasons x-rays couldn't be used for repeated measurements.

According to these results the clinical evaluation (but presumably also x-rays) timing should be standardized and performed or immediately at brace weaning, or after the everyday allowed weaning time. Moreover, the "concertina effect" should be studied more, to understand if it is real and important in clinical practice for final results.

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Do imbalance situations stimulate a spinal straightening reflex in patient with adolescent idiopathic scoliosis?

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Abstract. Correlation between balance and Adolescent Idiopathic Scoliosis (AIS) is still unclear. To identify the most useful type of physical exercises to be proposed for conservative treatment, is interesting to explore better this field. Our aim was to evaluate the changes of scoliosis curves in a group AIS patients while submitted to an unbalancing situation. We considered in a pre-post trial 14 AIS patients (46 curves), 12 to 15 years old, with 19.3±9.9° Cobb curves. Assessment has been made using GOALS (Global Optoelectronic Approach for Locomotion and Spine), a non-ionising instrument that allow a 3D reconstruction of the spine. We evaluated the patients twice in a standardised standing position: on the floor, and on a sway bench. On the sway bench there was a statistically (but not clinically) significant reduction of the curves. This was confirmed considering the average of the curves of each patient, but not when considering the worst curve. Looking at the curves, 13% worsened and 33% improved, versus 14% and 43% respectively looking at the patients. We did not find similar reactions in all patients, but in general a spinal straightening reflex while on a sway bench appears. In any case these variations are of low degree.
Keywords: scoliosis, exercises, physical therapy, balance

1. Introduction

Balance is a relevant function in everyday life, and in the literature there are papers on its impairment in adolescent idiopathic scoliosis (AIS) patients. The correlation between balance and AIS is still unclear, and two non exclusive hypotheses could explain these problems: a *biomechanical hypothesis*, which gives importance to such factors as the shape of the trunk and the changes in the relationships between body segments; and a s*ensory integration hypothesis*, which predicts impairments in the dynamic regulation of sensorimotor integration by the inappropriate weighting of sensory inputs [1].

Center of body mass sway (COM) has been demonstrated in these patients, and can be probably a consequence of the misalignment of the spine [2]. Moreover, children with AIS show poor balance, especially when visual and somato-sensory input is challenged [3], thus suggesting an integration deficit. Some studies have pointed out the possible existence of a vestibular problems in AIS, that can somehow affect a correct balance and postural control [4].

Physical exercises (PE) (outpatient and inpatient rehabilitation) have been recommended as the first line of treatment for small curves and those with a low risk of progression by various, mostly European, clinicians [5-7]. There are many PE approaches that showed to be effective in AIS in reducing brace prescription and avoiding progression of the curve [8-12]. In some techniques, balance reactions are used with the the aim of improving automatic postural reactions [9]. Recently Smania stressed that the increased sensory feedback due to PE could be an important stage in a rehabilitation program aimed at hindering, or possibly reversing, scoliosis progression [13]. Thus, to identify the most useful type of PE to be proposed for conservative treatment, is interesting to better explore balance function in AIS.

The aim of this paper is to evaluate changes of scoliosis curves in a group of AIS patients while submitted to an unbalancing situation.

2. Methods

We designed a pre-post trial; we selected a convenience sample of 14 AIS consecutive female patients affected by AIS, 12 to 15 years old. The mean Cobb angle was 19.3±9.9° and the total of curves considered was 36. Assessment has been made using GOALS (Global Optoelectronic Approach for Locomotion and Spine), a non-ionising instrument that allow a 3D reconstruction of the spine [14]. We evaluated the patients twice in a standardised standing position: first, on the floor (FS); and second, on a sway bench (SB). For statistics we used paired T test; to consider significant a variation, due to the high precision of the instrument [15], we considered 1° Cobb as measured by GOALS.

3. Results

On average, comparing SB to FS there was a statistically significant reduction of the curves from 19.3±9.9° (FS) to 18.6±9.6° (SB). This was confirmed looking at the average of the curves of each patient, but not when looking at the worst curve (from 26.1±9.4° in FS to 25.4±10.2° in SB), where statistical significance was not reached. Looking at the curves, 13% worsened and 33% improved in SB versus FS; looking at the patients these percentages were 14% and 43% respectively.

4. Discussion

In general we observed a spinal straightening reflex with patients in SB, even if there were some individual differences: half of children had an improvement, suggesting a useful stimulation due to the unbalance condition. This reaction was more important for the entire spine than for the worst, structural curves, that improved even if not reaching statistical significance.

From these data we can draw that PE in difficult balance situations cause automatic reactions that aspecifically straighten the spine. Moreover, balance control is reduced in patients affected by AIS [3], and a specific training could be proposed without negative consequences on the spine.

Unfortunately, the small population of the present study did not allow a more accurate subgroup analysis. Nevertheless, a general conclusion about the impact of this specific training can already be drawn. Balance reaction stimulation do not seem to be effective per se in order to revert spinal curvature in AIS, and mainly in the most important curves; nevertheless, this PE strategy could be of help in the treatment of AIS, since it can cause feedback and feed-forward reactions, whose importance in the postural control of the trunk has been stressed [13].

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Congenital scoliosis – presentation of three severe cases treated conservatively

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Abstract. In view of the very limited data about conservative treatment of patients with congenital scoliosis (CS) available, early surgery is suggested already in mild cases with formation failures in the first three years of life. It is common sense that patients with failures of segmentation will not benefit from conservative treatment at all and the same applies to failures of formation with curves of > 50 degrees in infancy.
Materials and Methods. Two patients with rib synostosis denied surgery before entering the pubertal growth spurt. These patients have been treated conservatively with braces and Scoliosis In-Patient Rehabilitation (SIR) and now are beyond the pubertal growth spurt. One patient with a formation failure and a curve of > 50 degrees lumbar has been treated with the help of braces and physiotherapy from 1.6 years on and is still under treatment now at the age of 15 years.
Results. Severe decompensation was prevented in the two patients with failure of segmentation, however a severe thoracic deformity is evident with underdeveloped lung function and severe restrictive ventilation disorder. The patient with failure of formation is well developed, now without cosmetic or physical complaints although his curve progressed at the end of the growth spurt due to final mal-compliance.
Conclusions. Failures of segmentation should be advised to have surgery before entering the pubertal growth spurt. In case they deny, conservative treatment can at least in part be beneficial. For patients with failures of formation conservative treatment should be suggested in the first place because long-term outcomes of early surgery beyond pubertal growth spurt are not yet revealed.

Keywords. Congenital scoliosis, conservative treatment, indication for surgery

1. Introduction

In view of the very limited data about conservative treatment of patients with congenital scoliosis (CS) available, early surgery is suggested already in mild cases with formation failures in the first three years of life. It is common sense that patients with failures of segmentation will not benefit from conservative treatment at all and the same applies to failures of formation with curves of > 50 degrees in infancy.

Purpose of this study was to reveal the effects of conservative treatment in this rare patient population.

2. Material and Method

Two patients with rib synostosis (Fig. 1 and 2) denied surgery before entering the pubertal growth spurt. These patients have been treated conservatively with braces and Scoliosis In-Patient Rehabilitation (SIR) and now are beyond the pubertal growth spurt. One patient with a formation failure (Fig. 3) and a curve of > 50 degrees lumbar has been treated with the help of braces and physiotherapy from 1.6 years on and is still under treatment now at the age of 15 years.

3. Results

Severe decompensation was prevented in the two patients with failures of segmentation, however a severe thoracic deformity is evident with underdeveloped lung function and severe restrictive ventilation disorder.

The patient with failure of formation is well developed now without cosmetic or physical complaints although his curve progressed at the end of the growth spurt due to mal-compliance.

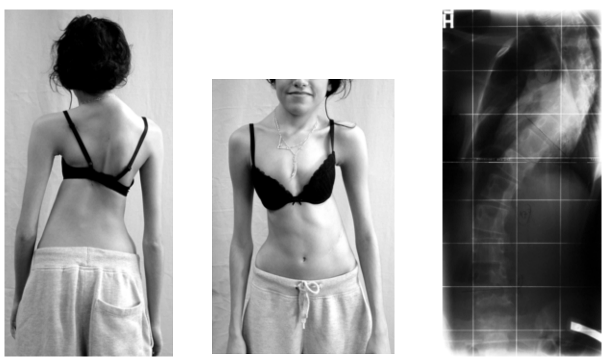

Figure 1: Follow-up from 10 years to 18 years. Progression from 10–12 years, after that stable. At 10 years the patient had 62° and progressed to 71° at the age of 12. Last x-ray: 72°. VC: 650 ml / 19% of the predicted value.

4. Discussion

So called long-term studies reporting on congenital scoliosis patients treated surgically reveal follow-up periods of 3-6 years with most of the patients being still before the pubertal growth spurt at final follow-up [1-4].

While the complications reported for the entity of congenital scoliosis varies widely between 0 and 48% in short- to mid-term [5-8]. The long-term complication rate for congenital scoliosis patients operated on is not yet reported.

Figure 2: From 2002 (64°) before pubertal growth spurt until 2007 (59°) at Risser 4 (15 years.) no progression has been detected. The ATR has been reduced with the Chêneau braces applied from initially 17° to 9° in January 2008 during the last SIR. VC: 1.640 ml / 33% of the predicted value.

Figure 3: 52° at the age of 18 months, in between the curve without brace on was down to 40°, 58° at final follow-up with Risser 4 after final mal-compliance. The patient had no cosmetic complaints. A small lumbar hump is visible but no decompensation.

To conclude from single case reports that: "The early fusion prevented the customary severe progression of this condition and early death due to cor pulmonale ", somehow seems biased pro surgery when there could be the possibility that even without surgery cor pulmonale would not necessarily be the consequence of an untreated congenital scoliosis [9,10].

On the other hand the patients reported on in these case reports are not yet beyond 50 years of age and might develop cor pulmonale in the future.

5. Conclusions

Failures of segmentation should be advised to have surgery before entering the pubertal growth spurt. In case they deny, conservative treatment can at least in part be beneficial. For patients with failures of formation conservative treatment should be suggested in the first place because long-term outcomes of early surgery beyond pubertal growth spurt in adulthood are not yet revealed.

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Conservative scoliosis treatment in patients with Prader-Willi syndrome

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Abstract. Patients with Prader-Willi syndrome often suffer from scoliosis of major degrees. Due to current literature surgical intervention seems the gold standard of treatment although the rate of complications in this condition are reported to be significantly higher than in patients with Adolescent Idiopathic Scoliosis. Purpose of this study was to reveal the effects of conservative treatment in this rare patient population.
Materials and Methods. A case series of patients with this condition has been investigated to estimate as to whether Prader-Willi patients with scoliosis may benefit from conservative scoliosis management. 9 Patients with this condition have been found in our out-patient database. 5 of these retarded patients (3 girls, two boys) today are 19 years and older and therefore are without any significant residual growth. Average Cobb angle was 47 degrees (34 – 66 degrees) at 12 years, average observation time was 6.4 years.
Results. Two of the five patients progressed. Average Cobb angle after follow-up was 52 degrees. No progression beyond 70 degrees has been found after cessation of growth. In one patient the curve deteriorated clearly after reducing brace wearing time and therefore was due to non-compliance.
Conclusions. Stabilisation of scoliosis due to Prader-Willi syndrome is possible by means of conservative management. To expose this patient population to the risks of surgical management seems not to be justified.

Keywords. Prader-Willi syndrome, scoliosis, surgery, complications, indications

1. Background

Children with Prader-Willi syndrome frequently have musculo-skeletal problems such as joint hyperlaxity, hypotonia, delayed bone age, and scoliosis. Their musculo-skeletal problems are magnified by the extreme obesity many of these patients exhibit [1].

Osteopenia, poor impulse control and defiant behaviors, and diminished pain sensitivity are aspects of PWS that may complicate all facets of orthopaedic nonsurgical and surgical management in this patient population. The treating orthopaedic surgeon must plan carefully and proceed with caution when treating children and adults with PWS [2].

Patients with Prader-Willi Syndrome often suffer from scoliosis of major degrees. Due to current literature surgical intervention [3] seems the gold standard of treatment although the rates of complications in this condition are reported to be significantly higher than in patients with Adolescent Idiopathic Scoliosis. Purpose of this study was to reveal the effects of conservative treatment in this rare patient population.

2. Material and Methods

A case series of patients with this condition has been investigated to estimate as to whether Prader-Willi patients with scoliosis may benefit from conservative scoliosis management. 9 Patients with this condition have been found in our out-patient database. 5 of these retarded patients (3 girls, two boys) today are 19 years and older and therefore are without any significant residual growth. Average Cobb angle was 47 degrees (34 – 66 degrees), average observation time was 6.4 years.

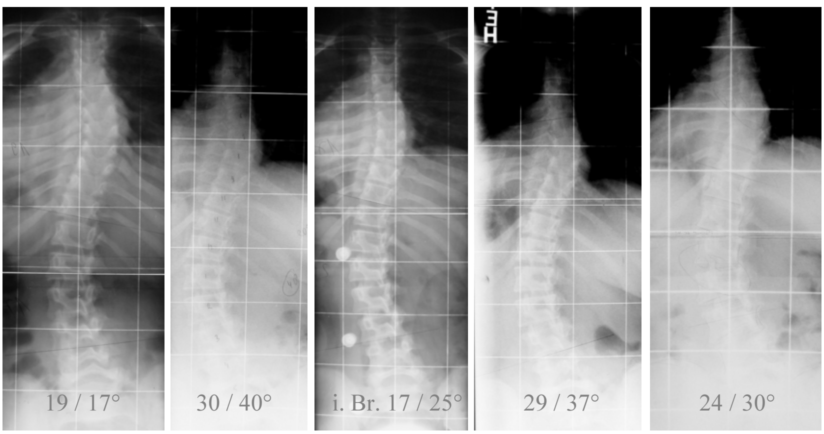

Figure 1. Left: First presentation at the age of 11 years, 2nd. from left: Brace indication at 12 years, middle: In brace correction, 2nd. from right: At weaning at the age of 20 years and on the right: Four years without brace at 24 years. During the last 4 years the woman lost weight.

3. Results

Two of the five patients progressed. Average Cobb angle after follow-up was 52 degrees. No progression beyond 70 degrees has been found after cessation of growth. In one patient the curve deteriorated clearly after reducing brace wearing time and therefore was due to non-compliance.

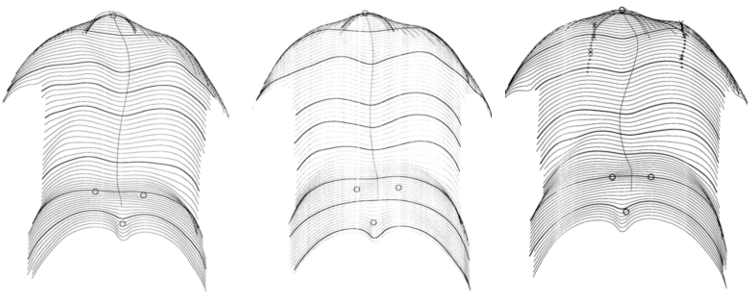

Figure 2. Surface scans of the patient who in the end was progressive due to non-compliance (Start of treatment, intermediate result and final result at the age of 19 years) without significant clinical deterioration.

4. Discussion

In current literature there is no evidence that scoliosis surgery in patients with Prader-Willi syndrome improves signs and symptoms of scoliosis during lifetime. Therefore to expose this patient population to the high risks of surgery [3] seems not to be justified.

Conservative management can prevent curve progression in patients with Prader-Willi syndrome and has to be regarded to be indicated primarily.

On the other hand scoliosis in the case of a Prader-Willi syndrome seems to be less malignant than in other conditions when the results of conservative treatment are good at average in patients usually presenting with significant obesity.

Figure 3. Clinical pictures of the patient who in the end was progressive due to non-compliance (Start of treatment, intermediate result and final result at the age of 19 years) without significant clinical deterioration and in his last brace on the right.

Figure 4. 24 year old patient (to be seen on the right) next to her mother at the final follow-up. Her curve has improved significantly (see figure 1.) during the four years without brace, however performing physiotherapy regularly.

5. Conclusions

Stabilisation of scoliosis due to Prader-Willi Syndrome is possible by means of conservative management. To expose this patient population to surgical management seems not to be justified medically.

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Chapter 9

Abstracts

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FBN3 gene polymorphisms in adolescent idiopathic scoliosis patients

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Abstract. Previous studies have shown that genetic factors are important in the pathogenesis of idiopathic scoliosis. In view of the important role of fibrillin family in connective disorder with scoliosis and the recent linkage study on familial idiopathic scoliosis. FBN3 may be a candidate predisposing gene for AIS and a putative disease-modifying gene. However, to our knowledge, the relationship of FBN3 gene polymorphisms and the individual susceptibility to idiopathic scoliosis has not been studied.
Blood samples were obtained from 273 AIS patients and 287 healthy girls.. Anthropometric parameters of AIS group including age, body height, weight, arm span and Cobb angle were recorded. Polymerase chain reaction-restriction fragment length polymorphism (PCR-RFLP) technique was used to detect and analyze FBN3 gene distribution of AIS group and control group.
The genotype and allele frequency distribution were comparable between AIS and normal control. There was no association with curve severity, arm span, BMI in patients with AIS. In rs7257948, the frequency of TT in patients whose body height was≥160 cm was lower than those whose body height was<160 cm (P=0.01).
The FBN3 gene 4 exon polymorphism was neither associated with the occurrence nor the curve severity of AIS. FBN3 maybe the minor gene of phenotype in AIS patients.

Keywords: Adolescent idiopathic scoliosis, FBN3, gene polymorphism

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Investigation on the association between estrogen β receptor gene polymorphisms and the susceptibility of adolescent idiopathic scoliosis

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Abstract. It has been detected that the ER α XbaI polymorphism might be associated with the development of adolescent idiopathic scoliosis (AIS). And, some literatures reported that ER β polymorphism is associated with bone mineral density. It remained unclear whether ER β polymorphism is associated with the susceptibility of AIS patients. Blood samples were obtained from 288 patients with AIS and 232 healthy adolescent. Anthropometric parameters of AIS group including age, body height, weight, arm span, age of menarche, Cobb angle and Risser sign were all recorded. Polymerase chain reaction-restriction fragment length polymorphism (PCR-RFLP) technique was used to detect and analyze ER β gene distributions of AIS group and control group. The frequency ER β genotype was no significantly difference between AIS patients and control group. In AIS patients, the expression of Rr genotype in patients whose menarche age was ≥12 years was higher than those whose menarche age was <12 years ($P<0.05$), but there were no significant association of the genotype distribution with regards to body height, BMI, arm span, Cobb angle and Risser sign. There was no significantly association between ER β gene and the susceptibility of AIS. Rr genotype maybe play a important role in the progression of AIS patients.

Keywords: adolescent idiopathic scoliosis, ER β, gene polymorphism, susceptibility

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Vitamin D receptor gene polymorphisms: no association with low bone mineral density in adolescent idiopathic scoliosis girls

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Abstract. Genetic factor has been proven to be one of the key factors in the etiology of adolescent idiopathic scoliosis (AIS), and osteopenia has been well documented in the AIS patients. Vitamin D receptor (VDR) gene polymorphism has been found to be associated with low bone mineral density (BMD) in adults. However, the VDR gene polymorphism has not been discussed in AIS patients.Blood samples were obtained from 146 AIS girls and 122 healthy girls. Anthropometric parameters of AIS group including age, body height, weight and Cobb angle were all recorded. Polymerase chain reaction-restriction fragment length polymorphism (PCR-RFLP) technique was used to detect and analyze VDR gene distributions of AIS group and control group. BMD of the lumbar spine (L2-L4) and proximal femur were measured using dual energy x-ray absorptiometry in AIS group. The frequency of Bb genotype was significantly higher in patients than that in controls ($P<0.01$). The B allele seemed to be overrepresented in patients compared with controls ($P<0.01$).There was no distinction among the lumbar spine and proximal femur BMD of each genotype in AIS group ($P>0.05$). VDR gene polymorphisms have no association with the low spine lumbar and proximal femur BMD in AIS girls.

Keywords: Adolescent idiopathic scoliosis, vitamin D receptor, gene polymorphism, bone mineral

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Expression and significance of Sox9 in chondrocyte cells from adolescent idiopathic scoliosis patients

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Abstract. Although it is now widely accepted that growth is related strongly to the onset and progression of scoliosis, the pathomechanism or etiology of idiopathic scoliosis still is not clear. In mammals, most skeletal elements are formed through endochondral bone formation. Several studies demonstrate that Sox9 as the first transcription factor that is essential for chondrocyte differentiation and cartilage formation. To investigate a possible related molecular mechanism between pathogenesis of adolescent idiopathic scoliosis (AIS) and expression of Sox9 from chondrocyte level. The study include 15 AIS patients (13femals, 2males; mean age 13.1 ± 0.7y) and 8 patients without scoliosis(5femals 3males;mean age13.4±1.1y). The mean cobb angle of AIS patients was 50.7°±10.7 ,range from 40° to 72° .The chondrocytes from human iliac growth-plate were isolated、cultured and passaged in vitro. Then the expressive of Sox9 of chondrocyte from 2 groups were detected by using RT- PCR, Western blotting at p2 generation. Expression of Sox9 of chondrocyte increased obviously in AIS group as compared with control group (P<0.01), no matter from nucleic acid or protein level. The abnormal expression of the transcription factor Sox9 may be related to the molecular mechanism of the pathogenesis of AIS.

Keywords: Idiopathic scoliosis, Sox9, chondrocyte, etiology

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Promoter polymorphism of matrilin-1 gene (*MATN1*) is associated with susceptibility to adolescent idiopathic scoliosis: a case-control study

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Abstract. Previous studies have shown genetic factor is important in adolescent idiopathic scoliosis (AIS). Matrilin-1 is a non-collagenous protein, which function in the organization of the extracellular matrix. Matrillin-1 mutant mice showed similar phenotypes to scoliosis. A recent study showed that *MATN1* gene is a susceptibility region for AIS. Considering all above, *Matn1* gene could be considered as a good candidate gene for AIS. . For initial screening, 7 htSNPs were genotyped in 197 cases and 172 controls. Next, we confirmed the significant associations of the four SNPs in additional 223 cases and 288 controls. A single-marker and haplotype analysis were employed. Genotyping was performed by PCR-RFLP method. We found four SNPs in *MATN1* promoter region were significantly associated with AIS. By logistic regression analysis, we could conclude that 3 SNPs represented the same association signal as a single SNP, and that the significance was merely due to LD with the SNP. Promoter polymorphism of matrilin-1 (*MATN1*) gene is associated with AIS in a Han Chinese population. The results suggested that *MATN1* was an AIS predisposition gene.

Keywords: Idiopathic scoliosis, MATN1, gene polymorphism, susceptibility

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Left-right asymmetry gene expression domains are reversed in adolescent idiopathic scoliosis

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Abstract. We investigated whether asymmetrical growth of the spine in bipedal mice developing a scoliosis and in AIS patients could share a common pathomechanism involving the perturbation of left-right (LR) asymmetry genes. Paraspinal muscle biopsies were taken intraoperatively from AIS patients requiring a spinal surgery (n=20) and scoliotic bipedal C57Bl6j mice (n=20). In both cases, muscle biopsies were taken on both sides (left and right) at the apex of the curve as well as above and below the apex and were frozen in liquid nitrogen for subsequent RNA extraction with the Trizol method. Expression analyses of LR-asymmetry genes were performed by real-time PCR. Non-scoliotic bipedal mice (n=10) and quadrupedal ones (n=5) were used as controls. Expression analyzes showed that left-restricted genes were strongly expressed on the right side instead of the left side of the body in the case of right thoracic curves in scoliotic mice and AIS patients. These changes in spatial expression domain occur mainly at the apex of the curve in scoliotic mice and AIS patients.

Our results represent the first experimental demonstration that LR-asymmetry genes are reversed in AIS. These spatial changes occur at the apex of the curve and could explain the prevalence of right thoracic curves over the left ones. The observation of the same phenomenon in bipedal scoliotic mice and in AIS patients strongly argues that LR-asymmetry genes reversal is a key element of the pathomechanism leading to scoliosis.

Keywords: asymmetry genes, adolescent idiopathic scoliosis

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SNPs analysis of CHD7 gene and idiopathic scoliosis (IS) in Chinese

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Abstract. CHD7 gene was recently associated with familial form of idiopathic scoliosis (IS). However, the haplotype and alleles showing disease predisposition were also common variants found the population. Therefore, it implies that these high-risk alleles in CHD7 gene may also play a role in the genetic predisposition of sporadic form of IS. 540 Chinese female AIS patients (Cobb's > 20) were recruited as cases and 252 healthy Chinese female adolescent as control. The population genetic variation in CHD7 gene was represented in the HapMap data. Four SNPs (rs4237036, rs625979, rs1483207, rs17826359) located to the proximity of peak association found in the original report were examined. Genotyping was performed by PCR-RFLP. The 4 SNPs were not significantly associated with AIS. The 2 SNPs (rs4237036 and rs1483207) located in closest proximity to the region between exon 2 and 4 of CHD7 which had shown the strongest association in original report did not reveal any association in this Chinese AIS subjects. There was a high level of linkage disequilibrium within this gene. Among the 13 common haplotypes, many are common to Chinese and Caucasian. Therefore, this tagSNP approach would detect any disease association due to a common haplotype. The absence of association with CHD7 gene indicated that common variants in CHD7 play a minor role in genetic predisposition to sporadic IS, at least in the Chinese population.

Table 1 Genotype frequencies of 4 SNPs (rs4237036, rs625979, rs1483207 and rs17826359) in the study are shown.

SNP (rs no.)	Genotype Frequency					
	Control			Case		
rs4237036	5.5% (CC)	31.5% (CT)	63.0% (TT)	6.5% (CC)	36.0% (CT)	57.5% (TT)
rs625979	45.3% (AA)	34.7% (CA)	20.0% (CC)	43.8% (AA)	38.5% (CA)	17.7% (CC)
rs1483207	44.8% (CC)	47.0% (CG)	8.2% (GG)	51.7% (CC)	37.1% (CG)	11.2% (GG)
rs17826359	61.3% (AA)	32.3% (AT)	6.4% (TT)	58.1% (AA)	36.6% (AT)	5.3% (TT)

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Collagen I Alpha 2 Gene Polymorphism Association Study in Adolescent Idiopathic Scoliosis

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Abstract. Adolescent idiopathic scoliosis (AIS) patients have lower bone mineral density (BMD) than their peers. Study showed that polymorphisms of type I collagen alpha 2 (COL1A2) gene was related to the spine BMD of adolescent female. It is hypothesize that COL1A2 gene may be associated with AIS and its related phenotypes. The polymorphism of COL1A2 gene in AIS girls was compared with control population and its association with the anthropometry and BMD of AIS patients was tested. Girls with AIS(n=522) and control(n=250) at age 12-16 were included with anthropometric data. The PvuII polymorphism of COL1A2 was characterized by PCR-RFLP. The spinal and femoral neck BMD were measured. The association of the gene polymorphism to the occurrence of AIS was tested by Chi-square. Standardized anthropometric parameters and BMD of AIS patients were compared between different genotypes. The genotype frequency of PP, Pp, and pp in AIS patients were 6.1%, 40.2%, and 53.6%, respectively. The distribution was significantly different from that of the control subjects (p=0.033). The BMC of the spine in AIS girls with pp was significantly lower than patients with P allele (PP and Pp)(p=0.008). The BMI of the AIS girls with pp genotypes had significantly lower BMI than others as well(p=0.035). AIS girls with pp genotype were shown to associate with the occurrence of AIS while this genotype also had significantly lower BMI, bone mineral status. It is suggested that COL1A2 gene might play an important role in the development of scoliosis and its related phenotypes.

Keywords : Scoliosis. Type 1 collagen, bone mineral density

z-score of	PP+Pp	pp	p value
Body Weight	-0.109 ± 0.929	-0.299 ± 0.933	0.021
BMI	-0.35 ± 0.81	-0.501 ± 0.812	0.035
Corrected Body Height	0.547 ± 1.179	0.388 ± 1.218	0.134
Arm Span	0.327 ± 2.719	0.442 ± 1.124	0.521
L2-4 BMD	-0.427 ± 0.913	-0.572 ± 0.907	0.072
Left Femoral Neck BMD	-0.229 ± 0.977	-0.403 ± 0.963	0.043
Right Femoral Neck BMD	-0.197 ± 0.97	-0.365 ± 0.992	0.053
ND FN BMD	-0.23 ± 0.967	-0.399 ± 0.975	0.048
D FN BMD	-0.197 ± 0.98	-0.369 ± 0.981	0.048
L2-4 Area	0.298 ± 0.962	0.076 ± 0.916	0.008
L2-4 BMC	-0.162 ± 0.881	-0.366 ± 0.859	0.008

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A Genetic Model For Studying The Etiopathogenesis Of Late-Onset Idiopathic Scoliosis

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Abstract: Strong evidences support a genetic etiology of late-onset idiopathic scoliosis (IS). Previous studies showed that familial IS could account for about 10% of the disease population. Genetic predisposition for IS can be attributed to multiple genetic loci. This polygenic predisposition is supported by recent genetic linkage studies. Furthermore, we hypothesize that additional genetic and environmental factor are determinants of disease progression which may be different from those related to disease predisposition. Therefore, a genetic model of etiopathogenesis of IS is proposed. The role of variation in genes related to the skeletal growth was studied in 600 adolescent girls with IS and 300 healthy age-matched controls. These variations were investigated for association with disease predisposition and/or disease progression. For the disease predisposition, genotypes were compared between the cases and controls. For disease progression, genotypes of the severe IS patients were compared to mild non-progressive IS patients. Estrogen receptor alpha gene and growth hormone receptor gene were not associated with either occurrence or curve severity of IS. Melatonin receptor 2 and collagen type I alpha 2 genes were associated with predisposition to IS and not with the progression. Insulin-like growth factor I was a determinant of disease progression alone. : Our ongoing genetic study strongly suggests that different sets of genes are responsible for the initiation and curve progression in late onset IS. It is likely that differential roles may be found for various environmental/anthropometric factors. The late-onset of IS fits to the model of complex trait disease.

Keywords: genetics, estrogen receptor gene, melatonin receptor gene

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Physical exercises and adolescent idiopathic scoliosis: results of a comprehensive systematic review of the literature

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Abstract: A previously published systematic review (2003) documented evidence on the efficacy of specific physical exercises to reduce progression of adolescent idiopathic scoliosis. A bibliographic search with strict inclusion criteria has been performed on the main electronic databases and through extensive hand search. We retrieved 19 studies: 1 randomised (RCT) and 8 controlled studies. A methodological and clinical evaluation has been performed. The 19 papers considered included 1654 treated patients and 688 controls. The highest quality study (RCT) compared 2 groups of 40 patients, showing an improvement of the curve in all treated patients after 6 months. We found 3 papers on Scoliosis Intensive Rehabilitation (Schroth), 5 on passive autocorrection-based methods (Schroth, side-shift), 4 on active autocorrection-based approaches (Lyon and SEAS) and 5 with no autocorrection. Apart from one, all studies confirmed the efficacy of exercises in reducing the progression rate and/or improving the Cobb angles. Exercises efficacy is proven by an RCT and several controlled studies. In 5 years 8 more papers have been published in indexed literature coming from all over the world and proving that interest on exercises do not come only from West Europe.

Keywords: Exercises, rehabilitation, literature review

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Identification of SRS 22r Domains Using Factor Analysis Methodology

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Abstract: The psychometric properties of the SRS-22r have been validated in a number of studies. However, to our knowledge a factor analysis of the language of origin English version has not been published. The purpose of this study is to examine the underlying domain/factor structure of the SRS-22r and validate the internal consistency of the identified domains. One hundred and sixteen adolescents (ages 8-18) with spinal deformities completed the SRS-22r. A principal component analysis with orthogonal rotation was then performed assessing the domain structure of the instrument. The underlying construct of each individual domain being measured was then validated using the Cronbach's alpha. Initial analysis identified only three domains (rather than five), with the construct in two of the domains contaminated by the questions from the management domain. After removing the two management questions, which influence other domains, four domains were identified: Pain, Function, Self Image, and Mental Health. Three questions [1 function; and 2 self-image] were identified that could be interchangeably placed in multiple domains. However, the internal consistency of all domains was best when these questions were retained in their original domain. Cronbach's alpha of the domains was 0.88 for Pain; 0.84 for Function; and 0.80 for Self Image and 0.90 for Mental Health. Finally, the internal consistency of the satisfaction/dissatisfaction with management domain was 0.73. Factor analysis of the SRS-22r confirms the placement of the 20 non-management domain questions in their respective four domains. Internal consistency was good to excellent in all domains.

Keywords: Psychometric assessment, scoliosis, SRS-22r

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Variations of Semicircular Canals Orientation and Left-right Asymmetry in Adolescent Idiopathic Scoliosis (AIS) Comparing with Normal Controls: MR Morphometry Study Using Advanced Image Computation Techniques

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Abstract Balance dysfunction has been reported to be associated with adolescent idiopathic scoliosis (AIS). This study sought to investigate for any morphometric difference present in vestibular system between AIS subjects and normal controls. High resolution T2W MR images of vestibular systems were obtained from 13 AIS girls with normal postural balance (PB), 9 PB-abnormal AIS girls and 20 matched controls. The 3D vestibular system surfaces were segmented by automatic computational pipeline. One best fit circle was assigned to each of the three semicircular canals. Shape of each canal was reflected by the radius of its circle while spatial relationship among the three canals was reflected by the length and angle formed between the corresponding lines connecting the centers of each pair of circles. Orientation asymmetry between left and right vestibular systems was measured by the Euler angles calculated to rigidly register the right to left vestibular surface. Statistical analysis was performed using one-way ANOVA. There was significant group difference in the shape and spatial relationship of the semicircular canals. In general, AIS had greater orientation asymmetry between left and right vestibular systems when compared with normal controls ($p=0.0265$). This difference was more exaggerated in PB-abnormal AIS ($p= 0.016$). Mean values of rotational angles around y-axis were as follows: control= -2.8593, PB-normal AIS= -1.0949, PB-abnormal AIS = 3.7309. Rotational asymmetry of the vestibular system might be one of the factors leading to postural dysfunction in AIS. Whether this structural change has any prognostic effect on curve progression warrants further longitudinal investigation.

Keywords: Balance dysfunction, vestibular system, scoliosis

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The SRS Outcome Questionnaire can discriminate between patients with spondylolisthesis and normal healthy adolescents.

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Introduction: The SRS-22 has been shown to be able to discriminate between patients with adolescent idiopathic scoliosis (AIS) and normal healthy adolescents. The SRS-22 is currently used to evaluate adolescent patients with spondylolisthesis but its reliability and validity has not been evaluated for this condition. The objective of this study was to test the response of the SRS-22 in an adolescent population with spondylolisthesis. The validated SRS-22 was used in 113 patients with spondylolisthesis, 144 with AIS and 64 healthy controls. Reliability was assessed with the internal consistency coefficients (Cronbach α), concurrent validity was done by comparison with the SF-12 and discriminant validity using ANOVA on clinical variables. The SRS-22 showed a good global internal consistency and in all of its domains. Mean scores and significant differences can be found in table 1. The factorial structure was coherent with the original questionnaire, with 59% of explained variance. High correlation coefficients were obtained between SRS-22 and SF-12 corresponding domains. Young children had higher scores than older patients in Activity and Mental health. Grade 1 as well as high grade (≥50% slip) patients had lower scores than grade 2 patients in Total and Activity domains. Patients having conservative treatment were less active and less satisfied compared to untreated and surgical patients. Patients with associated scoliosis had lower scores than patients with no secondary condition but without any statistical significant difference. Scores showed differences between the spondylolithesis, AIS and healthy subjects confirming that the SRS-22 can discriminate between the 3 groups. The SRS-22 showed satisfactory reliability and validity for clinical use in adolescents with spondylolisthesis. The SRS-22 demonstrates a clear gradient in response between subjects with low grade and high grade spondylolisthesis, AIS patients and healthy controls.

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The use of a decision tree increases accuracy when classifying adolescent idiopathic scoliosis using Lenke classification

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ABSTRACT: Lenke classification has shown fair reliability when used by surgeons. Rule based algorithms have shown to improve AIS classification using King classification. No such algorithms have yet been developed for Lenke classification. A computer classifier using an algorithm based on a decision tree was developed to classify curve types of AIS spines according to Lenke classification strictly from Cobb angle measurements. A simplified and clinically usable diagram of that decision tree was designed and introduced to surgical residents, nurses and orthopaedic surgeons. They were asked to classify 36 scoliotic curves strictly from radiographic measurements, using the Lenke classification description from the original article and then using the decision tree diagram as well. Wilkoxon ranking test was used for statistical analysis of gain in accuracy and assessment time. Instant classification by the computer classifier achieved 99% accuracy on a 603 patient database. When comparing accuracy from classifying curve types using the Lenke system description alone and in complement with the decision tree diagram, classification accuracy mean (SD) of 81% (24%) and 94% (6%) were achieved respectively. That difference was statistically significant (p=0.01). Classification times mean (SD) without and with decision tree diagram were 31.66 (8.99) and 23.33(9.69) seconds per item respectively. It was not statistically significant (p=0.10). Rule based algorithms and decision trees can improve AIS classification. The development of such algorithms can highlight ambiguous cases in classification description. Adaptation of algorithms developed for computer application to the clinical setting can increase clinicians' classification accuracy.

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Are there sub-types in Lenke-1 curves?

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Abstract: Current classification systems of adolescent idiopathic scoliosis (AIS) are limited because they are based on visual assessments of two-dimensional (2D) clinical indices (e.g. Cobb angle, central sacral vertebral line) calculated from calibrated radiographs. This study presents a cluster analysis using three-dimensional characteristics of 172 pre-operative Lenke 1 thoracic curve cases that were reviewed by the 3-D Spine Classification Committee of the SRS. Cobb angles, orientation of the plane of maximum curvature (PMC) of the main thoracic segment and constrained thoracic kyphosis were evaluated using 3D reconstructions from postero-anterior (PA) and lateral standing radiographs. The ISOData unsupervised clustering algorithm was applied to the structural curve parameters. Three subgroups (1 non-surgical and 2 surgical) were identified, with the orientation of the PMC being the primary discriminator. The non-surgical group (G1=22 cases) had Cobb angles (12°–32°), PMC (10°–66°), and kyphosis (27°–43°). The two surgical groups (G2=79 cases, G3=71 cases) had similar Cobb angles (41°–61°; 26°–54°) but exhibited different PMC orientations (G2: 65°–81°; G3: 76°–104°) and kyphosis (G2: 23°– 43°; G3: 7°–25°). Patients (G3) with higher PMC values also showed hypo-kyphosis characteristics. Patients with similar thoracic scoliosis curve characteristics in the coronal plane may exhibit very different characteristics in the sagittal plane, as evidenced by distinct PMC orientation. Classifying AIS using cluster analysis revealed structural differences characterizing inherent 3D complexities in the spine which are not clearly apparent in a single plane.

Keywords: cluster analysis, adolescent idiopathic scoliosis, pattern recognition.

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Posterior instrumented scoliosis correction in thoracic late onset idiopathic scoliosis: two year results

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Abstract: To evaluate the cosmetic improvement two years after posterior instrumented scoliosis correction in thoracic late onset idiopathic scoliosis. This is a prospective study of 18 patients with thoracic late onset idiopathic scoliosis treated by one surgeon (AAC). All patients were assessed before surgery and at 8 weeks, 1 year and 2 years after surgery. Each patient had radiographic assessment and SRS-22 questionnaires. Cosmesis was specifically assessed by the self image domain of the SRS-22, Scoliometer maximum angle of trunk inclination (ATI) and Quantec scan (Hump sum and Posterior Trunk Symmetry Index, POTSI). The thoracic Cobb angle improved by 66%. Cosmetically, maximum ATI improved by 38%, Hump sum by 40%, POTSI by 71% and SRS-22 self image domain by 36%. Using modern posterior instrumentation and techniques, we achieve good correction in the frontal plane as measured by Cobb angle and POTSI. However, transverse plane correction of the rib hump measured by maximum ATI and Hump Sum is less well corrected. The patient assessment of cosmetic improvement seems to follow the transverse plane improvement.

Keywords: Posterior surgical instrumentation, scoliometer, Quantec, Cobb angle improvement.

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Can surgical reduction correct spino-pelvic alignment in L5-S1 developmental spondylolisthesis?

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Abstract: This is a retrospective multi-centre analysis of 73 subjects (age 18±3 years) with developmental spondylolisthesis and an average follow-up of 1.9 years after reduction and fusion with instrumentation or cast (17 grade II, 40 grade III, 13 grade IV and 3 grade V). Spino- pelvic alignment was measured by a single observer on standing lateral X-rays using a computer software allowing a very high intra observer reliability. Paired Student tests and repeated measures analysis of variance were used to compare the measurements before and after surgery. After sub-classifying subjects into balanced and retroverted pelvis, pelvic shape was unaffected by surgery, as measured by pelvic incidence. However, grade, L5 incidence, slip angle, and shape of lumbar spine were all significantly improved. In addition, significant improvements were noted in pelvic alignment in both sub-groups, with 40% of cases switching groups, the vast majority from a retroverted to a balanced pelvis alignment. The direction and magnitude of these changes were significantly different by sub-group. In conclusion, while pelvic shape is unaffected by attempts at surgical reduction, repositioning of L5 over S1 significantly improves pelvic balance and spinal shape in developmental spondylolisthesis. These results emphasize the importance of dividing subjects according to pelvic balance, and further support the contention that reduction techniques might be considered for the retroverted pelvis subgroup.

Keywords: spondylolisthesis, retrospective multi-centre study, pelvic balance, reduction techniques

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The relationship between pelvic balance and a dome-shaped sacrum in developmental spondylolisthesis

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Spinal Deformity Study Group

Abstract: In order to analyze the differences in spino-pelvic alignment between flat and dome-shaped sacrum in high grade spondylolisthesis (HGS), the lateral standing X-rays of the spine and pelvis of 582 subjects with grade 1 to 5 developmental L5-S1 spondylolisthesis were analysed with acustom software allowing the calculation of spino-pelvic parameters. Three sub-groups were analysed: flat sacrum with slipping <35% (N=293) and HGS with slipping >35% with flat (N=215) or dome shaped sacrum (N=74). In addition, each HGS was classified as balanced or unbalanced pelvis, using the criteria of Hresko et al.

No significant differences in age or gender were found in the 3 sub-groups. Regarding the orientation of L5 superior endplate, the two groups with a flat sacrum had small differences, while subjects with a domed sacrum had significantly higher values. C7 had the same position in the three groups, but subjects with a dome shaped sacrum stood with a much higher pelvic tilt (32°) compared to both flat sacrum groups (14° vs 21°), and with a higher lumbar lordosis (LL) and more vertebrae in the lordotic curve. In HGS, subjects with domed sacrum were much more likely to stand with an unbalanced retroverted pelvis and a forward tilt of LL.

Subjects with a dome shaped sacrum stand with a spino-pelvic alignment which differs from those with a flat sacrum. The presence of sacral doming should alert the surgeon to the risk of an impaired spino-pelvic alignment and to the possible need for surgical reduction to correct pelvic balance.

Keywords: spondylolisthesis, dome shaped sacrum

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A historical and observational study to expose some etiopathogenetic factors that may be relevant to adolescent idiopathic scoliosis (AIS) in some patients

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Abstract: In 433 consecutive scoliosis patients referred to a Spine Centre 76 were removed after the surgeon made a diagnosis of infantile/juvenile idiopathic scoliosis, congenital scoliosis, congenital kyphosis/ Scheuermann's disease, neurofibromatosis, muscular dystrophy, Marfan's or Marfanoid syndrome, or spondylolisthesis. Next, 209 were eliminated for several reasons including older patients who did not attend with their parents, AIS patients whose mother or father had left the family home, straight spine, low IQ, tip toe walkers, other medical problems, back pain and a family history of scoliosis. The remaining 148 AIS patients were deemed 'healthy' by six criteria (McMaster et al 2006) and classified as:

1. Infant swimmers: 96 patients (88 girls 8 boys) taken to an indoor heated swimming pool in their first 12 months (McMaster et al 2006).
2. Poor diet: 27 patients (23 girls 4 boys). On questioning texture was the prohibiting factor in the child's inability to tolerate certain foods, resulting in a diet without fruit or vegetables. The food intolerance started at an early age and was established by the age of 5 years (Cheung et al 2006).
3. Chin on chest: 7 female patients were unable to place their chin firmly on their chest as reported by Floman (1998, 2000) in 12 AIS males with a mild scoliosis.
4. Observed eye asymmetry in one parent: 10 parents (14 patients all female) with exophthalmos or axial proptosis. No patient or parent was detected with craniofacial asymmetries as described Rousie, Berthoz and colleagues (1999, 2001, 2006ab).
5. Patients unable to classify: 8 patients (7 girls 1 boy). A distinguishing factor could not be found.

Keywords: Aetiology, swimmers, diet, eye asymmetry

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French-Canadian validation of the Spinal Appearance Questionnaire (SAQ) in the adolescent patients at a scoliosis clinic and its clinical application.

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Abstract: The SAQ was developed to measure patients' and parents' perceptions of their spinal deformity appearance. The objective of this study was to provide the French-Canadian spine community with a validated version of the SAQ. The SAQ was distributed to 254 French-speaking consecutive patients at the scoliosis clinics of CHU Sainte-Justine, in addition to the SRS Outcome Questionnaire (SRS-22). 182 fully completed questionnaires were obtained: 161 girls, 21 boys, mean age 15.0 (2.5) Cobb angle between 0 and 88 degrees. Intra-domain correlations were moderate to high (0.34 to 0.80, $p<0.01$) indicating that the items of the scales demonstrated a satisfactory internal coherence. Comparison of scores between SAQ-fv items and SRS-22 domains showed only high correlations (0.36 to 0.56, $p<0.01$) for the self-image domain, as expected in this test of convergent validity. A clear gradient in SAQ-fv scores according to Cobb angles was found in every scales. BMI, age, Risser and gender did not influence the questionnaire scores. Pre-operative patients' and parents' scores were significantly more affected when compared to other groups (observation, braced and post-op). In the SAQ-fv second part (Q9-Q16), a U-shaped distribution and a higher disagreement between parents and patients were observed, questioning the response scale construction. The SAQ-fv shows satisfactory validity and reliability in spinal deformity appearance evaluation. Since it is independent of patient's general characteristics it can discriminate between relevant clinical values and provide useful information for the clinical management of AIS patients.

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An energy-based mechanobiological growth model for simulating vertebral progressive deformities under multi-direction loads

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Abstract: Mechanobiological growth is the biological process whereby bone growth is modulated by mechanical loading. In scoliosis, it is generally assumed that mechanobiological modulation is capable of inducing asymmetric growth of vertebrae which thus develops as spinal deformities. It is hypothesized that mechanobiological growth can be expressed as an energy-based model. The objective is to develop an energy-based mechanobiological bone growth model, which allows simulating progressive deformities of vertebrae under multi-direction loads. Mechanobiological growth model in the longitudinal direction was the product of an energy-triggered bone development index and of a longitudinal orientational coefficient. This coefficient was developed from the energy tensor, which associated bone tissue mechanosensing multi-direction loads with the mechanobiological modification. This model was integrated in a finite element model of T7 vertebra from a 18° thoracic Cobb angle scoliosis. A published growth model (Stokes and Laible, 1990), which represents the relationship between longitudinal stress and bone growth, as well as related experiments were used to evaluate this model. The two models were first calibrated under tension loading in order to adjust growth parameters to obtain equivalent responses for that loading condition. One-year longitudinal growth under compression and shear loads was then simulated and compared. Under compression, both models triggered retarded growth, with homogeneous distribution on the vertebral body. These reduced growth indicted similar magnitudes with a comparative ratio of 1.14 (energy model/Stokes model). Under shear loading, both models induced negligible growth modulation (< 50μm / year). Simulations using the energy-based model agreed with the published model and relative experiments under longitudinal and shear loads. This model was able to simulate growth modulation under different loads. The energy-based model will further be used to associate complex loading environments to the potential asymmetric growth of vertebrae for studying the pathomechanism of spinal deformities.

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US and European Risser grading systems: which one best predict the curve acceleration phase in adolescent idiopathic scoliosis?

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Abstract: European Risser grading system divided the iliac crest into thirds and US system in quarters. Tanner-Whitehouse III (TWIII) method assess skeletal age based on wrist and small bones of the hand. A DSA score between 400 and 425 corresponds to the beginning of the curve acceleration phase in AIS[1]. First objective was to assess disagreement between the two grading system. Secondly, estimate which of the Risser grading system best predicts a DSA of 400 - 425. 103 AIS patients had a PA and lateral x-rays of the spine and a left hand and wrist. Risser sign was measured according to both grading system and bone age was calculated according to TWIII method. Kappa statistics and 2 multiple linear regression model with 5 indicators for Risser sign were performed. Kappa statistic between the US and European system was 0.674 (good agreement). Correlations between each system and DSA were 0.71. Risser 1 was the best predictor of the curve acceleration phase. DSA scores predicted with Risser 1 were 417 and 415 for US and European system respectively. This study showed a good agreement between US and European grading systems. Risser 1 best predicts the curve acceleration phase with both systems. Worldwide database are being created including the Risser sign, it is relevant to know that there is no difference between both grading systems. The DSA is not currently used in clinic, thus a closer follow-up should begin at Risser 1 since it represents curve acceleration phase.

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Decreased Lean Mass in Adolescent Idiopathic Scoliosis

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Abstract: Several studies have revealed that adolescent idiopathic scoliosis (AIS) patients had lower BMI than the normal controls, and some observations suggested that there maybe a relationship between AIS and body composition. It has been found that body fat mass was related to the severity of AIS during peripubertal time, but the difference of body composition between AIS and normal controls has never been studied. A total of 40 AIS girls and 27 normal girls with Risser 4-5 were recruited. The curve severity was measured using Cobb's method. Body composition was assessed by dual-energy x-ray absorptiometry (DEXA). One-way ANOVA test was used for comparisons between the groups. There were no difference in age, sex and Risser sign between two groups. Comparing to controls, the AIS patients had significantly lower bone mineral density(BMD) in arms, legs, lumbar and total areas. The lean mass in AIS patients is significantly lower, but the fat mass and total body bone mineral content is similar between two groups. Comparing to age matched controls, AIS patients have lower BMD and lower lean mass.

Key words: adolescent idiopathic scoliosis, bone mineral density, body composition.

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The Relationship Between RANKL/OPG and the Decreased Bone Mass in Adolescent Idiopathic Scoliosis Patients

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Abstract Osteoporosis is defined as an absolute decrease in total-body bone mass. Some investigators have reported that the prevalence of scoliosis was statistically higher in women with osteoporosis than in the general geriatric population. This study included 30 AIS patients and 14 healthy age-matched non-scoliosis adolescents. The average Cobb angle of AIS group was 52.7°. BMD of the lumbar spine and proximal femur was measured using dual energy X-ray absorptiometry in two groups. From anterior superior iliac spine, the human bone marrow was obtained with anticoagulation by heparine. And the MSCs were isolated by density gradient centrifuge from the mononuclear cells, and then were cultivated and serial subcultivated in vitro. Expression intensity of RANKL and OPG of MSCs was detected by RT- PCR. BMD of the lumbar spine (L2~L4) and proximal femur was obviously lower in AIS group than that of the control group. Increased expression of RANKL and decreased expression of OPG were found in MSCs in AIS group as compared with the control group ($P<0.01$). The abnormal expression of RANKL and OPG of MSCs may be responsible for the molecular mechanism of the decreased bone mass of adolescent idiopathic scoliosis patients.

Key words : Adolescent idiopathic scoliosis; Bone Mineral Density; Pathogenesis; Mesenchymal Stem Cells; RANKL; Osteoprotegerin

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Association Between Growth Hormone Gene and Adolescent Idiopathic Scoliosis

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Abstract: Curve progression in adolescent idiopathic scoliosis (AIS) is related to growth, and there were also several abnormalities in AIS patients, such as osteopenia, abnormal anthropometric measurement which is related to growth. Growth hormone (GH)/insulin-like growth factor-1 (IGF1) axis have been known as the pivot system in the regulation of the axial growth during puberty. GH is one of the most important elements in this axis. A total of 265 AIS girls and 193 normal controls were recruited. The curve severity was measured using Cobb's method. One polymorphism (rs2854184) in the promoter region of GH gene was selected for this study. Genotyping was performed by PCR-RFLP. Both the genotype and allele frequencies were comparable between case and control for rs2854184 ($p>0.05$). The mean maximum Cobb angle of different genotypes were similar with each other for rs2854184 ($p>0.05$ From the present study, GH seemed to be neither a disease predisposition gene nor a disease modifying gene of AIS for the studied variant.

Key words: Growth hormone; polymorphism; occurrence; curve severity; adolescent idiopathic scoliosis.

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Expression of melatonin receptor in chondrocyte of adolescent idiopathic scoliosis

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Abstract: Increasing evidence showed that AIS might be related to dysfunction of melatonin signaling pathway. Melatonin is a focus of studies of the mechanism underlying the development of scoliosis, and there is no research on the expression of melatonin receptors in the chondrocyte of patients with AIS. Thirty cases were divided into two groups, AIS group consisted of 22 patients (2 males and 20 females) with an average of 13.5±1.4 years old, ranging from 10 to 15 years old; and average Cobb angle of 50.9°± 10.1° (range, 40° ~ 72°) .Control group consisted of 8 patients without scoliosis (3 males and 5 females) , with an average of 13.4±1.1 years old, and ranging from 10 to 15 years old .The mRNA expression of melatonin subtypes melatonin recepter 1A (MT1) and melatonin receptor 1B (MT2) in chondrocyte detected by RT- PCR method. The MT1 and MT2 mRNA expression of chondrocyte in AIS patients was significantly lower than that in the control group ($P < 0.05$) . There is decreasing expression of MT1 and MT2 mRNA in chondrocytes of AIS patients, and this abnormal expression may be related to the molecular mechanism of the pathogenesis of AIS.

Keywords: Melatonin receptor, idiopathic scoliosis, mRNA, chondrocyte, etiology

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mRNA Expressions of Type I collagen, Osteocalcin and Osteoprotegerin in Iliac Cancellous Bone from Girls with Adolescent Idiopathic Scoliosis

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Abstract: In girls with adolescent idiopathic scoliosis (AIS), osteopenia has been widely reported with unclear molecular mechanism. Type I collagen, osteocalcin and osteoprotegerin are important either in bone structure or in bone biology. This study consisted of 43 girls with AIS. All girls aged 12-18yr, with Cobb angle > 40°. Small iliac cancellous bone samples were harvested during the operative procedures. After mRNA extraction, reverse transcription-polymerase chain reaction (RT-PCR) was used to assay mRNA expressions of type I collagen, osteocalcin and osteoprotegerin. Osteocalcin and osteoprotegerin mRNA contents were similar in Group A (normal BMD) and Group B (osteopenia), and significant correlations were not found between osteocalcin and osteoprotegerin mRNA contents and BMD values. However, subjects in Group A had slightly but not significantly higher mRNA contents of type I collagen than in Group B. And a weak positive correlation between mRNA contents of type I collagen and BMD values at both sites. Although significant correlations were not found between mRNA contents of type I collagen, osteocalcin and osteoprotegerin and BMD values, the association between mRNA contents of type I collagen and osteopenia in AIS girls should not be excluded.

Keywords: idiopathic scoliosis; bone mineral density; type I collagen; osteocalcin; osteoprotegerin; mRNA

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Expression of Runx2 and type X collagen in human vertebral growth plate of adolescent idiopathic scoliosis

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Abstract: Runx2 and type X collagen play important roles in vertebral growth, which has been involved in the development and progression of adolescent idiopathic scoliosis (AIS). Seventy-two specimens of vertebral growth plates were collected at the end and apex vertebrae of the scoliotic spine from 12 AIS patients. Expression of Runx2 and type X collagen were examined by immunohistochemistry and in situ hybridization. There were significant difference of the total expression of type X collagen, Runx2 protein and Runx2 mRNA between convex side and concave side of the apex vertebral growth plates. The total expression of type X collagen in the concave side of the lower end vertebral growth plates, and that of Runx2 in the concave side in the upper and lower end vertebral growth plate, were higher than those in the same side of apex($P<0.05$). The expression of Runx2 per cell in the concave side at the apex was higher than those in the convex side of the apex and in the concave side of the upper and lower end vertebral growth plates($P<0.05$). Expression discrepancy of type X collagen and Runx2 between convex and concave sides of the vertebral growth plate implicate a different chondrocytic kinetics, which may be a possible etiological factor or a secondary change in the progression of adolescent idiopathic scoliosis.

Keywords: idiopathic scoliosis, type X collagen, Runx2, growth plate

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Is corticospinal tract organization different in idiopathic scoliosis?

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Abstract: Our observations through intraoperative monitoring of spinal cord function during spine surgery guided us to test the potential role of cortico-spinal tract (CST) anomalies in the etiopathogenesis of idiopathic scoliosis (IS). CST function was assessed in awake IS and non-scoliotic (control) subjects by neurophysiological (single-pulse transcranial magnetic stimulation (TMS) of motor cortex) and functional (Complete Minnesota and Purdue Pegboard dexterity tests) approaches. The threshold intensity at which muscles are recruited by TMS can serve as an indirect measure of the density of innervation between CST axons and motoneurons of a given pool. TMS-evoked motor responses were recorded bilaterally (via surface electrodes) for several cervically (extensor carpi radialis, abductor pollicis brevis, and abductor digiti minimi) or subcervically (rectus abdominis, quadriceps femoris, and abductor hallucis) innervated muscles. In all subjects participating in our study, left-right (L-R) differencies in motor threshold (MT) were observed. In our 13 control subjects, large (>15%) asymmetries in MT were never seen, but occurred in 3 of our 11 (27%) IS subjects. The largest L-R asymmetries were revealed in subjects with Cobb angles higher than 40°. In addition, finger and hand dexterity was lower in IS subjects relative to controls. These findings suggest a different CST functional organization in IS, further underscoring the importance of neural factors in the etiopathogenesis of IS.

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Effects of in vivo Mechanical loading on extracellular matrix components of the growth plate

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Abstract: Clinical evidence demonstrates that mechanical loads are essential to normal longitudinal bone growth, yet if too important these loads can lead to progressive deformities such as adolescent idiopathic scoliosis. The controlled synthesis/degradation of growth plate extracellular matrix is essential to regulate normal longitudinal bone growth. A loading device was developed to precisely control a stress of 0.2 MPa applied for two weeks on the seventh caudal vertebra of rats (male, 28 days-old). Three groups were studied: baseline control, sham (loading apparatus installed but no load applied) and loaded groups. Growth modulation was quantified with calcein labeling and three main components of the extracellular matrix were assessed with safranin O coloration (proteoglycans) and immunohistochemistry (type II and X collagens). Average growth rates for C7 vertebra were 39, 33 and 28 μm/day for the control, sham and loaded groups. Compression modulated C7 growth by 29% ($p<0.001$) and 15% ($p<0.05$) as compared to controls and shams respectively. At the extracellular matrix level, no change was observed in the proteoglycans. Nevertheless, the expression of type X and II collagens was reduced in 66% and 83% respectively of the loaded rats. Static compression loading reduces bone growth rate. In vivo, this growth modulation involves remodeling of the extracellular matrix, which could in turn lead to changes in surrounding cellular activities.

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Transverse Plane Pelvic Rotation following Rotationally Corrective Instrumentation of Adolescent Idiopathic Scoliosis Double Curves

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Abstract: Noticeable pelvic rotation sometimes occurs; how often? Of 208 consecutive patients, 26 had double curves (Lenke 3 & 6). Rotationally corrective lumbar pedicle screw instrumentation was utilized in 23. Transverse plane pelvic rotation (TPPR) was quantified by the L/R hemi-pelvis width ratio from standing PA scoliosis radiographs. X-rays were oriented with the thoracolumbar/lumbar (TL/L) apex left. The L/R ratio is > 1 with left pelvis rotation [counterclockwise; 1.36 = ~ 5° (clinically noticeable)] and < 1 with right rotation [clockwise; 0.74 = ~ 5°]. Significance was determined by the Sign Rank non-parametric test. TL/L angle of trunk inclination corrected from 15° to 2° ($p < 0.0001$). Ninety-one % (21/23) had a readable x-ray sequence; pre-op L/R ratio average 0.91. Thirty eight % (8/21) had TPPR change of ≥ 5 degrees post operative; Seven clockwise, average L/R ratio of 1.01 (± 0.107) pre-op, 0.71 (± 0.167) post-op ($p = 0.0156$), 0.94 (ns) intermediate (11 mo.), and 0.86 (ns) at long term (32 mo.). Changed TPPR persisted in four; but was ≥ 5° from neutral in three, L/R ratio 1.00 pre-op and 0.69 (ns) long term. One of the eight had increased counter-clockwise TPPR (L/R 1.387), which resolved. At follow-up the SRS-22r total score averaged 4.7 for the eight patients with changed post-operative TPPR and 4.6 for the three with persistent increase. We believe this is the first report of translated scoliosis rotation corrective load to the pelvis; and provides reassurance that induced pelvic rotation usually resolves.

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A Multivariate Regression Model for Predicting the T2-T12 Kyphosis in Adolescent Idiopathic Scoliosis

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Abstract: Analyzing the sagittal profile of a scoliotic spine on the X-ray image can be at times quite difficult due to several anatomical structures overlapping in the thoracic region and irregular dosage of the X-ray beam which hinders the visibility of the vertebrae. There exists a known correlation between preoperative kyphosis and lordosis, as well as between the 2D curvature of the main coronal thoracic spine and the sagittal thoracic kyphosis. A predictor built on the most reliable information extracted from the X-ray images may therefore be able to estimate the thoracic kyphosis measurement between the T2 and T12 vertebrae. The main thoracic Cobb angle (C_{MT}) taken on the coronal X-ray image as well as on the lumbar lordosis ($L_{TL/L}$) computed on the sagittal image was used to built a reliable predictor of the constrained thoracic kyphosis angle between T2 and T12 ($K_{T2\text{-}T12}$) by training a quadratic multi-variant regression model by cross-validation. A database containing 732 scoliotic spines demonstrating several types of scoliotic deformities was used to train the proposed system. The database was separated into two parts, with training and testing subset of 366 scoliotic spines each. The cross-validation accuracy (ratio of correctly predicted angle within 1°) computed from the training dataset on 366 scoliotic spines was of 0.98. The accuracy on the testing datasets was of 0.78 for hypo-kyphotic curves (40 spines, kyphosis range 0–10°), 0.89 for normal kyphotic curves (257 spines, kyphosis range 10–40°) and 0.76 for hyper-kyphotic curves (69 spines, kyphosis > 40°). This paper presents promising results for a multivariate regression model which is able to predict the sagittal thoracic kyphosis between T2 and T12 built on the thoracic Cobb and lumbar lordosis measures. Although the estimate is not perfectly accurate, it falls within a reasonable range to assess adequately the sagittal curve of the spine.

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Poor Bone Mechanical and Structural Properties in 528 AIS Patients – Using Non-invasive Quantitative Ultrasound

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Abstract: Quantitative ultrasound (QUS) has found to be a useful tool in assessing the quality of bone non-invasively. Previous studies showed that a significant portion of AIS girls have low bone mineral density (BMD). However, studies in mechanical and structural properties of bone in AIS patients are limited. We aimed at to investigate the bone quality in AIS girls using radiation free calcaneal QUS. 528 AIS girls with initial Cobb angle ≥10° and 240 age-matched normal control girls were recruited. QUS measurement was performed at the non-dominant side of calcaneum. Parameters measured by QUS included broadband ultrasound attenuation (BUA), velocity of sound (VOS) and stiffness index (SI). Independent t-test was used for analysis. Results showed that there were no significant difference in age and menarchal age between AIS and controls ($p>0.05$). The mean Cobb angle for AIS girls was 30°±11. However, AIS had significantly lower in BUA, VOS and SI than those of the controls (BUA: 117.0±13.9 Vs 123.4±10.9; $p<0.01$; VOS: 1442.1±46.8 Vs 1447.9±53.8; $p=0.037$; SI: 353.2±69.3 Vs 379.6±69.3; $p<0.01$). The current study showed all the QUS parameters were found lower in AIS than those of age-matched controls. Results revealed poor bone quality may reflect the presence of abnormality in bone micro-architecture in AIS patients. Our previous study demonstrated that low BMD, measured by DXA, was found to be one of the risk factors in predicting curve progression. Further study in combining bone density and quality parameters for prognostication of curve progression in AIS could be of great clinical application.

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The Effect on the Intervertebral Pressure Distribution in a Goat Spine upon Implementation of a Spring-Like Device

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Abstract: The objective of this study was to implement a computer model to evaluate the effect of instrument stiffness on the intervertebral pressure during tensile loading on a goat spine. Seven spines (4 different goats, aged 4 to 7 months) were divided into four segments. With end vertebrae cemented in a customized fixture for MTS®, a spring was screwed into the right side of the spine. A pressure matrix with 4 sensors was inserted into the disc space. The compressive load (150 N) was decreased by slowly applying a tensile force until the net force was zero. A computer model of two vertebrae, one disc and a 10 or 20 N/mm spring was developed using Patran/Nastran® and the in-vitro tests. Figure 1 and 2 show that for a 50N compressive force, the intervertebral pressure increased for the 20 N/mm instrument as compared to 10 N/mm instrument. Computer modeling indicates that the intervertebral pressure for an instrumented spine is affected by resistance of the applied force and shifted toward the non-instrumented side. The model predicts the relationship between instrument stiffness and intervertebral pressure distribution, which will be critical in determining the impact of stiffness on the growth plate. Compared to the instrument with a stiffness of 10 N/mm, the 20 N/mm instrument, has an increased intervertebral stress that may further affect the modulation of the physis during growth.

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Stress shielding within the scoliotic spine: a progressive risk factor?

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Abstract: Asymmetrical loading of vertebral endplates is linked to the progression of idiopathic scoliosis based on the Hueter-Volkmann principle. Vertebral loads are induced via body weight and muscle dynamics, however stress distribution over the endplates is governed by regional stiffness. The morphology of a scoliotic spine entails local concave side remodelling: the interverbral disc degenerates, the nucleus migrates, and the trabecular bone mineral density augments. The purpose was to test the hypothesis that the concave-convex biases of the scoliotic spine play a role in the progression of the deformity by altering the stress distribution over the endplates. A right thoracic scoliosis (Cobb 26º) finite element model from T1 to L5 was built and calibrated respecting physiological behaviour. Growth dynamics regulated by mechanical stimuli were modeled according to the Hueter-Volkmann principle. Concave-convex mechanical properties and morphology respected reported in-vivo correlations. Stress analysis on the vertebral endplates and growth simulations were performed with and without presence of concave biases. Inclusion of concave biases increased asymmetrical stress on the apical vertebral endplate by 0.1 MPa and altered lateral stress distribution throughout the model. Concave biases increased vertebral wedging by a mean of 0.8º and induced an additional annual Cobb angle of 3.6º and 5.9º in the thoracic and lumbar sections respectively. Concave-convex biases of the scoliotic spine significantly modify the stress distribution on the vertebral endplates, and thus encourage additional progression.

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Suspension is better than side-bending to assess spinal flexibility in Adolescent Idiopathic Scoliosis

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Abstract: Spine flexibility is a decisive parameter for the planning of Adolescent Idiopathic Scoliosis (AIS) surgery. Side-bending is the gold standard test. However, it suffers from a poor reproducibility and it measures curve reducibility rather than flexibility since the forces involved are not known. A flexibility test consisting in a complete suspension of the subject by a harness was proposed. The aim of this study was to verify if suspension is a better method than side-bending to estimate spine flexibility. Five postero-anterior radiographs of 18 AIS subjects who underwent surgical instrumentation were analyzed: preoperative standing, right and left bending, complete suspension and postoperative standing. Cobb angles and axial rotation of apical vertebrae were measured to assess the preoperative reduction with both tests compared to the surgical correction. In addition, 2 flexibility indices per curve (in the coronal and transverse planes) were calculated from the suspension data. There was no statistical difference in preoperative curve reduction between the suspension and side-bending tests (39% vs 38%). The two tests underestimated the surgical correction (73%). Suspension produced larger preoperative axial derotation (29%) than side-bending (11%). The suspension test allowed calculating flexibility indices in the coronal (1.7 ± 0.6°/Nm) and transverse (0.5 ± 0.4°/Nm) planes. There was no correlation between reducibility and flexibility in the frontal plane (R^2=0.06) and a small correlation in the transverse plane (R^2=0.6). The suspension test is comparable to the side-bending to measure curve reducibility. In addition, suspension also allows measuring true flexibility of the scoliotic spine. This could help improving the planning of surgical instrumentation by a better knowledge of the torques required to correct the deformities.

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Classification of scoliosis deformity 3-D spinal shape by cluster analysis

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Abstract: Subjective or semi-quantitative methods can be used to classify curve types in scoliosis with the goal of rationalizing management and treatment. This paper reports a cluster analysis to determine objectively whether patients with scoliosis can be classified into distinct groups by 3-D curve shape. A cluster analysis was performed on an existing database of spinal shape of 110 patients whose spine was radiographed by a stereo technique at a scoliosis clinic in the period 1982-1990. Fifty-six were studied longitudinally (average 3.4 clinic visits each), providing 245 total observations. All patients had two scoliosis curves with apex between T4 and L3, and both Cobb angles >9 degrees by an automated measurement. Each curve was quantified by its Cobb angle, apex level, apex vertebra rotation and rotation of the plane of maximum curvature (8 variables). When the analysis searched for four clusters, the largest cluster (148 of 245 observations) was the pattern having counter-clockwise rotation of the planes of maximum curvature of both curves (typically a right upper scoliosis curve with kyphosis, and left lower scoliosis curve with lordosis). The other 3 clusters (48, 34, 15 observations) were the other permutations of these variables. Substantial overlap of all the other variables between groups was observed. Of the 56 patients seen longitudinally 25 were consistently grouped at all clinic visits. The group assignments can change with repeated observation, often because a slight curvature in the sagittal plane can change because of postural variation and measurement errors. The groupings according to the rotation of the planes of maximum curvature were distinct, but overlap of the other curve-shape variables between groups suggests that these spinal deformity classifications alone should not determine treatment strategy.

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Alteration of Mobility and Trunk Muscle Activation During Walking and Bending in AIS Patients with Posterior Fusion

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Abstract: The purpose of this study is to investigate the differences in joint movement of the lower extremity (LE), postural mobility and paravertebral muscle activity between patients who have undergone posterior fusion procedures for progressive idiopathic scoliosis and healthy volunteers. Kinematics of the LE and trunk were analyzed using an Electromagnetic Tracking System (Polhemus Inc., Colchester, VT) during level walking, and muscular activity measured during stationary flexion, extension, and lateral bending using surface EMG (Noraxon, Scottsdale, AZ). The study included 6 patients who had undergone posterior spinal fusion with instrumentation ranging from T1 to L3, and 10 healthy volunteers without spinal asymmetry. Mean age of patients was 13.6 years at surgery and 15.9 years at follow-up. Standard t-test was used to determine significance ($p<0.05$). There was a trend towards increased gait velocity and increased cadence in fused patients. Torso displacement in the sagittal plane was increased whereas truncal rotation was decreased post-fusion as compared to normal subjects. Significant reduction in pelvic tilt, as well as hip and knee ROM in both stance and swing phase were measured post-fusion ($P<0.05$). Dramatic reductions of the area, mean, and peak values of each EMG phase (flexion and relaxation) were seen in trapezius, latissimus dorsi, and multifidus activity during forward flexion, extension, and lateral bending in post-operative patients ($P<0.05$). Overall, patients who have undergone posterior spinal fusion for idiopathic scoliosis demonstrate altered gait patterns as well as diminished paraspinal muscular recruitment during spinal motions.

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Three-dimensional MRI analysis of the skull morphometry in adolescent idiopathic scoliosis girls: A pilot study

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Abstract: The parietal bone contour was more prominent while occipital bone contour was significantly smaller in adolescent idiopathic scoliosis (AIS) subjects. AIS also had shorter hypophyseal fossa and longer clivus in the basicranium when compared with normal controls. These observations can be accounted by a mismatch between membranous (calvarium) and endochondral (basicranium) ossification, which affecting the skull and vertebral column as a systemic process of abnormal skeletal growth in AIS. Abnormal skeletal growth in Adolescent Idiopathic Scoliosis (AIS) girls is observed in the vertebral column with a mismatch between endochondral and membranous ossifications. This study sought to investigate whether an abnormal growth pattern also affecting the skull resulting in morphological differences in the calvarium and basicranium between AIS girls and normal controls. The analysis was based on high resolution magnetic resonance imaging (MRI) and computer-assisted morphometric analysis. MRI images of the whole skull were obtained from 28 AIS girls (age 12-18, Cobbs angle >40 degrees) and 18 matched healthy controls. First, the shape of the calvarium (formed by membranous ossification) was assessed by computer-assisted 3D morphometric analysis with shape description. The configuration of basicranium (formed by endochondral ossification and without clear boundary on 3D image) was assessed on the best mid-sagittal image with both linear and angular measurements of the pre-defined anatomical points on the skull base. For the calvarium, the occipital contour was significantly smaller while the left parietal contour was more prominent in AIS subjects (Recursive feature elimination for support vector machine, SVM_RFE). For the basicranium, the length of hypophyseal fossa housing the pituitary gland was significantly shorter in AIS girls ($p<0.05$) and the length of clivus including the basioccipital synchondrosis was significantly longer in AIS girls ($p<0.05$). The present study suggests that abnormal skeletal growth is a systemic process in AIS, affecting not only their vertebral columns but also their skulls. These could be accounted by a mismatch between membranous (circumferential growth of vertebral column and calvarium) and endochondral (longitudinal growth of vertebral column and basicranium) ossification. The clinical significance of morphometric changes of the calvarium and basicranium is closely related to whether corresponding changes are present in the underlying cerebral structures.

Keywords: Adolescent idiopathic scoliosis, Magnetic resonance Imaging. Calvarium, Basicranium

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Enhancement of Low Intensity Pulsed Ultrasound on Spinal Fusion augmented with Stem cell-Bioceramic Composite

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Abstract: Low intensity pulsed ultrasound (LIPUS) was reported to enhance autograft implanted spinal fusion in rabbit model but none reported its effect on bioengineered stem cell-bioceramics composite as bone substitute. Bone marrow was aspirated from proximal femur of 15 week old New Zealand white rabbits. The mesenchymal stem cells (MSC) were then isolated and expanded in number with DMEM/osteogenic supplements/basic fibroblast growth factor. The MSC were impregnated on beta-tricalcium phosphate block (TCP). The bioengineered composite was implanted on L5 and L6 transverse processes of the same animal in posterior spinal fusion with decortication. LIPUS was applied for 20min daily on the back of rabbit for 7 weeks (LIPUS group, n=6). The untreated animals acted as control group (n=6). The spinal segments were harvested at week 7 and assessed by manual palpation, microCT assessment. The volume of transverse processes was measured by peripheral quantitative computed tomography (pQCT). By manual palpation, 67% of spinal segment in LIPUS group was found to be rigid but 0% in control group. The 3D microCT image of LIUPS group also showed inter-transverse process bony fusion beneath the TCP block whereas was not observed in the control group. In the pQCT result, the volume of transverse processes in LIPUS group was 28.2% greater than the control group. Non-invasive low intensity pulsed ultrasound enhanced tissue engineered stem cell-bioceramics implanted posterior spinal fusion. It will reduce the morbidity due to autograft harvesting.

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A New System for Classifying Torso Deformities in Scoliosis using Localized Shape Indices

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Abstract: Accurate classification of the severity and type of torso deformity is useful for the clinical management of scoliosis. Existing methods of classification are based on landmarks, statistics and machine learning. Landmark identification is difficult and prone to error. Statistics and machine learning often yield generic global classifications of severity such as *mild*, *moderate* and *severe*. This paper presents a new localized classification system for torso deformities in scoliosis comprised of a deformity type and a severity score. The system is based on local shape indices obtained from mathematical models called structured splines models. Structured splines models capture shape components in the coronal, axial and lateral planes. By dividing each torso into apical, thoracic and lumbar vertebra regions and considering the shape components in each of the three planes, we arrive at 32 deformity classes. Experiments on 20 images of 2 volunteers show that the system is robust to variations due to posture and positioning. Results of the analysis of 43 full-torso and 203 back-torso images of 65 scoliosis patients show that most scoliosis torsos occupy only 18 of the 32 classes. Experiments also show that the type of torso deformity strongly correlates to Lenke's spinal deformity classification for thin patients but not for plump patients. The severity of torso deformity strongly correlates to the severity of spinal deformity (Cobb angle) for thin patients. The severity of torso deformity strongly correlates to clinicians' score of deformity but not to clinicians' score of patient clinical history.

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A novel visualization scheme for monitoring and tracking of torso deformities in scoliosis

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Abstract: The clinical application of torso deformity to scoliosis management depends on reliable monitoring and tracking of torso shape as well as convenient display of the information obtained. Most existing methods classify torso deformity either by severity or type. This usually results in a single-valued deformation score or a classification into a few discrete clusters such as mild, moderate, severe. With the advent of more complicated characterization of scoliosis by severity and type as well by regional deformation variation, there is a need for torso deformity visualizations schemes that can present the complex information obtained in an easy to understand form. This paper presents a new visualization scheme for monitoring and tracking torso deformities. The basic element of the scheme, the status map, represents information about the overall severity and class of the deformity, as well as the deformation variations in different regions of the torso. By combining simplified versions of status maps from multiple clinical visits, we obtain the status chart. An inspection of this chart summarizes the overall clinical history (vis-à-vis torso deformity) for any one patient. Both back surface images and full torso images can be represented using this visualization scheme. To demonstrate the application of the scheme to scoliosis management, we applied it to full torso and back shape images obtained retrospectively from 20 scoliosis patients. Each patient had information from at least five consecutive clinical visits. Aside from the improvements in presentation obtained by the use of the scheme deformity patterns over time and the effect of clinical intervention can clearly be observed. We plan to extend the method to incorporate other clinical data in the future.

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Analysis of trunk external asymmetry in side-bending

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Abstract: The value of side bending test is important in the assessment of curve mobility and planning of scoliosis surgery. Our hypothesis is that side-bending test could also assess the reducibility of external asymmetry in the prediction of surgical outcome. However, the current method for analyzing trunk surface topography, based on horizontal cross-sections, is not suitable to side-bending. The purpose of this study was to develop a novel method to analyze the changes in external asymmetry in side-bending. The novel method consists in extracting the back valley curve, then defining cutting planes that are normal to the curve. The intersection between each cutting plane and the trunk surface defines a cross-section to be analyzed. Indices of external trunk asymmetry, such as the rotation of the tangent lines to the back and the rotation of the major axis of the cross-sections, are computed. When visiting the scoliosis clinic for their preoperative evaluation, patients had their 3D trunk surface geometry digitized with a multi-head Inspeck system in standing posture and in maximum voluntary right and left side-bending. For each patient, the surface reconstructions for the 3 acquisitions were analyzed with the proposed method. The standing geometry was also analyzed with the horizontal cross-section method. The resulting curves and indices were coherent with the observed deformations and changes between standing and side-bending. Comparison between the novel approach and the horizontal cross-section-based approach, for standing posture, indicated that the novel one tended to be more representative of the perceived asymmetry.

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Sagittal Spino-Pelvic Alignment in Lumbosacral Spondylolisthesis

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Abstract: In normal subjects, sagittal spino-pelvic alignment is such that the shape and orientation of each successive anatomical segment are closely related and influence the adjacent segments. However, the sagittal spino-pelvic alignment in developmental spondylolisthesis is still unclear. The purpose of this study is to evaluate the sagittal spino-pelvic alignment in spondylolisthesis and to compare it with normal subjects. Radiographs of 120 normal subjects and 131 subjects with developmental spondylolisthesis (91 low-grade, 40 high-grade) were reviewed. Subjects with high-grade spondylolisthesis were divided according to their sacro-pelvic balance: balanced vs. unbalanced sacro-pelvis. Parameters of the sacro-pelvis, lumbosacral region, lumbar spine, thoracic spine, and global balance were assessed. Parameters were compared between all groups and a correlation study was performed between all parameters. Significant differences in all parameters are found between the different groups, except for global spino-pelvic balance. The pattern and strength of correlations is similar between normal and low-grade subjects, showing interdependence between adjacent anatomical segments. The pattern of relationships was altered in high-grade spondylolisthesis, especially for subjects with unbalanced sacro-pelvis. A relatively normal spino-pelvic alignment is maintained in low-grade spondylolisthesis and in high-grade spondylolisthesis with balanced sacro-pelvis. Spino-pelvic alignment is abnormal in high-grade spondylolisthesis associated with unbalanced sacro-pelvis. The results of this study suggest that surgical reduction of the local lumbosacral deformity might be attempted to restore a normal spino-pelvic alignment in high-grade spondylolisthesis associated with unbalanced sacro-pelvis.

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Cerebrospinal Fluid (CSF) Flow Dynamics at the Craniocervical Junction in Adolescent Idiopathic Scoliosis: Morphological and Functional Study with Phase contrast Magnetic Resonance Imaging

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Abstract: Previous studies have documented obstructed CSF flow in patients with Chiari I malformation. Low-lying cerebellar tonsils and syringomyelia are also observed in AIS patients. We sought to investigate whether disturbed CSF flow is also evident in AIS subjects at the foramen magnum level and its relationship with level of cerebellar tonsils and dimensions of foramen magnum. Phase-contrast and conventional MR were performed in 105 adolescent girls, which include 69 AIS subjects (Cobbs angle 20-80, 40 had thoracic curve, 27 lumbar curve, 2 thoracolumbar curve) and 36 age-matched controls. Measurements of peak velocity of CSF flow in both the anterior and posterior subarachnoid space through foramen magnum, cerebellar tonsillar level related to the basion-opsithion (BO) line, anteroposterior (AP), transverse (TS) diameter and area of foramen magnum were obtained. Correlations were made among different parameters and SSEP findings. Peak CSF velocities through foramen magnum showed no significant difference ($p>0.05$) between AIS and normal subjects though 42% subjects in AIS group had the cerebellar tonsillar tip positioned 1mm below the BO line. The cerebellar tonsillar level in AIS subjects was significantly lower than the median tonsillar level in normal controls ($p<0.01$) while the AP diameter and area of foramen magnum were significantly larger in AIS subjects when compared with normal controls ($p<0.05$). Peak CSF velocities through foramen magnum were not significantly different in AIS subjects despite the presence of low-lying cerebellar tonsils. This might be explained by the compensatory effect of larger foramen magnum in AIS subjects.

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Is There any Regional Difference of Brain Tissue Densities Between Adolescent Idiopathic Scoliosis (AIS) Patients and Normal Controls: a Morphometric Study with High Resolution MR Brain Imaging

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Abstract: Observation of sub-clinical neurological abnormalities has led to proposal of neuro-developmental etiologic model for AIS. Longer latency in somatosensory –evoked potential (SSEP) and impaired balance control have been demonstrated in AIS subjects. In this study, we investigated whether regional brain tissue densities in AIS patients differ from matched control subjects. Nine left thoracic AIS girls (mean Cobbs angle 19°) and 11 matched controls; 20 right thoracic AIS girls (mean Cobbs 33.8°) and 17 matched controls underwent MR imaging of the brain. Fully automatic morphometric analysis was used to analyse the MR images; it included linear registration to a template brain and brain-tissue classification into grey matter (GM), white matter (WM) and cerebrospinal fluid (CSF). Tissue densities were compared between AIS subjects and controls. There was no significant difference between AIS subjects and normal controls when comparing absolute and relative (i.e. brain-size adjusted) volumes of grey and white matter. Using voxel-based morphometry, significant group differences (Controls > left AIS) were found in density of WM, in genu of corpus callosum, left internal capsule (anterior arm) and WM underlying orbitofrontal cortex of the left hemisphere. The above difference was not observed in right AIS group. Corpus callosum, major commissural fiber responsible for controlling the balance of right and left side of the body, was different in atypical left scoliosis while significant regional brain changes have not yet found in those with typical right thoracic scoliosis. Further investigation is warranted to see whether the above discrepancy is related to laterality of the scoliotic curve.

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A significant number of patients with AIS exhibit transverse plane pelvis deformation

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Abstract: Normal pelvis is generally considered symmetric with respect to the sagittal plane. Although a scoliotic spine exhibits curve asymmetry in the coronal plane it is yet to be established whether it is also accompanied by pelvic deformity. Radiographic measurements in the coronal plane are not always aligned. It is therefore difficult to gauge if the apparent pelvic rotation is due to global rotation in the radiographic plane or a true pelvic deformation attributed to the scoliotic deformity. Our objective was therefore to examine pelvic deformity in the transverse plane after eliminating any orientation misalignment due to global rotation in the radiographic plane. 43 AIS patients (26 Lenke-1, 7 Lenke-5), and 29 normal controls, reviewed by the 3D Classification Committee of the SRS, were evaluated using 3D reconstructions of coronal and lateral standing radiographs. This allowed computing 3 vertical axes passing through the center of the pubis (CPVA), the middle of the femoral head axis (CHVA) and the central sacral vertical line (CSVL). Their coplanarity was analyzed with and without mathematically realigning the femoral heads in the coronal plane. If the 3 axes were inside a corridor of ± 2 mm before and after realigning the femoral heads, the pelvis was considered as being 'normal' and symmetric. The pelvis was considered as deformed if the 3 axes were outside the ± 2 mm limits (before and after realigning the femoral heads in the coronal plane). 35% of Lenke-1 patients had a deformed pelvis while it reaches 47% for Lenke-5 cases. Only two Lenke-1 patients were globally rotated with respect to the radiographic plane. No pelvis deformity was observed in 86% of the control group. Deformation of the pelvis is frequent, even in thoracic scoliosis. Asymmetry of the iliac wings in the transverse plane is a true deformity of the pelvis in AIS. The cause of this deformity and its link with the deformation of the scoliotic spine needs to be further investigated.

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Reducing radiation exposure for scoliosis

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Abstract: The efficiency of two digital x-ray systems was evaluated: the new EOS™ and the Fuji FCR 7501S. Postero-anterior and lateral images were acquired with both systems for 50 consecutive adolescent patients with scoliosis. Images were taken sequentially with the Fuji System while the EOS acquires the two views simultaneously using vertical scanning of the patient with collimated fan beams coupled with linear gazeous detectors. Optically Stimulated Luminescent dosimeters (OSL) from Landauer were strategically placed on the patient to measure skin dose during the whole CR examination. Then, the set of OSL was replaced for the EOS exam. The same kVp was used for both acquisitions and mAs were chosen to produce images with similar SNR. Image quality assessment was obtained using a questionnaire targeting anatomic landmarks based on the European Guidelines for Quality Criteria for Diagnostic Radiographic Images in Paediatrics, and was performed by two radiologists and two orthopaedic surgeons.
Average skin dose was reduced locally by factors varying from 2.9 to 9.2. The variability of dose reduction for different locations is due to specific beam geometries. However, higher dose reductions were found where irradiation is maximal. Regarding image quality, over 93% of the anatomical landmarks on EOS images were given scores equal to or better than their counterparts on Fuji images. In conclusion, the EOS system reduced radiation exposure by a factor of up to 9.2 while maintaining image quality and diagnostic capability. Reduction of ionizing radiation is a primary concern for patients with scoliosis to prevent long-term adverse events.

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Abnormal Proliferative Response of Chondrocytes to Melatonin in Girls with Adolescent Idiopathic Scoliosis

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Abstract: Melatonin deficiency has been postulated as one of the etiology of adolescent idiopathic scoliosis (AIS). Although the serum melatonin level showed no difference between AIS and control subjects, melatonin signal pathway dysfunction in osteoblast and lymphocyte have been observed in AIS. Moreover, melatonin receptor 2 (MT2) gene was associated with AIS. Previous reports indicated that AIS girls have abnormal skeletal growth which is related to abnormal endochondral development. The present study is to investigate the effect of melatonin on chondrocyte proliferation in girls with AIS and compare it to normal controls. Chondrocytes from 8 AIS and 6 controls were released by serial enzymatic digestion and culture in defined medium for two weeks. Melatonin receptor expression (MT1 and MT2) in chondrocyte were detected by immunocytochemistry. Sub-confluence chondrocytes were treated with different concentrations of melatonin for two days before the cell viability was carried out. Both MT1 and MT2 receptors were detected on the cell membrane of the chondrocytes in AIS and control. Inhibition effect of melatonin on chondrocyte proliferation was found in normal controls. Melatonin showed inhibition effect on chondrocyte proliferation in normal controls but not in AIS. Significant difference were found at high dosage level. The effect of non-responsiveness of the chondrocytes to MLT might have important effect on the bone growth and contribute to the etiopathogenesis of AIS. The lack of response could result from underlying dysfunction of MLT signaling pathway.

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Normal expression of melatonin receptors (MT1, MT2) in BMSCs from adolescent idiopathic scoliosis patients and its significance

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Abstract: A melatonin deficiency has been suggested being at the source of adolescent idiopathic scoliosis (AIS). However, the relevance of melatonin in the etiopathogenesis of that condition is controversial. There is evidence shows melatonin signaling dysfunction in osteoblast from adolescent idiopathic scoliosis patients. But no study investigates melatonin signaling pathway in BMSCs. To study melatonin receptors (MT1,MT2) expression and to explore its significance in BMSCs from AIS patients. Eighteen AIS patients and ten volunteers were included. From anterior superior iliac spine, the human bone marrow was obtained with anticoagulation by heparine. And the MSCs were isolated by density gradient centrifuge from the mononuclear cells, and then were cultivated and serial subcultivated in vitro. Expression intensity of melatonin receptors(MT1,MT2) of BMSCs from the two groups was detected by RT- PCR. Flow cytometry demonstrated that the expanded mononuclear cells expressed mesenchymal stem cell markers. There was no statistical difference of melatonin receptors expression in BMSCs between AIS group and the controls ($P>0.05$). Melatonin receptors expression in BMSCs from adolescent idiopathic scoliosis patients is normal, which provides foundation for further study of melatonin signaling pathway in BMSCs.

Keywords: Melatonin receptor, idiopathic scoliosis, mRNA, mesenchymal stem cell

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ELEVATED PLASMA FACTOR P IS INVOLVED IN IDIOPATHIC SCOLIOSIS ONSET AND CURVE PROGRESSION

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Abstract: The study of the molecular changes occurring in pinealectomized chickens revealed an increased production of Factor P in paraspinal muscles of scoliotic chickens. This prompted us to investigate the involvement of Factor P, a multifunctional cytokine, in AIS pathomechanism. A group of 159 consecutive patients with AIS were compared with 35 healthy control subjects without any family antecedent for scoliosis and 70 asymptomatic offspring, born from at least one scoliotic parent, and who are considered at risk of developing a scoliosis. Plasma Factor P and soluble Factor P receptor (sFPR) levels were measured by enzyme-linked immunosorbent assays. Mean plasma Factor P concentrations in patients with AIS were significantly higher (p-value <0.001) in patients with AIS having a Cobb's angle >45° (1152.55 ± 378.48 ng/mL) than AIS patients with a Cobb's angle <45° (749.77 ± 313.18 ng/mL) or in healthy controls (561.47 ± 150.77 ng/mL). Diagnostic sensitivity and specificity of Factor P for AIS was 84.4 percent and 90.6 percent respectively (cut-off value ≥ 800 ng/mL). Interestingly, 49.2% of asymptomatic children at risk had Factor P values higher than 800 ng/mL (mean value of 1019.61 ± 424.13 ng/mL) as opposed to only 8.6% for the controls indicating that elevated plasma Factor P levels precede AIS onset. There were no significant differences in mean plasma sFPR levels between all groups. Our clinical data suggest that elevated plasma Factor P concentration could be a useful marker for diagnosis of AIS and prognosis of curve progression.

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The Effect of Melatonin on Proliferation and Differentiation of Osteoblasts in Adolescent Idiopathic Scoliosis Vs Normal Control

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Abstract. Low BMD and dysfunction of melatonin signaling pathway has been suggested as the possible key link to the spinal deformity in AIS. Prior studies shown that melatonin can influence and regulate skeletal growth and bone formation in human and animal models. However, there is a relative lack of direct evidence on the role of melatonin on AIS at the cellular and molecular level. To investigate the effect of melatonin on AIS osteoblasts at the cellular level. *In vitro* assays were performed with osteoblasts isolated from 7 girls with severe AIS and 7 controls. These were treated with different concentration of melatonin (0, 10^{-11}, 10^{-9}, 10^{-7}, 10^{-5}M). Cell proliferation was tested by MTT assay. As for differentiation, cells were cultured overnight in osteogenic medium. Then, they were given different concentration of melatonin for 3 days, prior to measuring the ALP activity. Moreover, mineralization of the matrix was qualitatively determined by alizarin red S staining after 18 days of culture. There was significant differences between control and AIS at the melatonin concentration of 10^{-9} to 10^{-5} M ($p<0.05$). In control, melatonin could stimulate proliferation when compared with the basal ($p<0.05$). Likewise, melatonin could also enhanced differentiation, with incubation overnight in osteogenic medium ($p<0.05$). Likewise, mineralized matrix was formed. However, none of the AIS osteoblasts could show any of the changes at the same concentration of melatonin. For the first time, we demonstrated there is a relative difference between AIS and control toward melatonin, which may play an important role in the etiopathogenesis of AIS.

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A Randomized Controlled Trial on Treatment Outcome and Patient's Acceptance of the SpineCor Vs Rigid Bracing System for AIS Girls

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Abstract: SpineCor was a flexible brace for treating AIS. Coillard et al and Weiss et al studied SpineCor and reported different results. To better understand the role of SpineCor for AIS, we evaluated its effectiveness and patient's acceptance using rigid braces as controls. This was a prospective randomized controlled trial on skeletally immature AIS girls managed by a dedicated team according to a standardized protocol. The average follow up was 67 months. All subjects have reached skeletal maturity. Clinical and radiographic assessments were made every three months. Patient's acceptance were assessed with a visual-analog-scale on 16 items at the 3rd, 9th and 18th months. An increase of Cobb's angle > 5 degrees within brace was considered a failure. The mean age, mean Risser and mean initial Cobb's angle for the SpineCor (n=22) and rigid-brace (n=21) groups were 12.3 and 12.6, 0.55 and 0.24, 24.0 and 24.4 respectively. 2 SpineCor and 3 rigid-brace subjects defaulted follow up. There were 7 failures in the SpineCor and 1 failure in the rigid-brace group (p=0.022 with the Log Rank test). Apart from 3 out of the 16 items, patient's acceptance and satisfaction were similar between the two groups. SpineCor seemed to give a less favourable result for curve control when compared with the rigid brace. Patient's acceptance was similar between the two groups except for 3 of the 16 items. A larger study was required for defining the role of SpineCor in treating AIS.

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Is Full Torso Imaging for the Assessment of Torso Deformity in Scoliosis Worth its Cost?

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Abstract: The widespread use of torso images for scoliosis management (post radiography) was primarily inspired by a need to reduce the radiation burden associated with regular follow-up of scoliosis patients. Early systems acquired only images of the back. Some reasons for this were: 1) back imaging posed a lesser technical challenge given the complexity of acquiring and combining images of various parts of the torso to create a full torso scan; 2) back torso images were easier to obtain from self-conscious adolescent girls (who are the majority of scoliosis patients); 3) much of the torso deformity associated with scoliosis is focused on the back of the torso. Technological improvements have since enabled the development of reliable full torso imaging systems. However, as expected, these systems are more expensive and complex than their corresponding back torso imaging counterparts. Full torso imaging also often involves other trade-offs like allowing female patients to wear 'modesty garments' that distort the natural torso shape. In this paper, we determined the relative information gain obtained from full torso images vis-à-vis back torso images from images acquired from 43 scoliosis patients. This was achieved by computing the entropy, or information content, of lossless shape models of the front and back of the torso. Our results show that an investment in a full torso imaging system would generally lead to a 25% increase in the available amount of information. This increase could justify the higher cost and complexity associated with full torso imaging if full torso indices are used in the clinical management of the deformity.

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Importance of the immediate correction for the effectiveness of brace treatment in AIS

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Abstract: The importance of the immediate in-brace correction has been emphasized but was never biomechanically quantified and explained. The study purpose was to evaluate the relationship between immediate in-brace correction and the resulting torque applied at the apex of the curve. 1024 different brace designs were simulated on patient-specific biomechanical models of three scoliotic adolescents. Each spine was modeled either as flexible or stiff. Fourteen brace design parameters were analyzed. The immediate correction of the scoliotic deformities and the resulting corrective bending moment applied at the apical level were evaluated. The efficiency of the 1024 braces was very variable. The most important design parameters were the strap tension, the trochanter extension position and the sagittal profile of the brace. The immediate correction of the scoliotic curves and the bending moment were highly correlated (mean R2: 0.88). The correction required to counterbalance the gravitational bending moments depended on the curve flexibility and ranged between 20% and 60%. This study confirms the importance of immediate in-brace correction because of its capacity to cancel the gravitational bending moments and hence to counterbalance the growth deformation process. A stiff spine needs less immediate correction than a flexible spine to have a resulting counterbalanced torque. The model could help designing a more efficient brace and predict the required initial correction.

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