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Aspects of postural alignment and postural control relevant for the evaluation and the treatment of Idiopathic Scoliosis patients.

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Cette thèse intitulée:
Aspects of postural alignment and postural control relevant for the evaluation and the treatment of Idiopathic Scoliosis patients.

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Résumé

L'objectif général de cette thèse était d'identifier les paramètres liés à l'alignement postural et au contrôle postural qui aideront à l'évaluation et au traitement de la scoliose idiopathique (SI). Pour cela, deux types d'évaluation posturale ont été élaborés. La première approche correspond à un modèle postural d'alignement et implique l'évaluation de la position et de l'orientation des segments du corps dans l'espace. La seconde, est une évaluation du contrôle postural en mettant en application une technique d'estimation du centre de masse (CdeM) des patients atteints de la SI.

Une évaluation de la posture debout sur des sujets atteints de la SI et de sujets contrôles a indiqué que les positions angulaires et linéaires moyennes du bassin, du tronc et des épaules pourraient être représentées à l'aide d'une période d'acquisition d'une durée aussi courte qu'une seconde. Dans un groupe de patients atteints d'une SI, des caractéristiques uniques pour chaque type de SI ont été trouvées. Les caractéristiques posturales les plus évidentes servant à décrire la posture des patients atteints de scoliose thoracolombaire gauche (ThLG), thoracique droite (ThD) et thoracique droite lombaire gauche (ThDLG) sont respectivement les suivantes : l'inclinaison du bassin, le décalage latéral des épaules par rapport à la base du support, la rotation relative et le décalage latéral des épaules par rapport au bassin, la rotation relative de la ceinture scapulaire par rapport au bassin et la rotation et l'inclinaison des épaules par rapport à la ceinture scapulaire.

Avec l'utilisation d'un corset souple, posé de manière spécifique pour chaque type de courbure rachidienne, il y avait une diminution significative de l'amplitude de cette dernière pour chaque type de scoliose. De plus, il y avait un changement postural spécifique pour chaque type de courbure. Pour les patients avec une courbure ThD, ces changements comportent la rotation opposée des épaules par rapport à la ceinture scapulaire, accompagnée par un mouvement couplé d'une inclinaison des épaules et du décalage latéral de T1 par rapport à S1. Pour les patients ThLG, il y avait un changement de l'inclinaison relative des épaules, de la rotation des épaules et de la ceinture scapulaire par rapport au bassin. Les patients avec une courbure ThDLG ont eu un changement de rotation du bassin, une rotation et l'inclinaison des épaules par rapport au bassin, une rotation des épaules par rapport à la ceinture scapulaire et finalement, un décalage latéral de T1 par rapport à S1.

L'utilisation d'une nouvelle technique pour estimer la position et le déplacement du CdeM chez les patients atteints d'une SI, a permis d'identifier des différences significatives en comparaison avec le CdeM estimé par un modèle anthropométrique. L'utilisation de la technique basée sur les plates-formes de force a souligné des différences importantes au niveau du contrôle postural pour les patients atteints d'une SI. La racine carrée de la valeur moyenne du carré entre le centre de pression et le centre de masse (CdeP-CdeM) était plus grande chez les SI que chez les contrôles. Les deux groupes ont démontré une tendance à se comporter comme un pendule inversé, cependant, le mouvement angulaire relatif, reflète une stratégie posturale unique aux patients atteints d'une SI.

Mots-clés: Scoliose Idiopathique, Posture, Équilibre, Biomécanique, Développement, Adolescence

Abstract

The general objective of this thesis was to identify postural alignment and postural control parameters that will assist in the assessment, and treatment of Idiopathic Scoliosis (IS). This specifically involved applying two approaches for the postural assessment of IS. The first is a postural alignment model, and implicates assessing the position and orientation of the body segments in space. The second, is the evaluation of postural control through implementing a novel technique to estimate the Centre of mass (COM) in IS patients and control subjects.

An initial evaluation of the quiet standing posture of IS and control subjects revealed that the mean angular and linear position of the pelvis, trunk and shoulders over 120 second period could be represented by that obtained during a short trial acquisition period of 1 second. The postural alignment evaluation of IS patients revealed unique postural characteristics measured in reference to the base of support and relatively between body segments specific to each type of IS curvature. The postural parameters that were important for characterizing right thoracic (RTh), left thoracolumbar (LThL), and right thoracic left lumbar (RThLL) curvatures included the tilt of the pelvis and lateral shift of the shoulders in reference to the base of support, relative rotation, tilt and lateral shift of the shoulders in reference to the pelvis, relative rotation of the shoulder blades in reference to the pelvis, and rotation and tilt of the shoulders in reference to the shoulder blades.

With the use of a non-rigid brace specific for each type of spinal curvature, there was a significant decrease in the amplitude of spinal curvature accompanied by a change in the postural parameters. For the RTh patients these changes involved the opposite rotation of the shoulder girdle in reference to the shoulder blades accompanied by a coupled movement of shoulder tilt and lateral shift of T1 in reference to S1. For the LThL patients there was a change in the relative tilt of the

shoulders, rotation of the shoulders and shoulder blades in reference to the pelvis. The RThLL patients had a change in the rotation of the pelvis, tilt of the shoulders, rotation and tilt of the shoulders in relation to the pelvis, rotation of the shoulders in reference to the scapula and lateral shift of T1 in reference to S1.

The application of a technique to estimate the position and displacement of the COM from a Force Plate, identified significant differences when compared with the COM estimated from an anthropometric model. Using this Force Plate based technique to evaluate the postural control of IS subjects, a greater root mean square of the COP-COM signal was found in comparison to control subjects. Both the IS and control subjects demonstrated a tendency to behave as an inverted pendulum, however, the significantly greater relative angular movement reflects a postural control strategy that is unique to IS patients.

Keywords: Idiopathic Scoliosis, Posture, Balance, Biomechanics, Development, Adolescence

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List of symbols and abbreviations

ANOVA	Analysis of Variance
A/P	Anterior-Posterior
ASIS	Anterior Superior Iliac Spine
AVG	Average
BMCMP	Brace Maintained Corrective Movement Principle
BOS	Base of Support
B	Brace
CI	Confidence Interval
cm	Centimeter
CMP	Corrective Movement Principle
Cobb	Angle of Cobb
COM	Centre of Mass
COM_{acc}	Centre of Mass Acceleration
COM_{gl}	Centre of Mass estimated from a force plate
COM_{anth}	Centre of Mass estimated from an anthropometric model
COP	Centre of Pressure
COP_r	Centre of Pressure of the Right Foot
COP_l	Centre of Pressure of the Left Foot
COP-COM	Centre of Mass – Centre of Pressure
CT	Computerized Tomography
D	Double
Fz_r	Vertical ground reaction force of the right foot
Fz_l	Vertical ground reaction force of the left foot
G	Group
GIBB	Gibbosity (Rib Hump)
Hz	Hertz
ICC	Intra Class Correlation

ILIO	Iliac Bone
IS	Idiopathic Scoliosis
kg	Kilogram
L	Lumbar
m	Meters
m	Mass
MRI	Magnetic Resonance Imaging
M/L	Medial-Lateral
mm	Millimetre
P/A	Posterior-Anterior
PEL	Pelvis
PSIS	Posterior Superior Iliac Spine
r	Correlation coefficient
REL	Relative
SD	Standard Deviation
SHLD	Shoulders
$\mathbf{SHLD_{BOS}}$	Shoulders in reference to the base of support
$\mathbf{SHLD_{PEL}}$	Shoulders in reference to the pelvis
$\mathbf{SHLD_{SHLDB}}$	Shoulders in reference to the shoulder blade
$\mathbf{SHLDB_{BOS}}$	Shoulder Blade in reference to the base of support
$\mathbf{SHLDB_{PEL}}$	Shoulder Blades in reference to the pelvis
S1	1^{st} Sacral spinous process
$\mathbf{S1_{BOS}}$	1^{st} Sacral spinous process in reference to the base of support
Th	Thoracic
ThL	Thoracolumbar
T	Time
T1	1^{St} Thoracic spinous process
$\mathbf{T1_{BOS}}$	1^{St} Thoracic spinous process in reference to the base of support
$\mathbf{T1_{S1}}$	1^{St} Thoracic spinous process in reference to the 1^{st} Sacral spinous process

°	Degree
2-D	Two Dimensional
3-D	Three Dimensional
RMS	Root Mean Square
RMSD	Root Mean Square amplitude Difference
ROD	Range of Difference
s	Seconds
RThLL	Right thoracic left lumbar
RTh	Right Thoracic
LTh	Left thoracic
LThL	Left thoracolumbar
RThL	Right thoracolumbar
LL	Left lumbar
RL	Right lumbar
x	Position

Dedications

To Francka and Alojzij

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Forward

The advent of new technologies in human movement science has provided the unique opportunity to improve the comprehension of disorders to the musculo-skeletal system. The challenge faced by rehabilitation experts, clinicians and researchers is to apply appropriate techniques that will improve the diagnosis, prognosis and treatment of these pathologies.

As a kinesiologist I have had the unique opportunity to develop an in depth understanding of the principles involved in the kinematic and kinetic analysis of human movement. The possibility to apply this knowledge within a multi-disciplinary setting studying Idiopathic Scoliosis motivated me to pursue my doctoral research at Sainte-Justine Hospital.

Introduction

Idiopathic scoliosis (IS) is recognized as a spinal pathology of unknown aetiology that affects approximately 1.2% of the population (Rogala et al., 1978; Stirling et al., 1996; Willner & Udén 1982). The greatest risk of progression of this pathology is found in young immature patients (Lonstein & Carlson 1984) during periods of growth and development (Little et al., 2000; Risser 1958) and is most notably marked by a complex rotation and deviation of the spinal column and thoracic cage (Stokes et al., 1987; Stokes et al., 1989). The presence of additional postural abnormalities (Manganiello 1987; Millis & Hall, 1979; Masso & Gorton, 2000), dysfunction to the proprioceptive (Cook et al., 1986; Keesen et al., 1992), vestibular (Jensen & Wilson 1979) vestibulo-spinal systems (Sahlstrand 1979), and postural equilibrium (Sahlstrand 1978; 1979; Lidstrom et al., 1988) have also been implicated in the characterization and aetiology of this pathology.

The quiet standing position has served to evaluate many aspects of IS, which includes postural alignment (De la Huerta et al., 1998; Denton et al., 1992; Le Blanc et al., 1996), postural sway (Lidstrom et al., 1988; Sahlstrand et al., 1978), and spinal deviation (Cobb 1948; Stokes et al., 1988). Although the amplitude of spinal deformation measured radiographically has served as the principal tool to diagnose and prescribe non-surgical treatment for IS patients, it provides little insight into the postural changes that accompany treatment, nor the mechanisms responsible for the correction or stabilisation of the spinal curvature. Recent development of postural evaluation techniques to evaluate postural control and postural alignment have demonstrated potential to improve the evaluation of IS patients. However, little emphasis has been placed on identifying the clinical utility of these models through characterizing the posture of IS patients and how this posture changes under treatment.

This thesis reviews the current techniques involved in the clinical evaluation and non-operative treatment of IS, as well as the pertinent concepts related to the evaluation of postural alignment and postural control of IS patients. The general scope and objectives of this thesis are outlined followed by manuscripts that address each objective individually. The principal result of each manuscript is then discussed in relation to pertinent literature as well as the strengths and limitations of the methodology utilised, and future research is outlined.

Chapter I: Idiopathic Scoliosis.

1.1 Natural history

Idiopathic scoliosis is recognized as a spinal pathology of unknown aetiology that evolves during periods of growth and development (Little et al., 2000; Risser 1958). The progression of this disease is marked by a complex rotation and deviation of the spinal column and thorax (Stokes et al., 1987; Stokes et al., 1989). Although, subtle postural asymmetries and deviations of the spinal column have been found to have a prevalence of 14-38% (Nissinen et al., 1989; Vercauteren et al., 1982) and 2.7 to 14% (Brooks et al., 1975, Kane 1977; Stirling et al., 1996), IS is not diagnosed until a lateral deviation of the spine exceeds 10°, and is accompanied by axial rotation (Kane, 1977). According to this definition, the prevalence of IS is 1-2% of the population (Rogala et al., 1978; Stirling et al., 1996; Willner & Udén 1982). The ratio of female to male is 1:1 for curves of 5-6°, however this ratio changes as the amplitude of curvature increases to 20° with a ratio of 5.4:1 (Rogala et al., 1978).

The risk of progression of spinal curvatures has been associated with the severity of the initial (Bunnell 1986; Lonsetin & Carlson 1984) type of curve (Bunnell 1986; Lonsetin & Carlson 1984), age (Bunnell 1986), menarche (Bunnell 1986; Lonstein & Carlson 1984; Peterson et al., 1995), skeletal maturity (Bunnell 1986; Lonstein & Carlson 1984; Peterson et al., 1995) and gender of the patient (Bunnell 1986; Peterson et al., 1995). The risk of progression was found to be greater when these factors were considered together (Lonstein & Carlson 1984). It was found that with a measure of the amplitude of spinal curvature between 20-29° referred to as Cobb angle (Cobb, 1948), and an indice of maturity of 0, 1referred to as Risser sign (Risser, 1958), or an age of 12 years, the risk of progression is 68% and 61% respectively. Whereas a more mature patient with a Risser sign of 2, 3 or 4, or an age of 15 years, the risk of progression decreased considerably and was estimated to be 1.6% and 4% respectively.

Although the greatest degree of curve progression may occur during periods of rapid growth, the spinal curve has also been found to progress after skeletal maturity. The progression 15 years after skeletal maturity was reported by Ascani et al., (1986) to be as high as 20° for curves larger than 40°, and 10° for curves less than 20°. In a retrospective study of patients evaluated between 1932 and 1948, Weinstein et al., (1981) reported at 20 – 30 years follow-up, an average progression of spinal curvature of greater than 5° for 44% of the IS patients. The largest amplitude of progression has been found in patients with right thoracic curvatures between 50 and 80° who progressed an average 11°, and the lumbar component of Double curves between 50 and 74° who progressed 7°.

IS patients have been reported to experience back-pain (17-73 %) (Joncas et al, 1996; Mayo et al., 1994; Ramirez 1997; Weinstein et al., 1981; Weinstein et al., 2003), shortness of breath or dyspnoea (22- 29%) (Ascani et al., 1986; Weinstein et al., 1981), psychological disorders (19%) (Ascani et al., 1986) and have visible postural deformities (Weinstein et al., 1981). The postural deformities were found to be present in IS patients for 72% of the thoracic curves between 20° and 156° (average 92.4°), 71% of the Double curves between 30° and 109° (upper curve average of 67.3°), 25° and 103° (lower curve average of 61.2°), 58% of the thoracolumbar curves between 45° and 145° (average 72°) and 46% of the lumbar curves between 16° and 78° (average 36.4°). A survival analysis of IS patients evaluated between 1927-1937 revealed an increased cumulative number of observed deaths between 40 and 80 years (Pehrsson et al., 1992). A positive correlation between time of onset and death also suggests that the earlier IS appears, the greater risk of severe dyspnea (Branthwaite 1986) and mortality (Branthwaite, 1986; Pehrsson et al., 1992).

Clinical evaluation.

The evaluation of IS patients involves obtaining appropriate information that will assist the clinician in assessing the severity of spinal deformity, its risk of progression and determining the optimal treatment approach. The subjective observation of the patient focuses on identifying structural postural abnormalities that may include limb length discrepancy, scapular asymmetry and lateral trunk shift of the C7 or T1 spinous process in reference to the sacral base. For the most part these observations have been subjective, with the exception of trunk shift that is quantified by using a plumb line and ruler, and trunk deformation estimated in the forward bending position with a scoliometer or similar device.

The radiological evaluation of the patient serves as the principal tool to identify a number of parameters that will assist the clinician in making clinical decisions. A frontal plane and lateral plane radiograph of the trunk and pelvis is essential to estimate the necessary spinal parameters. The severity of spinal curvature may be measured using the technique described by Cobb and often referred to as the angle of Cobb (Cobb, 1948). This angle is the angle between two-end vertebras that define the limits of a spinal curve (Stokes 1994). There are two-end vertebrae, one superior and one inferior. The superior vertebra is defined as the vertebra with a superior surface that is maximally angled towards the concave aspect of the curve. The inferior vertebra is defined as the vertebra with an inferior surface that is maximally angled towards the concave aspect of the curve (Stokes 1994). The inter-rater correlation coefficient of the Cobb angle detection has been reported to be 0.98, reflecting a strong reliability (Goldberg et al., 1988). The average between evaluator measurement error has ranged from 2° to 5° (Dutton et al., 1989; Carman et al., 1990; Goldberg et al., 1988). However, Carman et al., (1990) suggested that the 95 % confidence interval for between evaluator agreement was 8° for frontal plane measures, and 7° for sagittal plane measurements. Using tolerance limits, it was suggested that the clinically detectable change was 10°, and 11° for the frontal and sagittal planes respectively (Carman et al., 1990).

Additional radiological measurements include the Risser sign, and the degree of vertebral rotation. The Risser sign was originally identified on an Anterior-Posterior radiograph and is an index of maturity rated on a scale of 0-5. This index refers to the amount of ossification of the iliac epiphyses that is closely synchronized with the development of the vertebral growth plates (Risser 1958). This process of ossification may take 2-3 years, with completion averaging around 14 years for girls, and 16 years for boys. The estimation of the amplitude of vertebral rotation has been performed using a variety of techniques (Ho et al., 1993; Perdriolle & Vidal 1985). The most common is the technique developed by Perdirolle & Vidal (1985) that utilises the Torsion meter. When placed on a Posterior-Anterior radiograph this meter utilises the outer edges of the vertebra, and the longitudinal axis of the pedicles to measure vertebral rotation (Perdriolle & Vidal 1985).

Classification of the scoliosis curves is performed through the identification of the location and the side of the apical vertebra. A thoracic curve is defined by an apex situated between T2 and T11-T12 disc, a thoracolumbar curve has an apex situated between T12 and L1, or T12-L1 disc, and a lumbar curve is between L1-L2 disc and L4-L5 disc.

1.3 Treatment.

The treatment of IS has focused on altering the natural history of spinal deformity progression. Historically, axial traction and/or lateral forces were applied to the patient, achieved through a range of table/tree pulley devices that date back to Hippocrates (Kumar 1996). The basic principles of these techniques may be found in modern day bracing techniques where active and passive axial traction and/or the three point pressure principle is applied through an external brace or exoskeleton.

The first modern day rigid brace was developed for post-surgical neuromuscular scoliosis in 1945 (Blount et al., 1958). Although the material that is used has evolved, the basic components of this brace are still in use today. This includes a pelvic girdle, one anterior aluminium and two posterior stainless steel columns that run the length of the trunk, a neck ring with throat mould and two posterior occipital pads. A refinement of the Milwaukee Brace was made by Hall et al., (1975). For this modified brace, the exoskeleton was removed and replaced by a polypropylene shell, with polyethylene foam lining. With this concept, the principle of axial traction was replaced by the notion that the three-point pressure principle is effective in reducing the spinal curvature. Additional rigid bracing techniques made of thermo-plastics that rely on similar principles include the Wilmington brace (Bunnell et al., 1980) and Charlston brace (Price et al., 1990). In general these braces are prescribed for curves of 30°-40° if growth still remains, and for curves 20° - 29° if there is proven progression and there is still substantial growth potential. With the exception of the Charlston brace which is worn at night, the braces are worn for 22-24 hours per day, from the brace fitting until the patient reaches skeletal maturity, growth has terminated and 2-18 months post – menarche for females.

Other non-bracing techniques included surface (Axelgaard et al., 1983) or indwelling electrical muscle stimulation (Bobechko et al., 1979). The implantable electrodes were placed above and below, and laterally to the apex of the spinal curvature in the longissimus muscle (Bobechko et al., 1979). The muscle stimulation was performed at night with 10.5 second stimulation cycles (1.5 second stimulation, 9 second relaxation). The surface stimulation technique utilised surface electrodes placed on the convex side of the curvature at the level of the apical vertebra, 5 cm electrode disks were utilised to stimulate the muscle over a 6 second period with 6 seconds relaxation (Axelgaard & Brown 1983).

The effectiveness of therapeutic approaches in changing the natural history of IS has been the focus of both prospective and retrospective studies. The principal

Cobb angle has served as the principal measurement for evaluating treatment outcome. Nachemson & Peterson (1995), followed 129 patients by observation only, 111 braced patients and 46 patients treated with surface electrical stimulation within the context of a multi-centre study during a 4-year period. The participants of the study were girls diagnosed with IS, with a skeletal age between 10 and 15, with a Cobb angle between 25-35° for a single curve between T8 and L1. A failure in the treatment method was defined as an increase in the spinal curvature of greater than 6°. A survival analysis performed by Nachemson & Peterson (1995) on these patients found a successful treatment rate of 74% for patients treated with a brace, 34% for the observation patients and 33% for the patients treated with surface electrical stimulation. Although this was a prospective study, the main limitation is that each centre treated patients with one approach, so there was no randomization between groups.

A comparison between bracing techniques, observation and electrical surface stimulation was made in a Meta-Analysis of treatment efficacy by Rowe et al., (1997). This study reported a weighted mean proportion of success of 0.60, 0.62, and 0.93 for bracing 8, 16, and 24 hours a day respectively, and 0.49 for observation, and 0.39 for lateral electrical surface stimulation. However, this meta-analysis included the prospective study by Nachemson & Peterson (1995), serving as the only source of data for the observation group, and was based on a number of studies that are retrospective in nature. Retrospective studies have the advantage of surveying a large number of patients, over an extended time period. They have compared control untreated to treated patients (Miller et al., 1984), compared bracing techniques (Montgomery & Willner 1989), and long-term follow-up of patients (Carr et al., 1980; Lonstein & Winter 1994; Noonan et al., 1996). These studies have reported an overall average stabilization of the curve of 1-4° for the Milwaukee brace (Carr et al., 1980; Lonstein & Winter 1994; Noonan et al., 1996); with an aggravation of the curve during follow-up (Noonan et al., 1996). Emans et al., (1986) reported on 295 patients treated with the Boston brace, with 49% of the patients stabilized (no change of greater than 5°) and 39% had a correction of 5-15°. The overall failure rate of both bracing techniques has been reported to range from 11% (Emans et al., 1986), to 22% for the Milwaukee brace (Lonstein & Winter 1994). These studies have also highlighted some important prognostic factors related to successful outcome with brace treatment. Olafsson et al., (1995) identified that a 7° correction of the curve in patients with an initial in brace correction of greater than 50%. Poorer initial correction was associated with a poor post-treatment outcome. However, interpretation of the results of retrospective studies must be made with caution. Limitations exist in controlling the technique in which the brace was applied, the selection criteria used for including the patients in the studies, as well as the available information and how it was recorded.

Apart from assessing a change in the amplitude of spinal curvature using the Cobb angle, vertebral rotation is the second most common radiological measurement utilised to assess the effect of treatment with a bracing system. Using a 3D reconstruction technique of the spine, Labelle et al., (1996) noted that there was no change in vertebral rotation of IS patients evaluated prior to and 1 month after being fitted with the Boston brace. There was also no change found in vertebral rotation between the initiation of treatment with a rigid brace and during follow-up (Emans et al., 1986; Olafsson et al., 1995; Willers et al., 1993). However, a decrease in the amplitude of the Cobb angle as well as vertebral rotation in brace has been associated with a positive outcome (Olafsson et al., 1995). A negative outcome has been found for 93% of the patients who had an increase in brace Cobb angle and for 63% who had no change in Cobb angle or vertebral rotation (Olafsson et al., 1995).

The presence of a rib hump has been positively correlated to the amplitude of spinal deformation (Stokes et al., 1987; Stokes et al., 1988), however very few studies have evaluated if treatment with a brace will change this aspect of IS. An immediate effect on rib hump when wearing the Boston brace was not found (Labelle et al., 1996). However, a decrease in rib hump was found out of brace in patients followed up for an average period of 3.8 years (Theologis et al., 1993), and a decrease in trunk decompensation 4 years after the initiation of treatment (Korovessis et al., 2000).

Although the utilization of a rigid brace has become an accepted means of treating IS, there are some shortcomings and negative effects of this treatment approach. When a rigid brace is applied it has been found to constrain respiratory functions, such as decreasing vital capacity, functional residual capacity and total lung capacity (Kennedy et al., 1989), and also changing respiration dynamics with an increase in upper rib cage movement, and a decrease in abdominal wall and lower rib cage movement (Kennedy et al., 1989). Although, during long – term follow-up IS patients treated with a brace have been found to have similar to normal back pain and function during daily activities (Danielsson & Nachemson 2003). The treatment with a rigid brace has been found to affect the psychological health of the patient as seen through a lower self-esteem and greater depression (Freidel et al., 2002).

Recently a non-rigid brace was developed at Sainte-Justine hospital to address the limitations imposed by rigid bracing systems. This brace consists of a pelvic base and bolero that serves as an anchor for elastic bands that are fitted on the patient (Coillard et al., 1999; Coillard et al., 2003). The brace was designed to treat patients with a spinal curvature greater than 30° who are still growing, and for patients with curvatures under 30° who are not mature, have documented progression, and significant growth potential remaining. A survival analysis of the first patients treated consecutively with the non-rigid brace SpineCor found a probability of success of 0.92 and 0.88 for a combined treatment and follow-up period of 4 years for spinal curves less than 30° and greater than 30° respectively (Coillard et al., 2003). Evaluation with a scoliometer, has identified a significant decrease in thoracic and thoracolumbar rib humps for patients fitted with the non-rigid brace (Griffet et al., 2000). However, no studies have been performed to understand what the mechanisms and principles of curve correction are, and what are the postural changes that occur with the application of the brace.

Chapter II: Posture.

2.1 Principles of postural evaluations.

The evaluation of posture plays a fundamental role in assisting researchers to understand the function and dysfunction of the neuro-musculo-skeletal system, and assists clinicians in obtaining pertinent information to diagnose and treat neuro-muscular related pathologies. Posture is referred to as the general position of the body and its segments in relation to each other and to a vertical axis that is defined by gravity (Winter 1995). The basic elements that define an individuals posture include skeletal morphology and the active/passive properties of muscles. The control of the body segments for the purpose of stability and orientation is defined as postural control (Shumway-Cook & Woollacott 2000). This process involves relating somatosensory information to the CNS so that appropriate reflexes, postural synergies or planned movement strategies may be performed.

The common objectives of postural evaluations are to: 1) comprehend the normal neuromuscular control of posture inclusive of changes that occur with growth, maturation and degeneration with ageing; 2) identify changes that occur with specific pathologies, and define these changes as either adaptations or contributors to the pathogenesis of the pathology; 3) to provide the clinician with a non-invasive evaluative tool to assess a pathology and follow changes associated with treatment and pathology progression. However, the emphasis placed on evaluating specific aspects of posture and postural control has varied greatly between pathological populations and between the healthy young and elderly. The predominant structural aspect of IS has solicited considerable research into quantifying the position, orientation and deformation of skeletal structures. This has been pursued through medical imaging techniques using 2-D, or 3D radiography, computed tomography (CT) or magnetic resonance imaging (MRI). Non-invasive approaches focus on evaluating specific aspects of the underlying skeletal structures through visible surface anatomical landmarks. These techniques include surface imaging techniques such as Moiré Topography, raster-stereophotography, video-stereography, torso scans and landmark digitisation using an electrogoniometer, electromagnetic fields and ultrasound.

The mechanisms responsible for the maintenance of postural control have been evaluated in a quiet standing position, altered sensory conditions and expected and unexpected perturbations applied to the body. These approaches are based on a non-invasive assessment of the external forces on the body measured with a Force Platform, the kinematics of body movement, measured with a 2-D or 3-D opto-electronic system or the measurement of muscle activation obtained through electromyography.

2.2 Postural alignment.

There have been a number of techniques developed to quantify the postural alignment characteristics of IS patients. The objective of these techniques has been two fold; firstly to identify patients with IS so that they may be referred for closer follow-up and secondly to provide sufficiently accurate information to assess the amplitude of spinal curvature and changes that may occur during natural evolution and treatment.

The relationship of back surface rotation, vertebral rotation and vertebral lateral deviation was investigated by Stokes et al., (1988). A strong positive relationship was found between back surface rotation with vertebral deviation (r=0.79), and a moderate relationship between back surface rotation with vertebral rotation (r=0.70). The overall ratio between back surface rotation and vertebral rotation was found to be 0.55 (Stokes et al., 1988), and with surface rotation and Cobb angle it was found to be 0.49 (Stokes et al., 1988).

The amplitude of the relationship of the back surface and spinal deviation has varied according to the type of instrument used, the region of spinal curvature, and the nature of the parameter calculated. An overall moderate to strong positive correlation has been found for rib hump asymmetry (Pearsall et al., 1992; Duval – Beaupère 1992; Stokes et al., 1987; Stokes et al., 1988; Weisz et al., 1988) and surface angle which is the angle between two spinous processes defining the limits of a spinal curvature (Dawson et al., 1993, Thometz et al., 2000). A significant but weak correlation has been found for additional parameters of spinal deformity (Inami et al., 1999).

However, regression equations have been developed which report a relatively strong relationship between the digitized spinous processes, torso scanning and Cobb angle. In an evaluation of the surface digitization of spinous processes by Letts et al., (1998), correlation with the Cobb angle was 0.90, with a standard error of 6.6°. In an evaluation of the surface scanner, Jaremko et al., (2001; 2002b,c) predicted the Cobb angle using rib hump, left-right differences in torso width and age with a correlation of 0.91, and standard error of 6.1°. Jaremko et al., (2002a) also applied a neural network model to estimate the amplitude of spinal deformity with a correlation of 0.93 and standard error of 6°.

Recently, the quantification of postural alignment of the pelvis, shoulders, and thorax has been proposed as potentially useful for the evaluation of IS (Dao et al., 1997; Le Blanc et al., 1996; De la Huerta et al., 1998; Nguyen et al., 1998; Zabjek et al., 1999). The basis of this approach is to calculate angular measurements of rotation (transverse plane), tilt (frontal plane), version (sagittal plane) and linear measures of anterior- posterior (A/P) and medial-lateral (M/L) shift for each body segment. The measurements are made in reference to the base of support as well as relative to the pelvis and shoulder blades. The two techniques that have been applied include a video based acquisition (Beaudoin et al., 1998; De la Huerta et al., 1998; Nguyen et al., 1998; Zabjek et al., 1999), and a landmark digitisation technique using magnetic fields (Dao et al., 1997; Le Blanc et al., 1996) and ultrasound (Zabjek et al., 1999). An evaluation of inter-session reliability between 2 repeat visits with the video-based system (2 week interval) by De la Huerta et al., (1998) found an Intra Class Correlation (ICC) for IS patients and control subjects to range from 0.83 to 0.88, for rotation/tilt of the pelvis and shoulders. The inter-session differences were 1.2-1.5° for rotation, and 0.3° - 1.1° for tilt, and 6.7 to 8.4 mm for A/P and M/L shift of the pelvis and shoulders (De la Huerta et al., 1998). The intra-observer reliability using a sequential digitisation technique also found angular differences for rotation and tilt between 0.1 to 1.8° (Dao et al., 1997).

These evaluation techniques were originally applied to compare the postural alignment between IS and control subjects (Le Blanc et al., 1996; De la Huerta et al., 1998). In an evaluation of patients with a Cobb angle of less than 20° by De la Huerta et al., (1998), a greater clock-wise rotation and left lateral shift of the pelvis in reference to the base of support, and a greater absolute rotation of the shoulders was found when compared to an age matched control group. In patients with a Cobb angle that ranged from 24 -47°, a greater shoulder tilt, rotation of the shoulders in reference to the shoulder blades, and shoulder blades in reference to the pelvis and laboratory reference system was found to be greater than the control subjects (Le Blanc et al., 1996). Although these studies do highlight postural alignment parameters other than rib hump as being different in IS patients than control subjects, they did not address the question if the differences are specific to the type of spinal curvature. Nguyen et al., (1998) compared left thoracolumbar IS patients with an average Cobb angle of 25°, with a group of age matched control subjects. The left thoracolumbar patients were found to have a counter-clockwise tilt of the pelvis and a left lateral shift of T1 and T1 in reference to S1 that was greater than the control subjects. A further evaluation of a combined group of left thoracolumbar, left lumbar, and right thoracic left lumbar patients found acute radiological and postural changes when a shoe lift was applied (Zabjek et al., 2001). The noted radiological changes included a decrease in frontal plane sacral tilt and Cobb angle (7°), accompanied by postural alignment changes that included a decrease in pelvic tilt and relative version (sagittal plane rotation) of the iliac bones, and relative tilt of the shoulders in reference to the pelvis (Zabjek et al., 2001).

These studies underline a potential benefit of applying these non-invasive evaluation techniques to assist in characterizing the postural alignment characteristics of IS patients, predicting the amplitude of spinal deformation, as well as evaluating the changes in posture that may accompany treatment. However, these techniques are based on obtaining a sample of a patients posture in a fraction of a second such as from a photograph (Denton et al., 1992; Stokes et al., 1987), extended scanning periods of 5 to 15 seconds (Dawson et al., 1993; Jaremko 2001), a 1 to 2 minute sequential landmark digitisation period (Leblanc et al., 1996; Zabjek et al., 1999), or a short 1 second duration sample (De la Huerta et al., 1998; Zabjek et al., 1999; 2001). The source of error attributed to the evaluation techniques has been natural sway of the body (Dao et al., 1997; Goldberg et al., 2001; Zabjek et al., 1999). A comparison of the A/P and M/L positions of body segments of a rigid mannequin with control subjects using a video-based system vs. a sequential digitisation technique found differences of 2 to 10 mm respectively (Zabjek et al., 1999). However, there has been no study performed to evaluate the segmental displacement of these body segments during quiet standing such that a sample duration may be justified, and a better understanding of the techniques limitations with regards to postural sway be obtained. Also, the estimation of the position and orientation of the individual body segments has only been applied to a limited sample of the IS population, with no emphasis placed on the type of spinal curvature, nor the changes that may occur with the most common form of treatment which is bracing.

2.3 Postural control.

The evaluation of postural control in the quiet standing position has principally focused on evaluating the kinematics of the centre of pressure (COP) and the centre of mass (COM). The COP is the point location of the three components of the vertical ground reaction force vector, and in a motor control context represents the neural control output of the ankle and hip muscles (Winter, 1990, Winter et al., 1998). The COM is a balance point on a segment that is equal to the total segment mass, and a mathematical weighted average of the COM of each body segment in space provides the total body COM position (Winter 1990).

The movements of the COM and COP has been noted to be closely related to each other with the implication of the COP being the control variable and the COM the controlled variable (Winter et al., 1998). The inverted pendulum model is defined as the basis of this relationship, where there is a strong correlation between the horizontal acceleration of the COM and the COP-COM signal (Winter et al., 1998). Figure 1 presents the movement of the COP and the COM of a subject during quiet standing. The COP oscillates to either side of the COM to maintain it within the base of support.

The strategies employed to control the movement of the COP in the A/P and the M/L directions have been found to implicate different muscle groups. In the A/P direction the ankle plantar and dorsi-flexors are responsible for the movement of the COP while in the M/L direction the hip abductors and adductors are responsible for the movement of the COP through a load unload response of each limb (Winter et al., 1993, Winter et al., 1996).

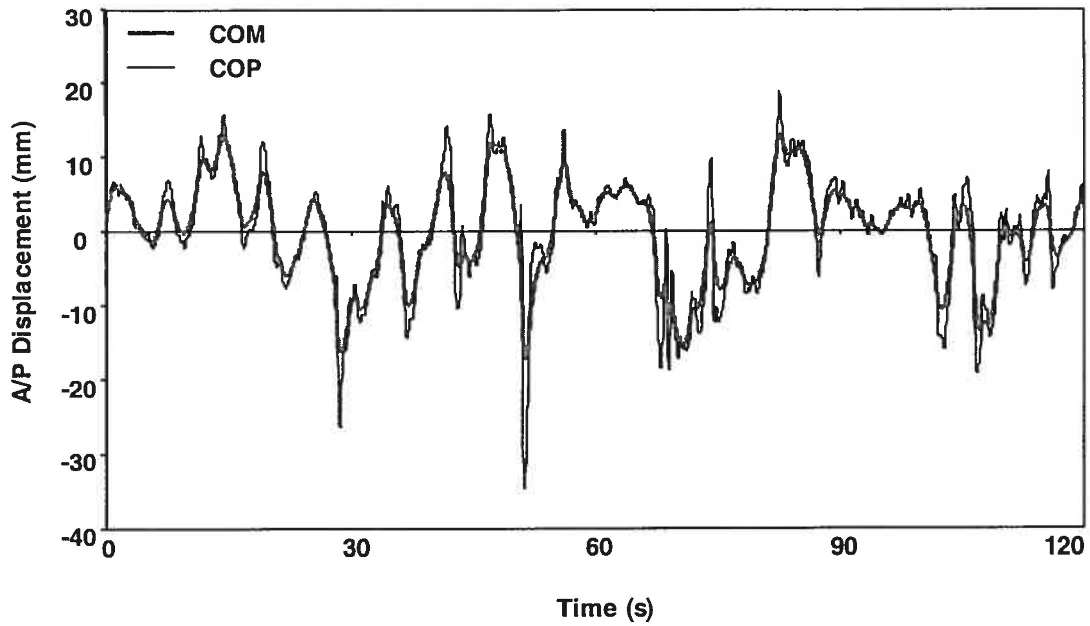

Figure 1: The COP and the COM A/P displacement (mm) during quiet standing of a typical subject during a period of 120 seconds. The thick line represents the COM, and the thin line the COP.

Obtaining an accurate estimation of the position and the displacement of the COM has been the focus of numerous studies. These studies have directly measured the position of the COM and moment of inertia in cadavers (Dempster & Gaughran 1967) and on live subjects, through a variety of techniques that includes stereophotogrammetry (Zatsiorsky & Seluyanov 1983; 1985), cross-sectional modelling of body segments (Jensen 1978; Jensen 1986; Jensen 1989), and medical imaging techniques (Pearsall et al., 1996). Of these techniques the cadaver studies were principally performed on adults and the remainder on adult subjects with the exception of the cross-sectional elliptical approach employed by Jensen (1989), who studied children and adolescents. The research by Jensen (1989) revealed that during growth and development there is a decrease in the COM proportion of the head and an increase in the COM proportion of the arms and legs. The positions of the COM relative to the proximal joint centres also shifted proximally in the upper legs forearms and arms (Jensen 1989).

Techniques have been proposed to estimate the COM and overcome the difficulties of anatomical landmark detection, and the estimation of anthropometric variables (segment COM and moment of inertia). These techniques involve estimating the position of the COM based on measurements obtained from a force plate. The techniques generally include 1) a filtering technique of the COP (Benda et al., 1994), 2) Newtonian mechanics based equations (Morasso et al., 1999), 3) filtering technique combined with a mathematical relationship between the COP and COM (Caron et al., 1997), 4) double integration of the horizontal ground reaction forces (King & Zatsiorsky 1997; Zatsiorsky &, King 1998). These techniques have been developed and initially applied to estimate the displacement of the COM in adult subjects in a quiet standing position with eyes open (Benda et al., 1994; Caron et al., 1997; King & Zatsiorsky 1997), voluntary oscillations (Caron et al., 1997; King & Zatsiorsky 1997) and one legged stance (Zatsiorsky & King 1998; Shimba 1984). Recently in a simulation study, Lenzi et al., (2003) compared the technique of Caron et al., (1997), Zatsiorsky & King (1998), and Shimba (1984), with a link segment model based on anthropometric parameters obtained from Winter (1990). Through changing the body segment parameters and evaluating each model in simulated quiet standing, ankle sway, hip sway and the sit to stand task the sensitivity of each technique was tested. The technique by Zatsiorsky & King (1998) was found to be unaffected by changes in body segment parameters, unlike the link segment model which was most sensitive to changes in body segment parameters across conditions (Lenzi et al., 2003). This independence to anthropometric parameters provides a possibility of overcoming the limited source of anthropometric data available for IS patients and healthy adolescents.

2.4 Postural control, growth and development.

The time and frequency characteristics of the COP during quiet standing have been evaluated during growth and development from early childhood through adolescence up until adulthood. These studies have suggested that there is a general age related improvement in the characteristics of the COP. An initial study that evaluated subjects from 2 to 93 years old (Hayes et al., 1984), identified children between the ages of 2 to 5 years old to have the largest amplitude of A/P and M/L displacement. The root mean square (RMS) displacement in A/P and M/L displacement over a 20 second period was found to decrease between the ages of 2 and 15 years old, with a significant but small negative correlation of age and RMS amplitude to be respectively -0.48 and -0.44 in the A/P and M/L directions (Riach & Hayes 1987). Additional analysis that included height and weight, added little to decrease the un-explained variance in the regression. However, this may be related to the strong inter-correlation between age, height and weight that was greater than 0.90 (Riach & Hayes 1987). Sakaguchi et al., (1994) evaluated the COP total path length, COP area and the ratio of A/P to M/L sway in a young population aged 4-18 years old with a control group of adults 20-28 years old. All three measurements demonstrated a decrease in amplitude with an increase in age, and were significantly larger for children under 12 years for COP path length and COP area, and under 9 years for the A/P and M/L ratio.

The velocity of the COP has been evaluated by Riach & Starkes (1994), in a population of 81 children aged 4 to 13 years old. The age of 7-8 years old was found to be the period where there was the most significant decrease in COP velocity in the A/P and M/L directions. Children between the ages of 4 and 7 were found to have comparable velocities that were larger in amplitude and group variability than children between the ages of 8-13 years old. Wolf et al., (1998), also noted that children between the ages of 5-6 years old had the largest postural sway, and 15-18 year olds the smallest. This was reflected through a decrease of 33% path length, 27% radial displacement, 25% M/L range of displacement, 54% area per second and 61% short term diffusion. The most significant change was found between the 5-6 year olds and the 7-8 year olds for the COP area per second (29%), and short-term diffusion rate (41 %).

The development of mature postural control strategies has been investigated under altered sensory conditions and in the presence of an external perturbation (Forssberg & Nashner 1982; Foudriat et al., 1993; Haas et al., 1986, 1989; Woollacott et al., 1987). In the presence of a base of support perturbation, muscle activation patterns similar to those of adults was detected in children as young as 3 years old (Woollacott et al., 1987). However, the latency of response was found to be significantly greater and more variable, up until the ages of 7 – 12 when there are greater similarities with adults (Woollacott et al., 1987; Forssberg & Nashner 1982). The early dependence on the visual and vestibular systems to provide information for postural control of infants was found to decrease through the ages of 3 –6 (Foudriat et al., 1993, Shumway-Cook & Woollacott, 1985) with more emphasis placed upon somatosensory information. This transition was reflected through a decreased latency in neck muscle activation in the presence of a base of support perturbation in children 2-3 years old, and 4-6 years old (Woollacott et al., 1987).

2.5 Postural control and Idiopathic Scoliosis.

The characteristics of the COP in IS patients have been investigated by a number of authors, during quiet standing with the eyes open (Adler et al., 1986; Byl & Gray 1993; Chen et al., 1998; Gauchard et al., 2001; Gregoric et al., 1981; Lidstrom et al., 1988; Nault et al., 2002; Sahlstrand et al., 1978; Sahlstrand & Lidstrom 1980), and under altered sensory conditions (Byl et al., 1993). IS were found to have a greater sway area than controls, (Chen et al., 1998; Nault et al., 2002; Sahlstrand et al., 1978), sway radius (Chen et al., 1998), and sway amplitude (Chen et al., 1998) defined by the sum of the A/P and M/L COP position over a 30 s time period (Chen et al., 1998). However, this is in contrast to the greater amplitude in A/P RMS, and sway area found in control subjects by Lindstrom et al., (1988), and no difference between control or IS for a dispersion factor (Adler et la., 1986; Byl & Gray 1993), or sagittal sway area, mean radius or path length (Gregoric et al., 1981). All of these studies had similar amplitudes in spinal curvature, however, the type of curvature was not specified, which may account for the observed differences. Gauchard et al., (2001) divided a group of IS into double, thoracic, thoracolumbar and lumbar groups. In this study, there was a significant difference found between groups for the sway path area, where the Double curves had the smallest area, and the lumbar curves had the largest sway area. Sahlstrand & Lidstrom (1980) evaluated progressive and non-progressive curves and did not find any difference between the groups.

Altering the sensory information from the vestibular or the visual systems has been found to affect the postural sway of IS patients more than control subjects. When the IS patients were evaluated in a quiet standing position with their eyes closed, Sahlstrand et al., (1978) found that there was a greater sway area and sway amplitude in both A/P and M/L compared to the control subjects. Stimulation of the vestibular labyrinth on the convex side of the curvature also tended to increase postural sway in IS children when compared to control (Sahlstrand et al., 1979). The effect of altering the visual condition was not found to affect the IS patients by Byl & Gray (1993). Only when additional tasks were added to eyes closed conditions such as standing on one foot, both feet in tandem, or an unstable surface with the head turning, there was a difference between the IS and control subjects identified. The addition of tasks to the eyes closed condition was also found to increase the postural sway of IS patients (Chen et al., 1998). Conditions were added by Chen et al., (1998) that included a maximal trunk flexion and extension, addition of a 2 kg mass close to the trunk and with the arms flexed forward. In contrast to the above findings, Lidstrom et al., (1988), and Adler et al., (1986), found that the eyes closed condition did not increase the postural sway greater than the control subjects.

The proprioceptive accuracy during a finger-pointing task was found to highlight a significant inaccuracy for the right arm in progressive IS patients, and non-progressive subjects with spinal asymmetry during a finger-pointing task (Keesen et al., 1992). The upper and lower extremities also had asymmetries in the threshold to detect joint motion, and a larger threshold in IS than control subjects (Barrack et al., 1984; Cook et al., 1986). These studies also identified that IS subjects found it more difficult to reproduce joint angles than control subjects (Barrack et al., 1984; Cook et al., 1986).

Objectives

The general objective of this thesis is to identify postural alignment and postural control parameters that will assist in the assessment, and treatment of IS. This specifically involves applying two approaches to the assessment of IS. The first is a postural alignment model, and implicates assessing the position and orientation of the body segments in space. The second, is the evaluation of postural control through implementing a novel technique to estimate the COM in IS patients and control subjects. The specific objectives that will be addressed in this thesis include:

1) Compare the linear and angular position and displacement of the pelvis, trunk and shoulders of IS patients and control subjects during quiet standing, and measure the influence of varying sample duration.

2) Compare the postural alignment characteristics of IS patients with different types of spinal curvature, and compare two techniques used to quantify these postural alignment parameters.

3) Quantify the change in postural alignment of IS patients with different curve types when fitted with a non-rigid brace.

4) Estimate the position of the COM in IS patients and control subjects using a force plate technique and anthropometric model and compare the difference between both models.

5) Evaluate the postural control of IS and adolescent control subjects through comparing the COP-COM RMS difference.

Chapter III: Manuscript #1

Evaluation of segmental postural characteristics during quiet standing in control and Idiopathic Scoliosis patients.

The quiet standing position has served as a basis to evaluate aspects related to spinal deformity and back surface asymmetry from childhood through to adolescence in healthy and individuals with IS. To perform these evaluations a variety of techniques have been utilised which includes medical imagery, surface topography, or torso scans, landmark digitisation and stereovideography. The premises of these techniques is to obtain a representation of the bodies skeletal configuration through one image or photograph, an extended scanning time of 5 to 15 seconds, or consecutive landmark digitisation. Since quiet standing is not static, body sway is a possible limitation to obtaining an accurate image of a patients postural alignment. The focus of this study is to evaluate the position and displacement during quiet standing of the pelvis, thorax and shoulders, and investigate the effect of changing the sample duration within the same 120-second trial.

Title: Evaluation of segmental postural characteristics during quiet standing in control and Idiopathic Scoliosis patients.

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Abstract

Background: Idiopathic scoliosis is characterized by a deviation of the spine, that progresses during periods of rapid growth and development. The complex nature of this pathology poses a challenge to the clinician to non-invasively evaluate and discriminate IS patients from non-pathological children. The primary objective of this study is to evaluate the linear and angular position and amplitude of displacement of the pelvis, thorax and shoulders of Idiopathic Scoliosis (IS) patients and control subjects during quiet standing. The secondary objective is to evaluate the effect of data collection duration on the estimation of these postural measures.

Methods: Eighteen healthy adolescent female, (age: 11±2 years) and 22 subjects with Idiopathic Scoliosis (age: 12±2 years, Cobb angle: 21°±5°) were recruited to participate in this study. The quiet standing posture of the subjects was evaluated with the assistance of infra-red emitting diodes placed on the body and tracked by an Optotrak 3020 position sensor over a period of 120 seconds (20 Hz), with 4 repeat trials. Angular measures of rotation, tilt and linear measures of Anterior-Posterior (A/P) and Medial-lateral (M/L) shift were calculated for the pelvis, thorax and shoulders in reference to the base of support, and for the thorax and shoulders in reference to the pelvis. The mean position, root mean square (RMS) amplitude, range of each parameter over the duration of the 120 second (s) trials, and the mean of 4 trials for each of these parameters was calculated for both groups individually. An Intra Class correlation was also calculated for both groups together. The effect of sample duration, 1s, vs. 15s, vs. 30s, vs. 60s, vs. 90s was compared to 120s. A minimum sample time was chosen and evaluated for stability over the 120s period, and between trial reliability evaluated.

Results: There was a strong ICC that ranged from 0.81 to 0.99 for the mean position of the linear and angular parameters. A comparison of the RMS amplitude of displacement revealed a significantly larger A/P displacement of T1 and S1 spinous

processes in reference to the base of support ($p<0.02$). There was no difference for the RMS or range of angular displacement of tilt and rotation for the pelvis, shoulders and thorax between groups. The mean value of the angular parameters revealed a significant difference between shoulder blade rotation in reference to the base of support and to the pelvis. There was no difference between groups for the remainder of the parameters with the control subjects having an asymmetry of 2-3° for rotation and tilt, which was similar to the scoliosis group as a whole, who had a slightly greater range of asymmetry between 2-5°. There was no difference between the sample durations of 1s, 15s, 30s, 60s 90 s or 120s to estimate the mean position of the body segments, however during these time periods the RMS increased significantly. A sample duration of 1 second with 4 repeat trials had good to excellent trial reliability with an ICC ranging from 0.84 to 0.98.

Conclusion: The IS and control subjects demonstrated similar angular and linear postural parameter displacement characteristics with the exception of A/P displacement. A rotation of the shoulder blades in reference to the base of support and the pelvis were the most evident postural deviations in the IS population, but considerable variability across subjects does exist. A representative sample of the mean position and orientation of the body segments is possible with repeated trials and sample durations as short as 1 second.

Keywords: Biomechanics, Posture, Idiopathic Scoliosis

Introduction

Idiopathic Scoliosis (IS) implicates a deformation and disorientation of the thoracic cage that accompanies the lateral deviation and rotation of the spinal column (Stokes et al., 1988; 1989). Quantifying this aspect of IS through invasive and non-invasive methods has been the focus of numerous studies. The upright standing position has been commonly adopted to evaluate radiologically the amplitude of spinal curvature (Stokes et al., 1988), and non-invasively back surface asymmetry (Denton et al., 1992), alignment (De la Huerta et al., 1998; Le Blanc et al., 1996; Zabjek et al., 2001) or postural sway (Lidstrom et al., 1988; Sahlstrand et al., 1978) from childhood through to adolescence in healthy and individuals with IS.

To perform these postural evaluations, a variety of techniques have been utilised which includes clinical observations made subjectively, or objectively with a plumb line, ruler and scoliometer (Coté et al., 1998), two or three dimensional (2-D or 3-D) radiography (Delorme et al., 1999) surface topography (Denton et al., 1992) torso scans (Dawson et al., 1993; Jaremko et al., 2001;2002a;2002b), landmark digitisation (Le Blanc et al., 1996; Letts et al., 1998; Mior et al., 1996; Zabjek et al., 1999), forceplate (Lidstrom et al., 1988; Sahlstrand et al., 1978) or opto-electronic measurement systems (De la Huerta et al., 1998; Zabjek et al., 2001, Masso & Gorton 2000). The premises of these techniques are to obtain a representation of the bodies skeletal configuration from one image or photograph (Denton et al., 1992; Stokes et al., 1987), an extended scanning time of 5 to 15 seconds (Dawson et al., 1993; Jaremko 2001), or through consecutive landmark digitisation over a 1 to 2 minute period (Le Blanc et al., 1996; Letts et al., 1998; Mior et al., 1996, Zabjek et al., 2001). The limitation of these approaches has been suggested to be related to body sway or to the positioning of the patient (Goldberg et al., 2001; Zabjek et al., 1999). Using five trials, good intra-session and inter-session reliability of angular measurements were reported using a short acquisition duration in IS patients, and a sequential digitisation technique in adult subjects (De la Huerta et al., 1998; Zabjek et al., 1999). However, between session variability for the A/P position of the shoulders and pelvis has been noted to be as large as 19 mm and 15 mm respectively. Body sway, often characterized by the displacement of the Centre of Pressure (COP) (Ferdjallah et al., 2002; Riach & Hayes 1987; Wolff et al., 1998), has been found to have excursions between 18 to 20 mm in the Anterior-Posterior (A/P) direction, and 12 to16 mm in the Medial-Lateral (M/L) direction for children between 7 and 14 years (Wolff et al., 1998). The characteristics of the COP in the time and frequency domains have been found to be sensitive to the duration of data acquisition, with a sample duration time of at least 60 seconds required to obtain a stable measurement, and as high as 120 seconds to maximize the resolution required for adequate frequency domain analysis (Carpenter et al., 2001). The number of repeated evaluations required to obtain a stable measurement has also been suggested to be up to 4 trials for the RMS amplitude of the COP-COM signal (Corriveau et al., 2000). Apart from COP and COM investigations, there has not been a thorough investigation of the angular and linear displacement of the pelvis, thorax or shoulders during quiet stance. These postural parameters have demonstrated the potential to provide useful clinical measures for IS, and a clarification of the optimal sampling duration will assist in the choice of measurement devices, and evaluation protocols.

The primary objective of this study is to compare the linear and angular position and displacement specific to the pelvis, thorax and shoulders of IS patients and control subjects during quiet standing. The secondary objective is to evaluate the effect of data collection duration on the estimation of the position and orientation of the body segments.

Methods

Subject Population

The IS subjects participating in this study were recruited from an orthopaedic clinic, and the control subjects were recruited from the general community. All subjects read and signed an information and consent form approved by the research centre's ethics committee. Inclusion criteria for the IS subjects was a confirmed diagnosis for IS with a frontal plane radiograph. In the IS group, 8 subjects had a double curve, 7 a thoracolumbar curve, and 7 a thoracic curve. The healthy subjects were recruited from the general community and friends and family of the researchers. They were initially screened with a scoliometer to ascertain that there was no thoracic, thoracolumbar or lumbar prominence greater than 5° in the forward bending position (Bunnell & Delaware 1984). There was a total 18 healthy control subjects (age: 11 ± 2 years; 39 ± 11kg; 1.44 ± 0.13 m) and 22 IS subjects (age: 12 ± 2 years; 42 ± 12kg; 1.48 ± 0.11 m; Cobb: 21° ± 14°) who participated in this study.

Data collection

The data acquisition protocol involved the marking with a dermographic pencil surface anatomical landmarks located on the base of support, pelvis, spine, thorax and shoulders (See Figure 1). Only the landmarks pertinent to the present study will be described in detail here. These included, bilaterally the calcaneus, tip of the 2nd metatarsal, medial and lateral maleolus, greater trochanter, anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), the most lateral and superior tip of the iliac crest (ILIO), lumbar, thoracolumbar and thoracic prominence, inferior angle of the scapula, and acromion. The spinous processes of the 1st thoracic vertebra (T1) to the 1st sacral bone (S1) were also identified. The 3-D position of the anatomical landmarks needed to calculate the postural parameters was obtained using an Optotrak 3020 system. Infra-red emitting diodes were placed on T1, S1, and bilaterally on the trochanter, PSIS, inferior angle of the scapula, acromion, tragus, the thoracic, thoracolumbar and lumbar prominences. The landmarks situated on the base of support (calcaneus, tip of 2nd metatarsal and maleolus) were digitised with a probe in reference to the optotrak frame of reference. The diodes placed on the right and left PSIS, and the S1 served to define a rigid body. The ASIS and ILIO were digitised in reference to this rigid body that was then used to reconstruct the 3-D position of these landmarks in the Optotrak frame of reference.

The data collection required the subject to place their feet within a standardized foot template, with the heels 28 cm apart, and the feet at an angle of 15° to the sagittal plane. No other instruction except to stand still and look straight ahead at a target approximately 2 meters away was given to avoid the modification of the natural posture of the subject. With the subject in a quiet standing position, the 3-D co-ordinate of each marker was obtained at a frequency of 20 Hz by the Optotrak system. Each quiet standing trial had a duration of 120 seconds, there were 4 trials obtained for each subject (Corriveau et al., 2000). Between each trial, the subject was allowed to move their feet, or sit down to ensure that there was no accumulated fatigue through the duration of the protocol.

Postural parameters

The postural parameters evaluated in this study were developed to quantify and to extend the clinical evaluation performed by the orthopaedic staff at a Spinal Pathology Evaluation Center (De la Huerta et al., 1996; Zabjek et al., 1999). The goal of this approach was to evaluate the position and orientation of different body segments as well as to measure anthropometric characteristics of the patient. The parameters used in this study are listed in Table 1.

This approach is based on the three-dimensional localization of anatomical structures. These structures are readily identified over the skin and permit to quantify all of the postural parameters. The first set of landmarks, the middle of the heel and the tip of the second toe of both feet, was used to define the global co-ordinate system specific to the base of support (BOS) of the subject. The lateral malleoli, and the greater trochanters defined the legs of the patient. The geometry of the pelvis in terms of tilt and rotation is described using the PSIS, ASIS and the ILIO. Pelvis tilt and rotation in reference to the base of support (PEL_{BOS}) was calculated using individual bilateral points (ie., right and left PSIS). The distance between individual bilateral points (ie. right and left PSIS) served as the line of reference to calculate the angle of pelvis tilt (Frontal) and rotation (Transverse) in reference to a specific plane. In a similar manner, the angles of tilt and rotation were calculated for shoulders ($SHLD_{BOS}$), shoulder blades ($SHLDB_{BOS}$) and for rotation of the thoracic (Th_{BOS}), thoracolumbar (ThL_{BOS}) and lumbar (L_{BOS}) prominences. The $SHLD_{BOS}$ was defined by the acromion, the $SHLDB_{BOS}$ by the inferior angle of each scapula, and the Th_{BOS}, ThL_{BOS} and L_{BOS} prominences by their respective bilateral landmarks. Figure 2 presents an example of how the angles for the $SHLDB_{BOS}$, $SHLD_{BOS}$,, $SHLD_{SHLDB}$ were calculated.

- Insert Figure 1 about here -

- Insert Figure 2 about here -

Anterior-posterior (A/P) position and medial-lateral (M/L) position of the pelvis and shoulders were measured in the transverse plane as the distance between S1, T1 and a point on the centre of the BOS and defined as $S1_{BOS}$, $T1_{BOS}$. The measures of rotation, tilt and shift were also measured in reference to local segments. The local segments included the pelvis (PEL), and the SHLDB, giving the following relative measures. The $SHLD_{PEL}$, $SHLDB_{PEL}$, Th_{PEL}, ThL_{PEL} and L_{PEL} prominences in reference to the pelvis, and the $SHLD_{SHLDB}$ in reference to the SHLDB. The A/P and M/L position of T1 relative to S1 ($T1_{S1}$) were measured as the relative position of both landmarks in the transverse plane. The angular measurements are positive when counter-clockwise as seen from posterior, apical and right point of views. The linear measurements are positive going forward, upward and to the left of the patient.

Statistical Analysis

For each trial, the mean, root mean square (RMS) and range for the linear and angular measures was obtained over the duration of each 120 seconds. A student t-test was used to compare the control subjects to the IS patients ($p<0.05$). A two way mixed effect model was used to calculate the Intra- class correlation coefficient (ICC) expected from the average of 4 trials excluding the systematic effect of the trial.

To evaluate the optimal duration of data acquisition to estimate the postural parameters, two analyses were performed. The first included a comparison with a repeated measures ANOVA of the mean and RMS over a period of 1, 15, 30, 60, 90 and 120 seconds within the same trial. These durations were chosen to represent sample durations already utilised in the literature (Corriveau et al., 2000; De la Huerta et al., 1996; Dawson et al., 1993; Jaremko 2001). Based on this evaluation a minimum sample duration was chosen to estimate the average angular and linear position at specific times of the trial that were 1, 30, 60 and 90 seconds. The expected ICC for this minimum sample duration from an average of 4 trials and for 1 trial excluding the systematic effect of the trial was also calculated.

Results

The mean position and 95 % confidence intervals of the linear and angular parameters over the 120 second period are presented in Table 1. There was a significantly greater ($p<0.05$) rotation of the $SHLDB_{BOS}$ and $SHLDB_{PEL}$ in the scoliotic group than in the control group. There was no difference between groups for the remainder of the parameters with the control subjects having from 2-3° for rotation and tilt, which was similar to the scoliosis group, who had 2-5° of tilt (See Table 1).

- Insert Table 1 about here -

The RMS and range of angular displacement over the duration of the trial (120 seconds) for global and relative measures of segment rotation and tilt was similar between the IS and control subjects. The within trial range was between 3° and 6° for rotation and 1° to 3° for tilt, with an average RMS of under 1°. The range and RMS amplitude of A/P displacement of $T1_{BOS}$ and $S1_{BOS}$ was significantly greater ($p<0.05$) for the IS patients (See Figure3). For $T1_{BOS}$ (IS vs. controls), the range of displacement was 58 vs. 37 mm and the RMS amplitude was 10 vs. 7 mm. For $S1_{BOS}$, the range of displacement was 47 vs. 29 mm and the RMS amplitude was 9 vs. 6 mm for the IS vs. control subjects. In the M/L direction, there was no difference between groups for $T1_{BOS}$ and $S1_{BOS}$, but there was a trend for the IS subjects to have a greater range (T1: 29 vs. 19mm, S1: 26 vs. 15mm) than the control subjects.

- Insert Figure 3 about here -

The angular displacement of the PEL_{BOS}, $SHLDB_{BOS}$ and $SHLDB_{PEL}$ over time for a typical control subject is presented in Figure 4. Note that the relative rotation of the $SHLDB_{PEL}$ oscillates around -1° and will at some instances be positive, whereas the rotation of the pelvis oscillates around -4° and always stays negative.

- Insert Figure 4 about here -

Sample Duration

There was no difference between the sample durations of 1s, 15s, 30s, 60s, 90s or 120s to estimate the mean position of the body segments. However during these time periods a repeated measures ANOVA identified a significant increase in RMS over each period ($p<0.05$). A 1 second sample obtained at 15s, 30s, 60s, and 90s did not reveal a significant difference in the mean position between samples ($p<0.05$). There was a strong ICC that ranged from 0.86 to 0.99 for the mean position of 4 repeat trials of 120 seconds each for all parameters (See Table 2.). The ICC for the mean of 4 trials for 1 second ranged between 0.84 to 0.98. With the rotation of the $SHLD_{BOS}$ and PEL_{BOS} the weakest ICC was 0.84, and the strongest for tilt of the pelvis in relation to the base of support at 0.98. If 1 trial for 1 second is chosen the ICC decreased greatly for the variables of rotation in reference to the base of support. The lowest was PEL_{BOS} rotation (ICC: 0.60, CI: 0.44 to 0.76), and the highest was $SHLDB_{PEL}$ (ICC: 0.85, CI: 0.77 to 0.92). For tilt in relation to the base of support the weakest ICC was for the $SHLD_{PEL}$ (ICC: 0.82, CI: 0.72 to 0.90).

- Insert Table 2 about here -

Discussion

The first objective of this study was to evaluate and compare angular and linear postural alignment parameters during quiet standing for IS patients and control subjects. These parameters included rotation, tilt, A/P and M/L shift of the pelvis, thorax and shoulders in reference to a global reference system defined by the base of support, and relative measurements between body segments.

The IS patients and the control subjects had a similar mean amplitude of rotation and tilt for the majority of parameters, with differences between groups only in the rotation of the $SHLDB_{BOS}$, and rotation of the $SHLDB_{PEL}$ in reference to the pelvis. This observed difference was expected, since a rotation of the thorax has been well documented in IS patients. Subjective observation of scapular asymmetry has also been found to account for a significant percentage of the observed variance for the impression of total back surface asymmetry (Raso et al., 1998). The similarities between the two groups for the other parameters may be attributed to a greater range of scoliosis parameters that were found to be within -13° to 8° for rotation, and –2° to 7° for tilt. This large range may be attributed to the range in amplitudes of the patients spinal curvature, but also to the presence of different curve types within this population of IS patients. This group had both right thoracic, right thoracic left lumbar and left thoracolumbar curves, indicating that the apex of the curve is situated on different sides of the spinal column. Although, all of the control subjects tested negative with a scoliometer for IS (rib hump <5°), there was still a range of tilt between –2° to 2°, and rotation of between –4° to 4° measured on the different body segments. The majority of the control subjects had mean linear and angular positions that exceeded the minimum amplitude of variation due to postural sway which were found to have an average RMS of less than 1° and 10mm respectively. A similar presence of some degree of postural asymmetry in normal subjects has also been suggested by previous authors (Burrwell et al., 1983; De la Huerta et al., 1998; Nissinen et al., 1989). A rib hump of 1 to 5 mm has been previously reported to be present in up to 61 % of the population (Nissinen et al., 1989), with the prevalence of 4.8 % of lower leg length inequality in patients who have a rib hump of at least 6 mm (Nissinen et al., 1989). Since the control subjects of this study have not fully matured, there is still a possibility that a spinal curvature may develop. Further research is required to determine which postural abnormalities are indicative of future curvature progression.

The within trial amplitude of displacement assessed through the range and RMS in the postural parameters was found to be similar between groups, and between the global and relative measurements for rotation, tilt and M/L shift. Only, in the A/P direction did the IS have a greater range and RMS amplitude of displacement of $T1_{BOS}$ and $S1_{BOS}$. The range and RMS of the A/P displacement is larger than that found by previous studies that have only evaluated the displacement of the COP (Wolff et al., 1998; Ferdjallah et al., 2002). However, the inference that IS patients have greater A/P body sway characteristics than control subjects is the same as previously reported when evaluating the COP sway area (Chen et al., 1998; Nault et al., 2002; Sahlstrand et al., 1978).

The ICC of the mean angular or linear position was excellent (0.92 to 0.99) for the mean of 4 trials of 120 seconds in duration. The excellent ICC for the mean angular or linear positions are higher than the within session reliability reported for other postural evaluation techniques (De la Huerta et al., 1998; Zabjek et al., 1999). This can be attributed to both high accuracy and precision of the opto-electronic system utilised, as well as the duration and sampling frequency of each trial (Sampling Frequency 20 Hz, Duration: 120 seconds, Samples: 2400) and the 4 repeat trials. The comparison of sample durations to estimate the mean angular and linear parameters found that there was no difference between a 1 second trial or a 120 second trial. In contrast the RMS significantly increased for all sample durations with the largest RMS at 120 seconds. These results are similar to Carpenter et al., (2001), who found that there was no difference in the mean position of the COP with varying sample durations, however the RMS increased with increased sampling duration. With 1 second as sample duration, good reliability was found with the ICC for the mean of 4 trials ranging between 0.84 to 0.98. However, the ICC estimated for 1 trial dropped considerably for the parameters of rotation measured in reference to the base of support, emphasising the importance of obtaining more than 1 trial for these measurements.

The results of this study have a number of implications related to the possible measurement error that may be found in surface topography, surface scan or landmark digitisation techniques. The increased RMS due to postural sway noted with increased sample time, suggests that the shortest scan time, or landmark digitisation time is necessary to minimize between segment artefact caused by body sway. The potential for postural sway to have a detrimental effect in identifying a postural asymmetry seems to be greater for postural asymmetries of smaller amplitudes. This is caused by the possibility of the angle or the lateral deviation changing from positive to negative with postural sway.

Conclusion

The IS and control subjects demonstrated similar RMS displacement in rotation and tilt, with the exception of a significantly greater A/P displacement of T1 and S1 in relation to the BOS for the IS group. The presence of a postural deviation expressed through a rotation of the shoulder blades in reference to the BOS and relative to the pelvis was present in the IS patients. A representative sample of IS postural alignment may be obtained with an acquisition duration of 1 second, with good reliability with 4 repeated measures.

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Table 1: The mean angular and linear position of global and relative body segment parameters for the IS and control subjects (Avg = Average; -95 %, + 95 % = Confidence Interval).

		Control			Scoliosis			
		Avg	- 95%	+ 95%	Avg	- 95%	+ 95%	
Rotation (°)	PEL_{BOS}	2.1	0.2	3.9	1.0	-0.3	2.4	
	$SHLD_{BOS}$	2.3	0.9	3.8	1.5	0.1	2.9	
	$SHLDB_{BOS}$	1.2	-0.2	2.6	-2.1	-4.1	-0.1	*
	Th_{BOS}	2.0	0.3	3.7	-1.8	-4.1	0.4	
	ThL_{BOS}	0.2	-0.1	0.4	-0.1	-0.3	0.2	
	L_{BOS}	1.5	-0.3	3.3	1.4	-0.4	3.2	
Tilt (°)	PEL_{BOS}	1.7	0.9	2.5	2.6	1.4	3.7	
	$SHLD_{BOS}$	-0.1	-0.8	0.7	0.0	-1.1	1.0	
	$SHLDB_{BOS}$	0.3	-1.4	2.0	1.0	-1.3	3.2	
A/P Shift (mm)	$T1_{BOS}$	26.8	14.4	39.2	24.2	16.7	31.7	
	$S1_{BOS}$	17.0	6.7	27.4	13.8	5.8	21.7	
M/L Shift (mm)	$T1_{BOS}$	7.9	2.4	13.4	4.3	-5.2	13.8	
	$S1_{BOS}$	2.6	-2.2	7.3	0.4	-6.3	7.2	
Relative								
Rotation (°)	$SHLD_{PEL}$	0.3	-1.4	1.9	0.5	-1.4	2.3	
	$SHLDB_{PEL}$	-0.9	-2.0	0.3	-3.1	-4.8	-1.5	*
	Th_{PEL}	-0.1	-1.4	1.2	-2.9	-4.8	-0.9	
	ThL_{PEL}	-1.9	-3.5	-0.2	-1.1	-2.3	0.2	
	L_{PEL}	-0.6	-1.7	0.6	0.4	-1.1	1.8	
	$SHLD_{SHLDB}$	1.1	0.1	2.2	3.6	1.2	6.0	
Tilt (°)	$SHLD_{PEL}$	-1.8	-2.9	-0.7	-2.6	-3.6	-1.7	
	$SHLDB_{PEL}$	-1.4	-3.2	0.4	-1.6	-3.5	0.3	
	$SHLD_{SHLDB}$	-0.4	-1.7	0.9	-1.0	-2.6	0.5	
A/P Shift (mm)	$T1_{S1}$	9.8	1.6	17.9	10.4	2.2	18.7	
M/L Shift (mm)	$T1_{S1}$	5.3	2.4	8.3	3.8	-1.0	8.7	

* $p<0.05$

Table 2: The Intra-class correlation coefficient (ICC) and Standard Error of Measurement (SEM) for the mean angular and linear position of 4 repeat trials for the IS and control subjects together (Avg = Average; Lower = Lower Bound; Upper = Upper Bound).

		ICC			SEM
Global		Avg	Lower	Upper	
Rotation (°)	PEL_{BOS}	0.92	0.86	0.96	1.0
	$SHLD_{BOS}$	0.92	0.86	0.96	0.9
	$SHLDB_{BOS}$	0.96	0.93	0.98	0.9
	Th_{BOS}	0.96	0.92	0.98	1.0
	ThL_{BOS}	0.95	0.92	0.98	0.1
	L_{BOS}	0.94	0.90	0.97	0.9
Tilt (°)	PEL_{BOS}	0.98	0.97	0.99	0.3
	$SHLD_{BOS}$	0.98	0.96	0.99	0.3
	$SHLDB_{BOS}$	0.99	0.99	1.00	0.4
A/P Shift (mm)	$T1_{BOS}$	0.98	0.97	0.99	2.9
	$S1_{BOS}$	0.98	0.97	0.99	2.4
M/L Shift (mm)	$T1_{BOS}$	0.96	0.93	0.98	3.4
	$S1_{BOS}$	0.95	0.92	0.97	2.9
Relative					
Rotation (°)	$SHLD_{PEL}$	0.98	0.96	0.99	0.6
	$SHLDB_{PEL}$	0.98	0.96	0.99	0.5
	Th_{PEL}	0.98	0.97	0.99	0.5
	ThL_{PEL}	0.92	0.86	0.96	0.9
	L_{PEL}	0.99	0.98	0.99	0.3
	$SHLD_{SHLDB}$	1.00	0.99	1.00	0.3
Tilt (°)	$SHLD_{PEL}$	0.97	0.94	0.98	0.4
	$SHLDB_{PEL}$	0.99	0.98	0.99	0.5
	$SHLD_{SHLDB}$	0.99	0.99	1.00	0.3
A/P Shift (mm)	$T1_{S1}$	0.98	0.96	0.99	2.6
M/L Shift (mm)	$T1_{S1}$	0.97	0.95	0.98	1.5

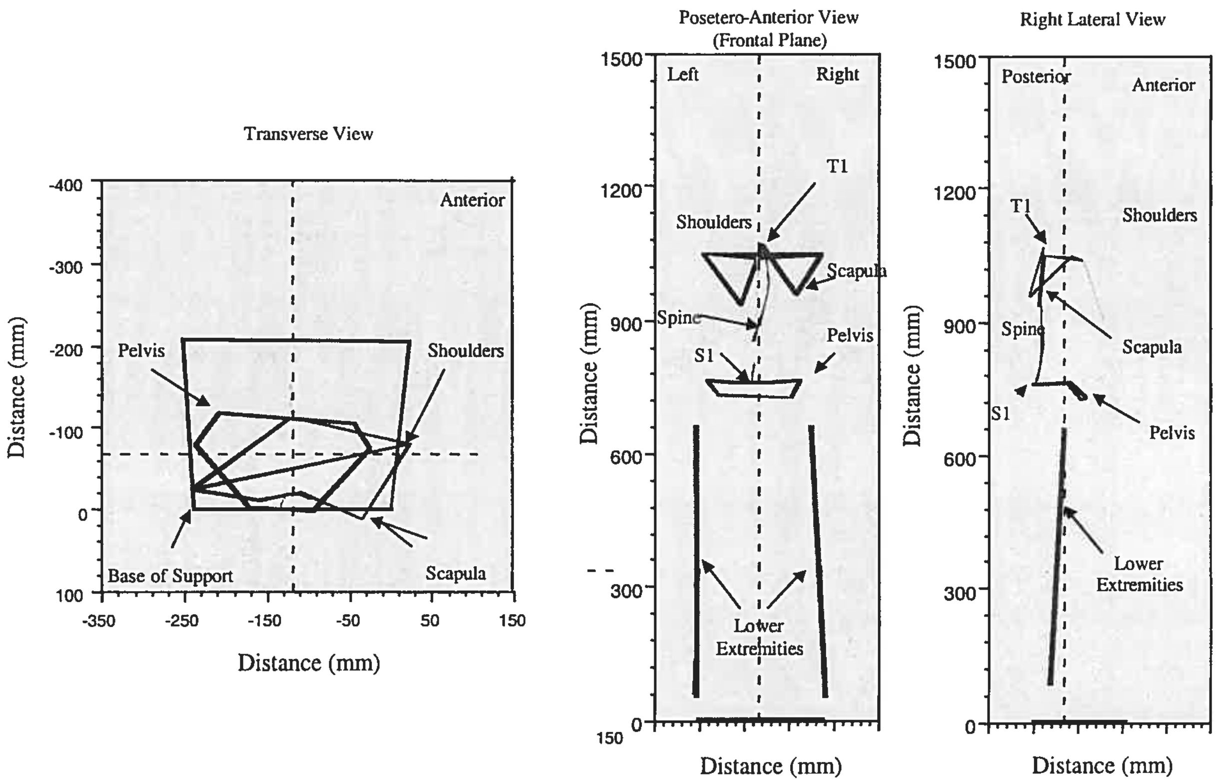

Figure 1: Postural geometry of an idiopathic scoliosis patient depicting the base of support, lower extremities, pelvis, shoulders and spinous processes represented in the Transverse (Apical), Frontal (Posterior-Anterior), and Sagittal planes (Right Lateral).

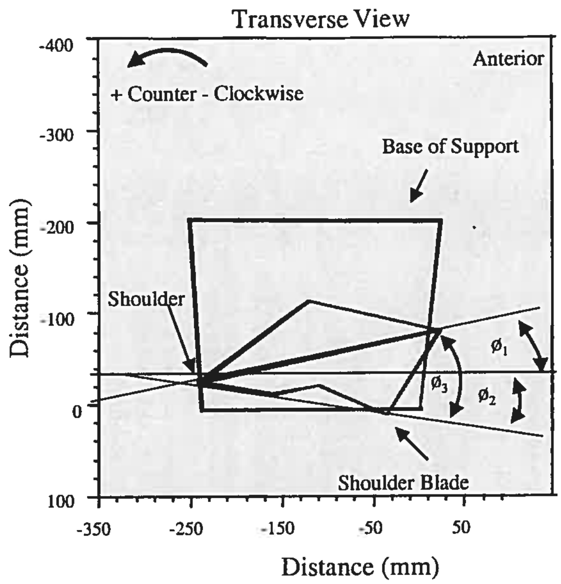

Figure 2: The transverse view (apical) of the landmarks which define the shoulder blade (SHLDB = inferior angle of each scapula), the shoulder (SHLD = acromions), and the line of reference of the base of support, and the relative angle between the two segments ($ø_1$= $SHLD_{BOS}$, $ø_2$ = $SHLDB_{BOS}$, $ø_3$= $SHLD_{SHLDB}$ ($ø_1 - ø_2 = ø_3$).

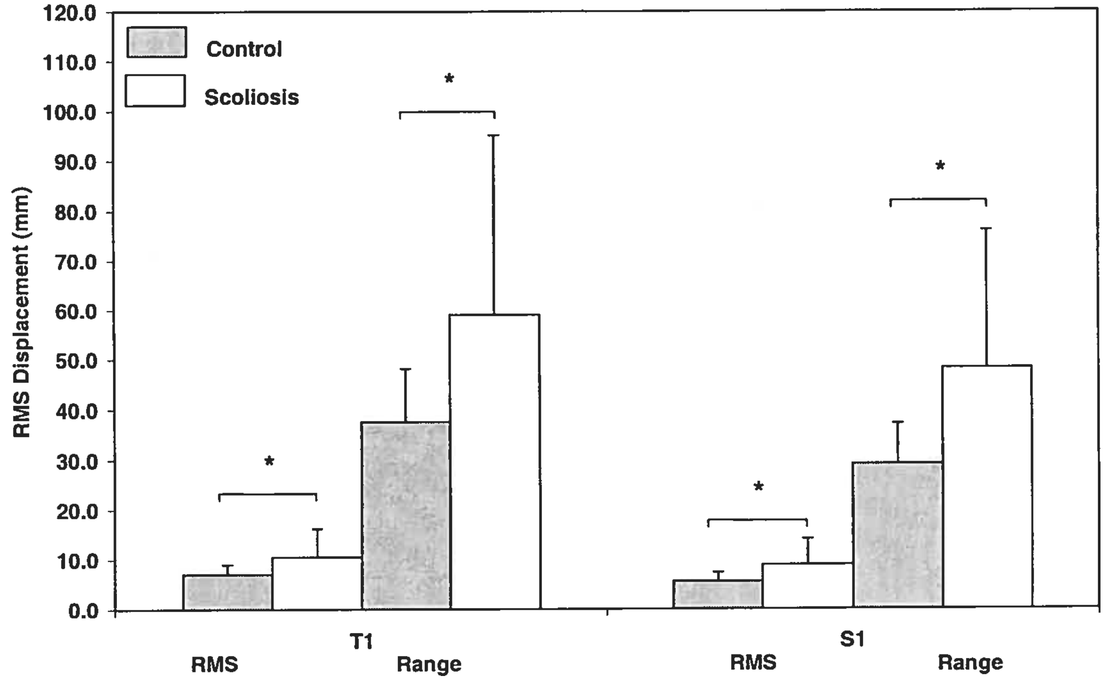

Figure 3: RMS and range of displacement for $T1_{BOS}$ and $S1_{BOS}$ in the A/P direction for the IS and the control subjects (* = p<0.05).

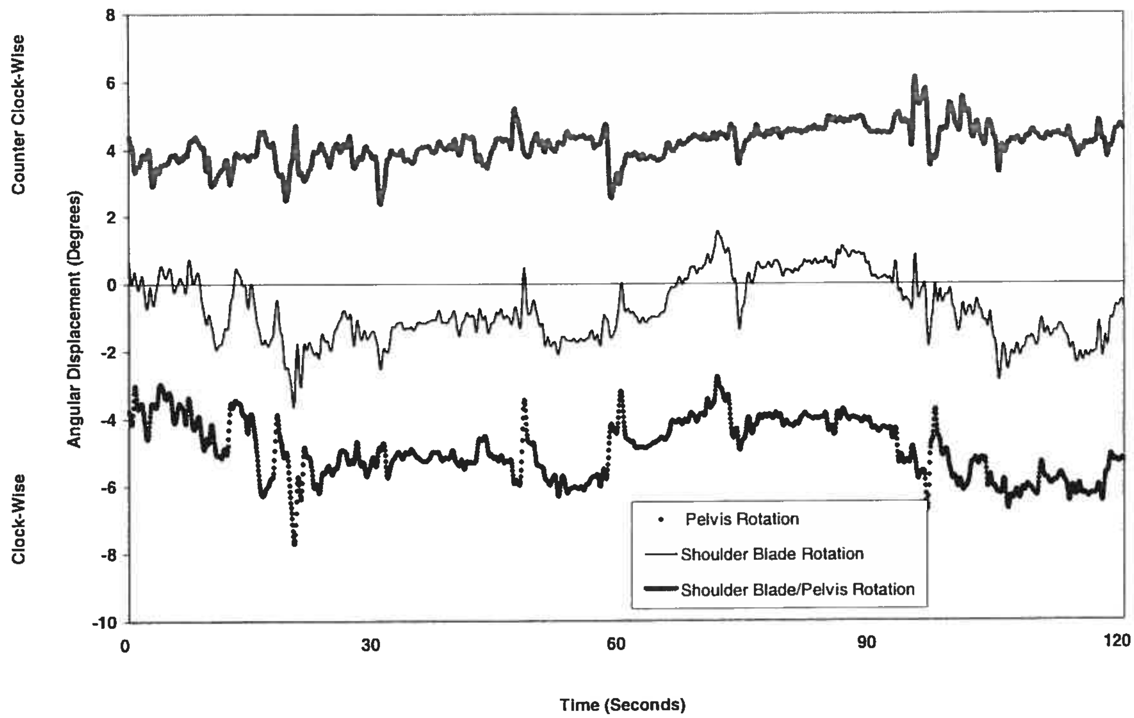

Figure 4: The angular displacement over a period of 120 seconds for a control subject. The angles measured are rotation of the pelvis (PEL_{BOS}) (solid line) and shoulder blades ($SHLDB_{BOS}$) (Solid-Dotted line) in reference to the base of support, and relative rotation of the shoulder blades in reference to the pelvis ($SHLDB_{PEL}$) (thin line).

Chapter IV: Manuscript #2

Postural alignment characteristics of Idiopathic Scoliosis patients.

The principal clinical tool for the classification and assessment of curve amplitude for IS patients is the frontal plane radiograph. Which involves the identification of the side and spinal level of the apical vertebra, and curve limit's. The clinical evaluation of IS patients involves the subjective observation of pelvis, scapular asymmetry and trunk imbalance. Only a few studies have quantified the position and orientation of these body segments, with a limited sample of IS patients. The focus of this manuscript is to identify unique postural characteristics in IS patients specific to the type of spinal curvature, and compare two techniques used to quantify these characteristics.

Title: Postural alignment characteristics of Idiopathic Scoliosis patients.

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Abstract

The objectives of this study were to first, compare the postural characteristics of Idiopathic Scoliosis (IS) patients with different types of spinal curvature, and second compare a stereovideographic and a sequential digitisation technique to estimate the postural characteristics of the IS patients. A total of 57 IS patients underwent a radiological, clinical and a postural geometry evaluations in an upright standing position as part of their regular follow-up. The posterior-anterior radiograph of the trunk was used to measure the amplitude of spinal curvature. The postural evaluation was performed using a stereovideographic and sequential digitisation technique, providing the necessary three dimensional (3-D) positions of anatomical landmarks. These landmarks were used to calculate postural parameters defining the position and orientation of the pelvis, shoulders and shoulder blades. These measurements included Lateral shift, as well as angular measures of rotation and tilt. The postural geometry model was found to be sensitive in defining postural differences between the right thoracic, left thoracolumbar, and right thoracic-left lumbar patients. A strong positive Intra-class correlation was also found between the parameters estimated with the stereovideographic system and with the sequential digitization system.

Key Words: Orthopaedics, Posture, Idiopathic Scoliosis, Biomechanics, Paediatrics

Introduction

The natural history of Idiopathic Scoliosis (IS) implicates a complex evolution of spinal deformation during periods of rapid growth and development. Quantifying the skeletal deformation has focused on invasive medical imaging techniques such as Computed Tomography (CT) [7], Magnetic Resonance Imaging (MRI) [22], and two and three dimensional (2-D/3-D) radiographic techniques [6, 23, 24]. The posterior-anterior radiograph (P/A) is the principal tool used during patient follow-up to assist in the classification, and assessment of vertebral apex (level and side), Cobb angle, vertebral deformation and patient maturity. However repeated exposure to X-rays may have potential negative health effects for the patient [10, 14], and in consequence non-invasive techniques have been developed to estimate the amplitude of spinal deformation and thoracic deformation [1]. Apart from providing an indirect estimate of spinal deformity, these approaches have provided little insight into the frequency, distribution, or how postural parameters are related to a group of IS patients defined by the type of spinal curvature.

For the most part these asymmetries such as a tilt of the pelvis or shoulders and a shift of the upper thoracic vertebra, are often evaluated subjectively during the clinical exam. These measures indicate the direction of an abnormality, with both linear (lateral shift of T1 and S1) as well as angular (rotation, tilt) components. However, within the present clinical context they do not fulfill the potential that they have in the decision making process for the clinician. This may essentially be attributed to the subjective nature of the exam, and the difficulty of interpreting this information and deciding why a postural abnormality would be important in the pathogenesis and evolution of IS.

Postural evaluation techniques have been developed which specifically evaluate non-invasively, the segmental disorientation (linear and angular) of body segments in three planes of reference [4, 16]. To obtain these 3-D co-ordinates, a sequential digitisation [2, 13, 31] or a stereovideogrpahic technique has been utilised [4]. The principal technical difference between the two techniques is based on the possibility of the patient moving during the sequential digitisation. Initial investigations comparing the two systems have found acceptable agreement, with the most notable difference in the Anterior-Posterior (A/P) direction when comparing a rigid mannequin to control subjects (2mm vs. 10 mm difference) [31]. However, IS affects the adolescent during periods of rapid growth , and is accompanied by increased postural sway [9, 18, 19, 21, 29], which has been noted to be as large as 18 to 20 mm in the A/P direction and 12 to 16 mm in the Medial-Lateral (M/L) direction [29]. Therefore, decreased stability may be a source of increased variability when using a sequential digitisation technique in a younger population and should be verified in IS patients. The first objective of this study is to compare the postural characteristics of IS patients with different types of spinal curvature. The second objective is to compare the postural characteristics obtained from a stereovideographic technique to a sequential digitization technique.

Methods

Patient Population

A total of 57 IS patients who were referred to the Spinal Pathology Evaluation Centre at Sainte-Justine Hospital underwent radiological, clinical and postural geometry evaluations as part of their regular follow-up. The patients were included in this prospective study based on their referral to the clinic for a suspected scoliosis, and read and signed an information and consent form approved by the ethics committee at the Centre de Recherche, Hôpital Sainte-Justine. Each patient underwent a standardised radiological and postural exam that were performed on the same day within 30 minutes to 2 hours of each other.

Radiological Exam

The radiological exam of the patient was performed using a numeric radiographic technique where the radiation of the patient is reduced to 62 % [20] normal radiographic techniques. In a standing position, the feet were placed within a foot template (20 mm vertical height) that imposed a distance of 28 cm between the posterior lateral surface of the heel, at an angle of 15° to the frontal plane. A posterior-anterior radiograph of the spine was taken with the superior limit being the cervical region and the inferior limit the inferior aspect of the pelvis. A sagittal radiograph of the spine was obtained at the same level providing a right lateral view of the patient. The type of scoliosis curvature for each patient was defined by the apex and side of the spinal convexity. The right thoracic (RTh) patients had a vertebral apex between T6 and T11 situated on the right side, the left thoracolumbar (LThL) patients had an apex between T12 and L1 situated on the left side, and the right thoracic left lumbar (RThLL, or Double) patients one apex between T6 and T11, and the second between T12 and L4. The amplitude of spinal deformity in the frontal plane and sagittal planes (Kyphosis: T2 to T12, Lordosis: L1 to S1) was measured using the Cobb angle technique.

Postural Geometry Evaluation

On a typical visit, the patients were requested to change into a bathing suit that permitted an unobstructed view of anatomical landmarks located on the shoulders, spine, thorax, pelvis, and lower extremities. These landmarks were palpated and marked with a dermographic pencil by an anthropologist. They included bilaterally the tip of the right and left second toe, and heels, the lateral malleoli, superior-lateral tibial plateaus and greater trochanters. The pelvis was defined by the right and left anterior superior iliac spine (ASIS), posterior superior iliac spines (PSIS), and superior lateral border of the iliac crests (ILIO). The spine was defined by every second spinous process between T1 and S1. The shoulders (SHLD) were defined by the left and right acromions. The shoulder blades (SHLDB) were defined by the inferior angle of each scapula. The gibbosity (GIBB) was defined by two bilateral points situated laterally to the midline of the spine, at a height of the most prominent aspect of the thoracic, mid-thoracic and lumbar regions.

The patients postural alignment was evaluated in an upright standing position, with their feet in the same standardised foot position as used for the radiological exam. The evaluation was performed twice with two different systems, a sequential digitization system (Free Point$_{TM}$: GTCO Corporation) and a stereovideographic system (Motion Analysis Corporation). The accuracy and precision of these two systems as evaluated from the distance between two points (50 cm) was inferior to 1mm. The sequential digitization system, consists of a hand held probe, that has two ultrasound emitters and three ultrasound receivers that were configured in a triangular formation and placed on the wall. The 3-D position of the pointer tip, was determined by the time it took from the emission of the ultrasound to the time it was detected by the three receivers. The landmarks were digitised once in a sequential order, starting from the head, down to the feet [31]. The stereovideographic system consisted of 8 high speed video cameras connected to a video processing unit and computer. The cameras were arranged such that there was a full anterior and frontal view of the patient with a minimum of 2 cameras viewing each individual anatomical landmark. The patient was in a quiet standing position with the arms slightly abducted. The 2-D position of the anatomical landmarks were obtained during a data acquisition period of 1 second at a sampling frequency of 30 Hz. A direct linear transformation algorithm was utilized to reconstruct the 3-D position of each anatomical landmark (X,Y,Z). Three repeat trials were recorded for each patient, the average of these trials was considered as representative for the postural geometry of the patient.

Postural Parameters and Reference System

The 3-D position of each landmark served as input for the calculation of the postural parameters. The technique used to calculate the postural parameters is the same as that reported previously, but is described here in more detail [4, 31]. The schema presented in Figure 4, 5 and 6 presents the patient using the 3-D co-ordinates of the anatomical landmarks, in the frontal, sagittal and transverse planes. The first set of landmarks, the middle of the heel and the tip of the second toe of both feet, was used to define a local co-ordinate system specific to the patient, referred to as the base of support (BOS). The projection to the ground of these four points also defined the patient's base of support. The origin of the co-ordinate system is set at the right posterior angle of the base of support. The Z axis is set at 0 mm at the floor level and is vertical. The Y axis is defined along the posterior edge of the base of support (left positive) and the X axis is defined as the cross product of the first two X and Y axis (forward positive). The angular and linear measures were calculated in reference to this system. The pelvis was defined by the PSIS, ASIS and ILIO on the right and left sides. A geometrical average of the three points on each side (PSIS, ILIO, ASIS) served to calculate a distance representing a line of reference for the pelvis (PEL_{BOS}) to calculate the angle with the frontal (tilt) and transverse planes (rotation). This technique was used for all angular measures. For example the right and left acromion and inferior angle of each scapula was used to define the $SHLD_{BOS}$ and $SHLDB_{BOS}$

respectively. Gibbosity ($GIBB_{BOS}$) was calculated in a similar manner with respect to the frontal plane. These angles are counter-clockwise when positive, and as seen from a posterior, apical point of view.

Lateral shift of the shoulders and pelvis was calculated from the distance between $T1_{BOS}$, $S1_{BOS}$ and the centre of the BOS. These measurements were positive anteriorly, vertically and laterally to the left of the patient.

Relative measures were calculated between the pelvis (PEL), SHLD and SHLDB for rotation and tilt. This involved subtracting the pelvis angle from the SHLD ($SHLD_{PEL}$) and SHLDB ($SHLDB_{PEL}$), and the SHLDB angle from the SHLD ($SHLD_{SHLDB}$). Relative shift between T1 and S1 was also obtained in a similar manner ($T1_{S1}$).

Statistical Analysis

Descriptive statistics were used to describe the IS population. The differences between the RTh, LThL and RThLL were evaluated using the stereovideographic system with a one-way ANOVA. A Bonferroni post-hoc analysis was performed to identify differences between groups with a level of significance of $p<0.05$. Descriptive statistics were used to highlight trends in the postural characteristics of each group. The mean absolute difference between the postural parameters estimated with the stereovideographic system and the sequential digitisation system was calculated. A two way mixed effect model was used to calculate the Intra-class correlation excluding the systematic effect of the evaluator.

Results

Patient Radiological Characteristics

The mean (± sd) Cobb angle for all of the patients on their first visit was 25°±10°, Kyphosis was 28°±12°, and Lordosis 48°±11°. There was a total of 18 RTh, 15 LThL, and 24 RThLL curves. The initial radiological characteristics defined by the type of curvature are presented in Table 1.

-Insert Table 1 about here –

Postural Characteristics Specific to type of curvature.

The ANOVA revealed a significant difference ($p<0.05$) between the LThL, RThLL, and RTh patients in most of the parameters (See Figure 1, 2 and 3). In the frontal plane the LThL and RThLL patients had a counter-clockwise tilt of the PEL_{BOS} that was significantly greater than the RTh patients. The LThL patients also had a clock-wise tilt of the $SHLDB_{PEL}$ that was opposite in direction to the counter-clockwise tilt of the RTh and RThLL patients. The $SHLD_{PEL}$ tilt was also in the clock-wise direction for the LThL patients, opposite to the RTh patients.

-Insert Figure 1 about here –

The shoulders represented by T1 were shifted to the left of the pelvis ($T1_{S1}$) and the base of support ($T1_{BOS}$) for the LThL and RThLL patients, which was significantly different from the RTh patients who had a slight deviation to the right.

-Insert Figure 2 about here –

The LThL patients also had a counter-clockwise $GIBB_{BOS}$ rotation that was opposite to the clockwise $GIBB_{BOS}$ of the RTh and RThLL patients, opposite in rotation to the LThL patients. These patients also had a significantly smaller rotation of the $SHLD_{PEL}$ and $SHLD_{BOS}$ and a significantly smaller rotation of the $SHLD_{SHLDB}$ than both the RTh and RThLL patients.

-Insert Figure 3 about here –

The RTh and RThLL patients had a clock-wise rotation of the $SHLDB_{PEL}$ and $SHLDB_{BOS}$, with a counter clock-wise rotation of the $SHLD_{PEL}$ and $SHLD_{BOS}$. The relative rotation of the $SHLD_{SHLDB}$ for both groups was in the counter-clockwise direction. Figure 4, 5 ad 6 presents a characteristic postural geometry for a LThL, RTh and RThLL patient.

-Insert Figure 4 about here –

-Insert Figure 5 about here –

-Insert Figure 6 about here –

Agreement between Techniques to estimate postural parameters

The mean absolute difference, standard deviation, and the ICC is presented in Table 2 for the comparison between the postural parameters estimated from the stereovideopgrahic system and the sequential digitisation system. A strong ICC is noted for all parameters, except for the rotation of the shoulders and the rotation of the shoulder blades.

-Insert Table 2 about here –

Discussion

The first objective of this study was to evaluate the postural characteristics of IS patients with different types of spinal curvature. The patients in this study had not received prior treatment for IS and underwent the clinical, postural geometry and radiological exams as part of their screening or pre-treatment evaluations. When the patients were divided into groups according to the traditional classification of IS patients, numerous significant differences were found between the three groups. Although considerable research has been devoted to quantifying back surface asymmetries [3, 5, 8, 11, 12] and establishing a relationship with the amplitude of spinal curvature [12], only a few have focused on a specific group [16] or compared the patients according to the type of spinal curvature [11]. Inami et al., (1999) investigating a group of IS patients with a Cobb angle ranging from 10° to 67° found a greater POTSI score for thoracic and thoracolumbar patients than for double curvature patients. Although, the nature of the parameters are slightly different, the results of the present study suggesting multiple postural differences between groups of IS patients are in agreement with those of found with the POTSI index [11].

The location and direction of the postural characteristics observed in this study for each group of scoliosis patients implies a unique interaction between the spinal curvature and the adjacent anatomical structures. Previous research has positively associated the Cobb angle with vertebral rotation, rib rotation, and back surface rotation in patients with a thoracic curvature [23]. There also has been an association between the amplitude of maximal surface rotation to 1 vertebral level from the curve apex [24, 25]. In the present study, the thoracic patients had a clock-wise $GIBB_{BOS}$ with an amplitude of 4°, and the thoracolumbar patients an opposite $GIBB_{BOS}$ of approximately the same magnitude. Stokes et al., (1987) also found similar rotations of 4° and 5° in the thoracic and thoracolumbar levels using Raster stereophotography. In the present study, the $GIBB_{BOS}$ was accompanied by a clock-wise rotation of the $SHLDB_{PEL}$, reflecting scapular asymmetry. Asymmetry of the scapula has also been suggested to be a predictor of overall back surface asymmetry in a group predominantly consisting of thoracic patients [17]. This is to be expected since the shoulder blades are situated over the rib cage, and in consequence to rib cage disorientation there is a clockwise rotation of the shoulder blades, and a counter-clock-wise rotation of the shoulders. Shoulder rotation was also observed by Masso and Gorton (2000) in a group of right thoracic pre-operative patients. Using a similar technique, a predominance of counter-clockwise shoulder rotation, also referred to as shoulder protraction was found in 63 % of patients [16]. In contrast, this aspect of shoulder and scapular rotation was found to be less pronounced in the thoracolumbar patients of this study. This may be related to the position of the vertebral apex that is situated in the thoracolumbar region. In the present study, the thoracolumbar patients had greater PEL_{BOS} tilt than the thoracic patients. The presence of pelvic tilt has been documented to be a pertinent variable for lumbar and thoracolumbar scoliosis patients [15], and may be a result of sacral tilt [30], a lower leg length inequality or muscular imbalance [28]. These results emphasize the notion that the principle plane of deformity for the thoracic patients is the transverse plane, and for the thoracolumbar patients it is the frontal plane. For the right thoracic left lumbar patients, postural deformations would be found in both planes, due to the location of two curves, one in the thoracic and one in the lumbar region.

The clinical evaluation of IS patients considerably revolves around the evaluation of the Cobb angle, in the sagittal and frontal planes. To reduce the irradiation of the patient a number of non-invasive evaluation techniques have been developed and correlated with the Cobb angle [3, 22, 24]. Despite their success with Cobb angle prediction, the parameters studied have not been utilized to describe other aspects of IS patient posture and do not provide additional insight into the evolution of the pathology. This leaves the clinician with two avenues of understanding the pathology. The first is clinical, where a number of clinical measures have to be interpreted and the second is the use of mechanical models that are limited to their applicability in a clinical setting. The association of postural abnormalities to the pathology of IS has been limited to their global relationship with the Cobb angle deformity, as well as the relationship with postural alignment, (i.e. – lateral shift associated with compensated and decompensated scoliosis). However, this approach limits the clinical exam to measurements that may have a large inter-evaluator difference leading to measurements that would be difficult to relate to the patient's evolution and treatment progression. Through incorporating a standardized evaluation technique that can assess independently the pelvis, thorax, shoulders and spine a closer follow-up of the patient be obtained. The postural geometry model was specifically developed to quantify the clinical exam, and at the same time increasing the number of postural parameters that could be evaluated. Although previous research has underlined the presence of postural abnormalities in scoliosis patients [4], the current study identified which characteristics are unique to a specific type of spinal curvature. To optimize the clinical utilisation of this type of evaluation further research should investigate which parameters provide redundant information, and which parameters may be used to classify scoliosis patients.

In the present study the strongest agreement between the two systems was found to be for parameters that had a component in the vertical and M/L directions, and the weakest for measurements that involved an A/P component. This result is similar to that found in adult subjects comparing the same two systems [31]. The most notable difference between the two systems was for the A/P shift of the $SHLD_{BOS}$ and relative measure of the $SHLD_{PEL}$. This difference in measurement is related to three factors. The first would be the A/P position of the body, which would have some variability each time the patient placed their feet in the foot template. The second factor is associated to the postural sway of the patient. Postural sway in the A/P direction principally occurs about the axis of the ankle joints [26]. This sway is greater in the A/P direction than in the M/L direction, when the feet are shoulder width apart. The effect of this error can be noted in the angular measure of rotation, which had greater differences than the angular measure of tilt. The calculation of rotation, involves the coordinates that are largely dependent on the A/P and M/L position. The calculation of tilt is most dependent on the M/L and vertical position, where there is little vertical movement, and M/L movement is controlled by a load unload response between the right and left limbs [27]. The effect of postural sway may be reduced if repeated digitisations of the same landmarks are obtained, but also if the order of digitisation is organized to minimise the time between sequential digitisations. The third factor may be related to the order chosen to digitise the anatomical landmarks. In this study, the right acromion was digitised, followed by the inferior angles of the right and left scapula, followed by the left acromion. This order may have resulted in the patient moving between the digitisation of the right and left acromions. Future studies should investigate changing the order of landmark digitisation, to minimise the time between the digitisation of two consecutive landmarks.

The sequential digitisation system was compared to the stereovideographic system due to its potential applicability in a clinical environment. Although, the stereovideographic system has the advantage of providing repeated samples of passive markers in real time, a disadvantage arises due to the overall cost, expertise, and time required to perform the evaluation limiting its regular utilisation in a clinical environment. The sequential digitisation system is less costly, and simpler to use making it a more pertinent clinical tool to obtain postural alignment measurements. However, environmental conditions such as changes in temperature, humidity and air flow merit attention when utilising the system, since these factors may influence the accuracy of the system.

Conclusion

The postural characteristics of the IS patients was found to be specific to the type of curvature. These characteristics were most prominent in the transverse plane for RTh patients, in the frontal plane for LThL patients and in the frontal and transverse planes for the RThLL patients. A strong agreement between the stereovideographic system and the sequential digitization system suggests that the sequential digitization system has potential for the clinical postural evaluation of IS patients.

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Table 1: Radiological characteristics of untreated IS patients (Avg = average, SD = Standard Deviation).

Curve Type	Apex	N	Cobb angle (°)		Kyphosis (°)		Lordosis (°)	
			Avg	SD	Avg	SD	Avg	SD
Thoracic	T6-T11	18	25	10	26	13	48	10
Thoracolumbar	T12-L1	15	17	11	33	10	43	12
Double								
1st	T6-T11	24	32	10	25	11	51	10
2nd	T12-L4		27	7				

Table 2: Average absolute difference and Intra-Class Correlation Coefficient for postural measures calculated with the stereovideographic system and the sequential digitisation system. (Avg = Average; SD = Standard Deviation ICC = Intra Class Correlation, Lower Bound = -95 % Confidence Interval, Upper Bound = + 95 % Confidence Interval).

	Absolute Difference		ICC		
	Avg	SD	Avg	Lower Bound	Upper Bound
PEL_{BOS} Tilt (°)	1.0	0.7	0.92	0.84	0.96
$SHLDB_{BOS}$ Rotation (°)	5.7	4.6	0.59	0.19	0.79
$SHLD_{BOS}$ Rotation (°)	3.3	3.0	0.65	0.30	0.82
$SHLD_{BOS}$ Tilt (°)	1.2	1.1	0.92	0.84	0.95
$SHLD_{PEL}$ Rotation (°)	2.8	2.4	0.92	0.84	0.96
$SHLD_{PEL}$ Tilt (°)	1.5	1.3	0.92	0.84	0.96
$SHLDB_{BOS}$ Tilt (°)	1.7	1.8	0.92	0.83	0.96
$SHLDB_{PEL}$ Tilt (°)	2.1	2.0	0.92	0.85	0.96
$SHLDB_{PEL}$ Rotation (°)	3.0	3.0	0.71	0.42	0.85
$SHLD_{SHLDB}$ Rotation (°)	2.7	2.4	0.90	0.80	0.95
$SHLD_{SHLDB}$ Tilt (°)	1.9	2.0	0.84	0.68	0.92
$T1_{S1}$ M/L Shift (mm)	6.1	4.4	0.93	0.86	0.96

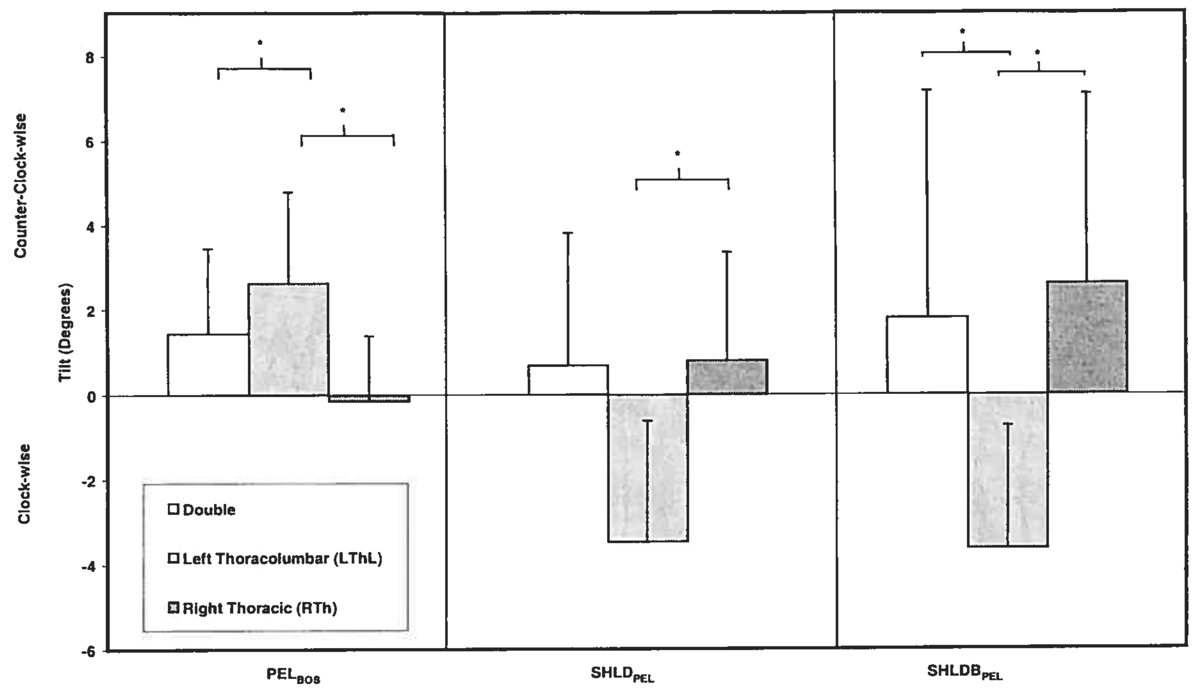

Figure 1: Angular parameters in the frontal plane for the right thoracic (RTh), left thoracolumbar (LThL), and right thoracic left lumbar (RThLL) patients (*$p<0.05$). Reference to base of support (BOS): PEL_{BOS} = Pelvis. Reference to pelvis (PEL): $SHLD_{PEL}$ = Shoulders; $SHLDB_{PEL}$ = Shoulder blade.

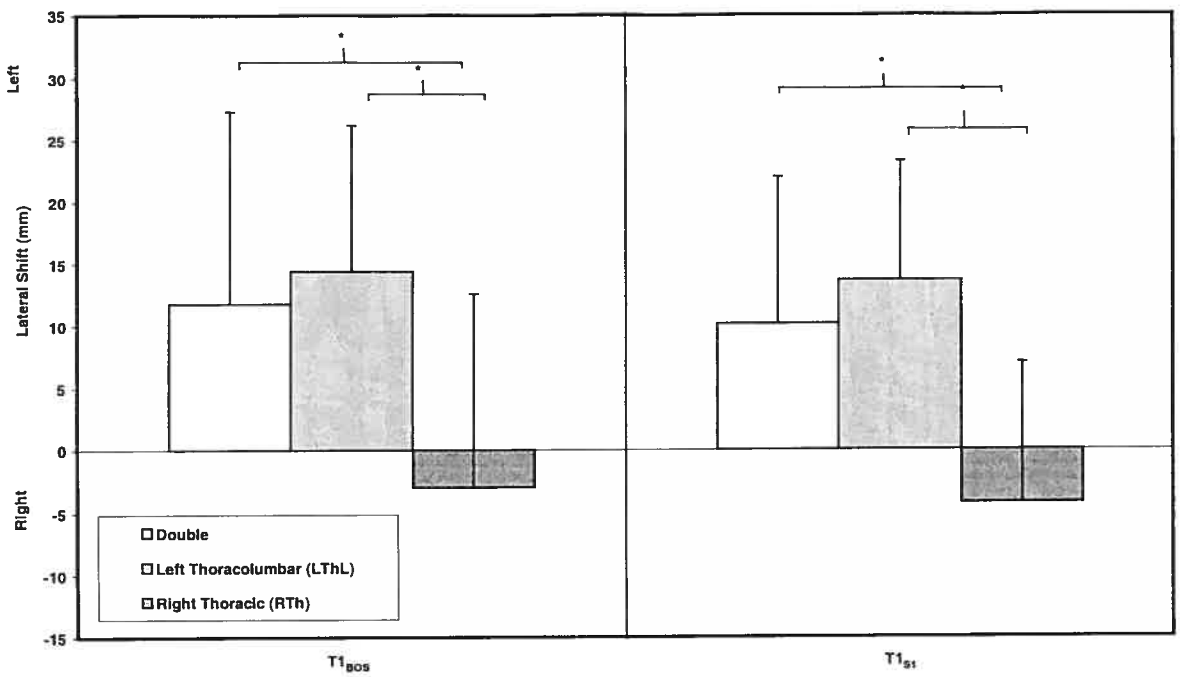

Figure 2: Linear parameters in the frontal plane for the right thoracic (RTh), left thoracolumbar (LThL), and right thoracic left lumbar patients (RThLL) (*$p<0.05$) Reference to base of support (BOS): $T1_{BOS}$ = 1st Thoracic spinous process. Reference to 1st sacral prominence (S1): $T1_{S1}$ = 1st Thoracic spinous process.

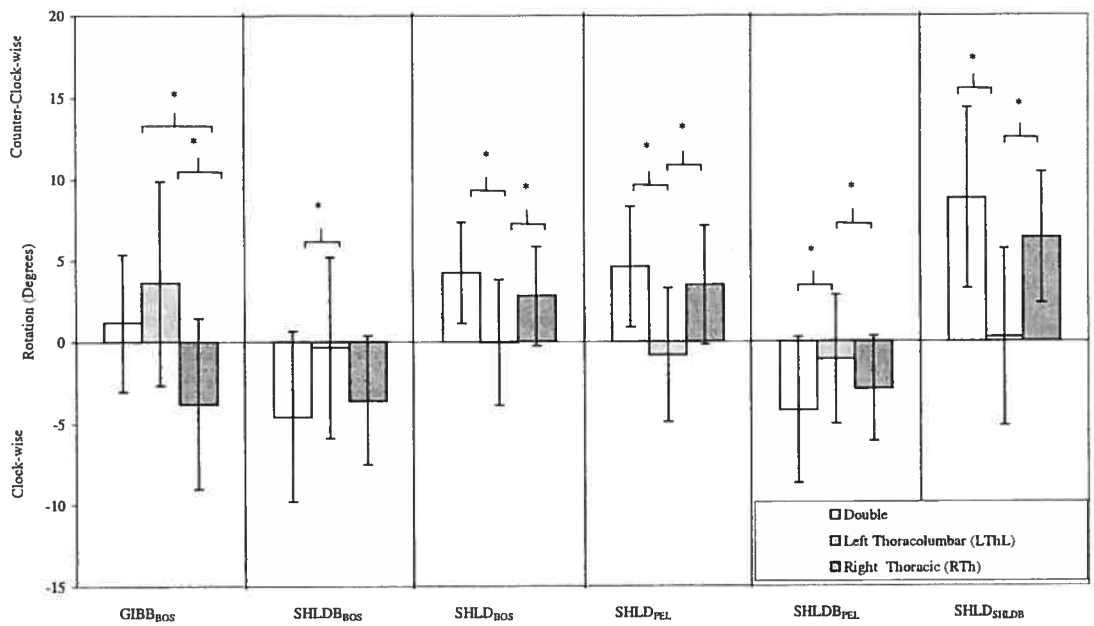

Figure 3: Angular parameters in the Transverse plane for the right thoracic (RTh), left thoracolumbar (LThL), and right thoracic left lumbar (RThLL) patients (*p<0.05). Reference to base of support (BOS): $GIBB_{BOS}$ = Gibbosity; $SHLDB_{BOS}$ = Shoulder blade; $SHLD_{BOS}$ = Shoulder. Reference to the pelvis (PEL): $SHLD_{PEL}$ = Shoulder; $SHLDB_{PEL}$= Shoulder blade. Reference to shoulder blade: $SHLD_{SHLDB}$ = Shoulder.

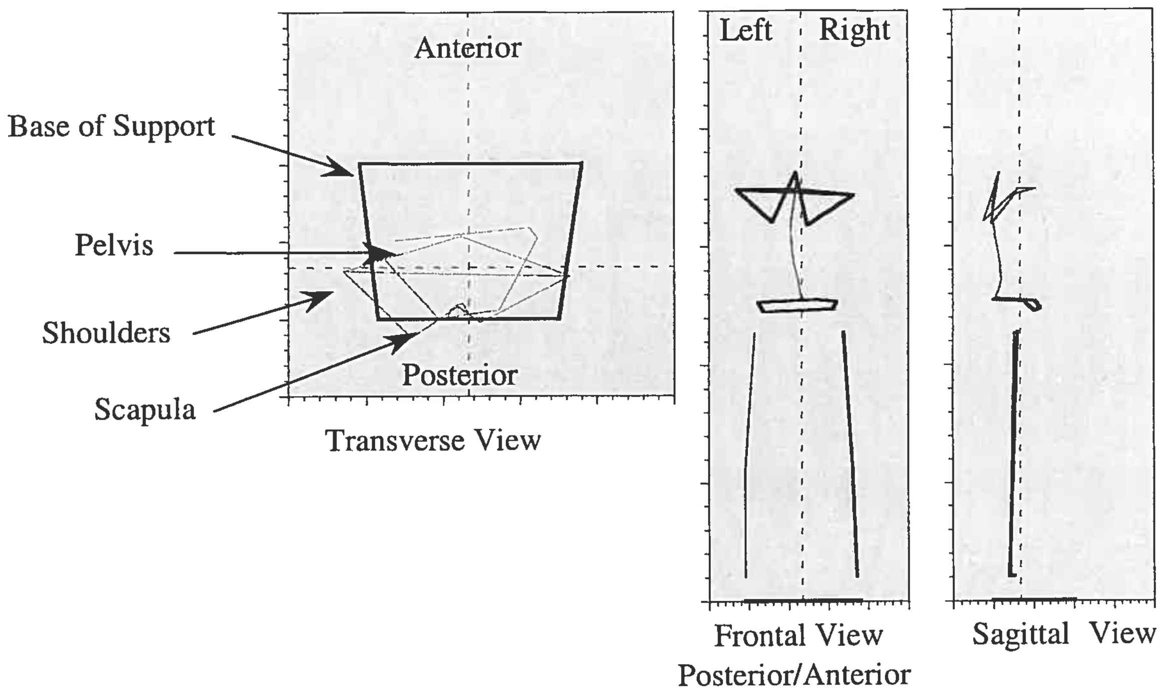

Figure 4: A typical postural representation of a left thoracolumbar patient.

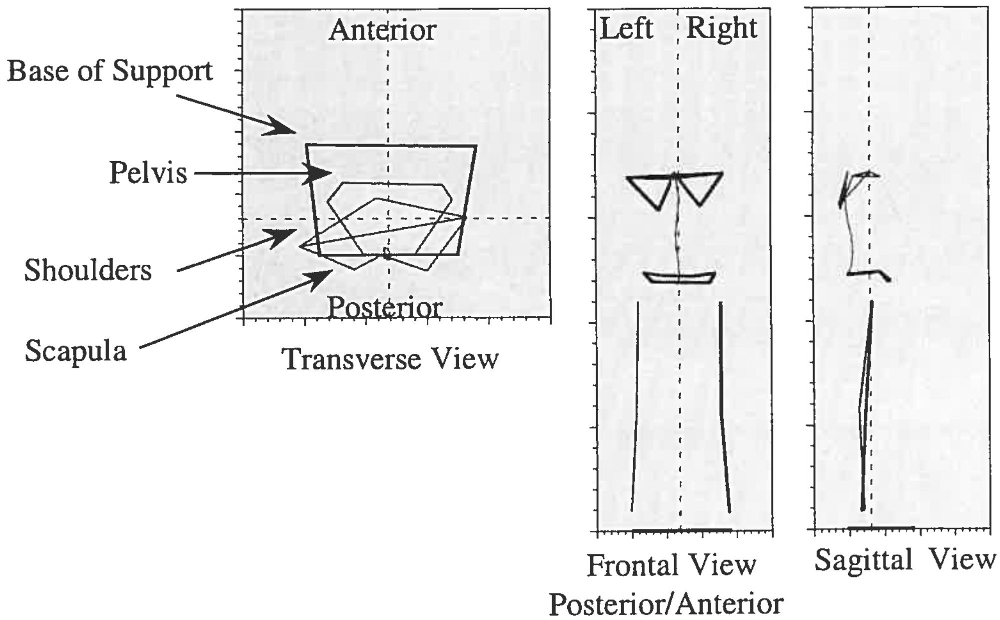

Figure 5: A typical postural representation of a right thoracic patient.

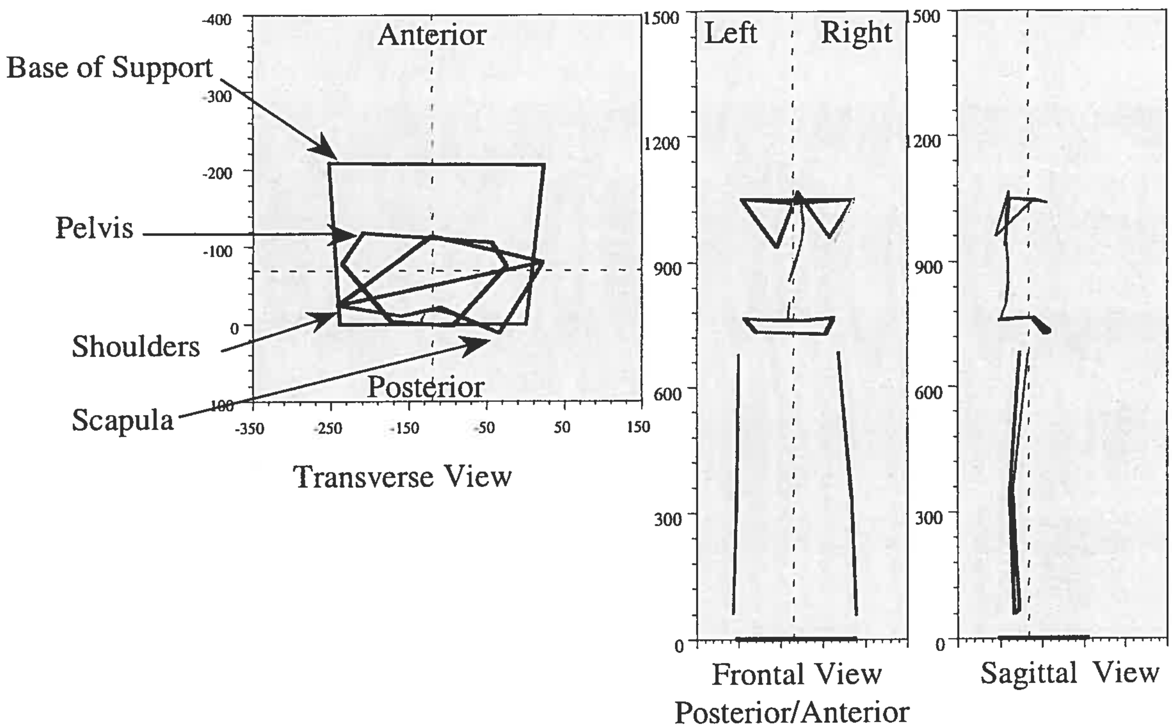

Figure 6: A typical posture of a right thoracic left lumbar patient.

Chapter V: Manuscript #3.

The change in postural alignment induced by a non-rigid brace fitted on Idiopathic Scoliosis patients: A comparison of different curve types.

The natural history of IS patients is specific to the type and amplitude of spinal curvature. Traditional treatment of IS patients has focused on the application of lateral forces through the spine and rib cage using a 3 point pressure technique and in some cases traction of the spinal column. There is little adaptation of the shape and form of these rigid braces to the specific type of IS curvature. The scope of this manuscript is to investigate the change in posture induced by a non-rigid brace fitted uniquely in reference to the initial postural and radiological characteristics of the IS patient.

Title: The change in postural alignment induced by a non-rigid brace fitted on Idiopathic Scoliosis patients: A comparison of different curve types.

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Abstract

The objective of this prospective study was to evaluate the acute change in spinal curvature and posture of Idiopathic Scoliosis patients when a curve specific ''corrective movement principle'' (CMP) is applied. A total of 113 patients diagnosed with progressive Idiopathic Scoliosis underwent a comprehensive evaluation (clinical, radiological, and postural geometry) prior to and following the application of the CMP. The principal radiological parameters included the Cobb angle for the estimation of the degree of spinal curvature in the frontal and the sagittal planes. The postural geometry evaluation was used to quantify the position and the orientation of the pelvis, shoulders and thorax. These two evaluations assisted to define the patient classification, which guided the unique application of the CMP to each type of curvature. A non-rigid brace (SpineCor©) was used to apply the CMP, and a second comprehensive evaluation was performed to evaluate the spinal and postural changes induced by the CMP. There was a significant decrease in the frontal plane Cobb angle with the brace induced CMP. This decrease in spinal curvature was also accompanied by curve specific postural changes to the tilt, rotation, and shift of the pelvis, shoulders and thorax. These postural changes reflect the unique CMP that was used for each type of scoliosis curvature. The results of this study indicate that it is possible to acutely decrease a scoliosis curvature using a treatment technique that is based on the CMP.

Key Words: Orthopaedics, Posture, Idiopathic Scoliosis, Biomechanics, Paediatrics

Introduction

The prevalence of Idiopathic Scoliosis (IS) is estimated to range from 2-4% of the population [5,34]. The principal characteristic of IS is the torsion and deviation of the spine in the frontal plane which is accompanied by individual vertebral deformity [35] and disorientation [30]. In addition, the unique segmental specific vertebral morphology [23,33] and mobility, [33] as well as the risk factors such as growth [16] complicate the precise definition of the pathomechanics of disease progression and the definition of an optimal treatment approach.

The material and forms of external rigid bracing systems have changed considerably over the years with numerous techniques utilised [20, 33]. However, the underlying treatment principles have not changed. These principles include traction and a lateral force applied to the trunk resembling the three-point pressure principle [18]. The initial reducibility of scoliosis curves based on this approach has been found to range from 50 to 62 % of the initial spinal curvature [10,25]. This reducibility is gradually lost during growth and development of the adolescent with definite limitations in maintaining the reduction after weaning [10,25]. There are also a number of patients who ultimately progress to surgery [10,25]. Surgical treatment has been found to stabilize and reduce the scoliosis curve [9, 26]. However, the negative consequences such as the risk for revision [11, 12] and decreased mobility [4] has led to the acceptance of rigid brace treatment as a viable means to reduce and stabilize spinal curvatures [10, 28].

There are several limitations of the current bracing techniques. Some are included in three-point pressure principle, which is the assumption that the same principle of force application (amplitude and direction) can be used at different spinal levels. The efficacy of these forces that are applied through the bracing systems [1,2] has also been questioned. With a radiological study finding no immediate effect of a rigid brace on rib hump [19].

The unique morphology (skeletal and muscular) and mobility of each spinal level [33] suggests that a treatment approach that functions in accordance to these characteristics warrants further attention. Therefore, in this study, a curve specific ''corrective movement principle'' (CMP) is proposed. The objective is to quantify the induced change in spinal curvature and posture of IS patients when the ''corrective movement principle'' is applied.

Material and Methods

Patients

A total of 113 patients, 100 girls and 13 boys, were included in this study. These patients attended the Spinal Pathology Evaluation Centre at Sainte-Justine Hospital and were evaluated for the follow-up of their orthopaedic spinal problem. Inclusion criteria were: 1) Confirmed diagnosis of IS with normal clinical neuromuscular exam; 2) Initial Cobb angle equal or superior to 15°; 3) A progression of 5° or more within the last year and/or a high potential risk of evolution; 4) No prior treatment (e.g. rigid brace) for their IS, with the exception of physiotherapy.

Evaluation Protocol

Each IS patient underwent a comprehensive evaluation before the fitting of the brace and immediately after performed on the same day within 30 minutes to 2 hours of each other.. This included an anthropometrical, clinical, radiological and postural geometry examinations. The anthropometrical evaluation involved the palpation of surface anatomical landmarks that served as markers for the clinical and postural geometry evaluations. A total of 56 anatomical landmarks were palpated and marked with a dermographic pencil. The landmarks were situated bilaterally on the 1) Base of support: tip of the second toe, heels, lateral malleoli, 2) Lower extremities: superior lateral border of the tibial plateau, greater trochanter, 3) Pelvis: superior lateral border of the iliac crest, posterior superior iliac spine, anterior superior iliac spine, 4) Shoulders: right and left acromion, 5) Scapula : inferior angle of scapula. Every second spinous process was also marked from T1 to S1. The clinical exam involved both subjective observations of the patients posture (static and dynamic), as well as the evaluation of the history of the patient.

The radiological exam of the patient was performed using a numeric radiographic technique where the radiation of the patient is reduced to 62% [29] of standard radiographic techniques. A posterior-anterior radiograph of the spine was taken with the superior limit being the cervical region and the inferior limit the inferior aspect of the pelvis. A sagittal radiograph of the spine was obtained at the same level providing a right lateral view of the patient. The apex and side of the spinal convexity defined the type of curvature. The amplitude of spinal deformity in the frontal plane, Kyphosis (T2 to T12) and Lordosis (L1 to S1), were measured using the Cobb angle technique [6].

The postural geometry evaluation was performed using a Motion Analysis system (Motion Analysis Inc.). This system consisted of 8 high-speed video cameras connected to a video processing unit and computer. The locations of the cameras were arranged such that there was a full anterior and posterior view of the patient with a minimum of 2 cameras viewing each individual anatomical landmark. The patient was evaluated in a quiet standing position with the arms slightly abducted. The technique used to calculate the postural parameters specific to the pelvis, shoulders and scapula is the same as that reported previously [8,3]. This technique defines the right heel as the body reference system also referred to as the base of support (BOS). The rotation, tilt and lateral shift are then calculated in reference to the BOS, for of the pelvis (PEL_{BOS}), shoulder blade ($SHLDB_{BOS}$) and shoulders $SHLD_{BOS}$ and between segments such as shoulders in reference to the pelvis ($SHLD_{PEL}$), shoulder blade in reference to the pelvis ($SHLDB_{PEL}$) or shoulders in reference to the shoulder blades ($SHLD_{SHLDB}$). The angular measurements of rotation and tilt were obtained by first calculating the distance between two bilateral landmarks (ie, right and left inferior angle of the scapula to define the rotation of the scapula). Secondly, calculating the angle that the line representing this distance makes with the frontal and transverse planes. Medial-Lateral (M/L) shift was obtained by subtracting the position of the T1 and S1 spinous processes from the centre of the base of support ($T1_{BOS}$, $S1_{BOS}$) and also between T1 and S1 ($T1_{S1}$).

The convention used in this study for the angular measurements was positive when counter-clockwise as seen from posterior (Frontal plane), apical (Transverse plane) and right point of views (Sagittal plane). The linear measurements are positive anteriorly, vertically and to the left of the patient. These conventions in simpler terms may be explained in the following manner. A clock-wise tilt of the $SHLD_{BOS}$ in the frontal plane reflects a left acromion that is higher than the right acromion. A counter clockwise rotation of the $SHLDB_{BOS}$ in the transverse plane is reflected by the right inferior angle of the scapula situated anteriorly to the left inferior angle of the scapula.

These evaluations served to define the amplitude and severity of the spinal curvature, the type of spinal curvature as well as additional postural characteristics unique to each type of curvature. This was followed by the definition and application on the patient of the curve specific ''corrective movement principle'' (CMP) by the attending physician. A non-rigid brace (SpineCore©) was used to favorise and maintain the CMP on the patient. This non-rigid brace is composed of a pelvis base and a bolero fitted to the upper trunk as an anchor to manipulate the orientation of the pelvis, thorax and shoulders through the use of four elastic bands. The brace was fitted to favorise the CMP in order to evaluate the induced changes on the spine and posture.

The Corrective Movement Principle (CMP)

The CMP evaluated in this study is based on the unique kinematics of the thoracic, thoracolumbar and lumbar segments of the spine. The amplitude and direction of these kinematics is defined by the shape of the vertebra, the geometry of its articular facets, the spinous processes and the presence or absence of rib articulations. Soft tissues such as muscles and ligaments also control, and limit actively or passively, the amplitude of the movement depending on the orientation of their vector of origin and insertion.

The mobility of the thoracic spine, from T1 down to T11, is directed not only by the orientation of the zygapophyseal facets in the frontal plane, but also by its articulation with the ribs, and muscle action. The thoracic segment shows relatively important segmental motion in the transverse plane, with small amplitudes of flexion/extension [33]. In the thoracolumbar region, the joints with the rib cage are less constraining and the orientations of the facets are directed progressively in a sagittal direction. As a result, this segment could produce large movements in the frontal plane, some coupled movements in the sagittal plane, but very little in the transverse plane. The shape of the lumbar vertebrae is very specific with facets in a complete sagittal plane. This segment could produce very large amplitudes of flexion/extension but little lateral bending and almost no rotation.

Since the movement amplitude of the thoracic spine is larger in torsion, the corrective movement should also be planned to occur in this direction. The correction of a right thoracic curve should then include a de-torsion of the thorax relative to the shoulder girdle (Figure 1). The shoulder girdle should be rotated to a neutral position or, if possible, progressively into a clockwise rotation. The corrective movement is then obtained by rotating the thorax in a counter-clockwise direction relative to the shoulders (See Figure 1: A, B). This action will also prevent the shoulder rotation from being absorbed by the thoracolumbar or lumbar segment of the spine. This movement represents a de-torsion between the vertebral segments over and under the apex, associated with coupled movements in the frontal and sagittal plane. They then reach an improved alignment with the vertebrae involved in the scoliosis. The corrective movement is also accomplished with a slight down tilt of the right shoulder (See Figure 1: A). The right lateral shift of T1 in relation to S1 should consequently be reduced (See Figure 1: C). This combination of movements should result in the straightening of the spine.

- Insert Figure 1 about here -

In the thoracolumbar region (T11, T12 and L1), the movement of greater amplitude is the lateral bending. Thus the corrective movement includes a change in the bending of the trunk in the frontal plane. For a left thoracolumbar curve, it goes from a clockwise to a counter-clockwise bending of the trunk in reference to the pelvis. The right thoracolumbar curves require the opposite movement. To account for the frequent pelvis tilt of these patients, the use of a shoe lift should also be considered. This horizontalisation of S1 will then accentuate the desired action of the corrective movement in the frontal plane.

In the lumbar region under L1, the main permissible movement is the flexion/extension in the sagittal plane. However, this action is also closely associated with the natural "C" shape configuration of the lordosis. However, its close location relative with the pelvis that represents a strong base, should allow some alternative strategy. The corrective movement is then designed principally to occur in the frontal and the sagittal plane. It includes a right shift of the trunk relative to the pelvis, combined with a lateral inclination of the trunk to the left. This produces an extension of the lumbar vertebrae by bringing them into the direction of their natural position.

Since the double curvatures cover all segments of the spine, a specific plane of mobility could not be used. For these patients, the corkscrew shape of the spine represents the geometry to change. In these cases, the principal corrective movement includes torsion of the shoulders relative to the pelvis around a longitudinal axis. This specific spine shape should not be seen as a combination of two curves. The kinematics involved is different and is reflected by a specific postural geometry.

Brace Components and Fitting.

The non-rigid brace is composed of a pelvic base, crotch bands, thigh bands, bolero and corrective elastic bands (See Figure2). The pelvic base is composed of a thermo deformable plastic, which when placed on the patient is stabilized by the crotch and thigh bands. The bolero serves as the attachment for the corrective elastic bands. It is placed on the patient so that the fabric lies between T4 and T12, centered to the midline of the spine. Once the desired CMP is chosen for the patient, and a shoe lift (if necessary) with appropriate height is decided upon, the CMP is manually applied to the patient (See Figure 1.). The corrective elastic bands are then attached to the bolero and the pelvic base with appropriate tension and direction so that the CMP is maintained (See Figure 2.). Within the context of this study the brace was fitted on the patients by one of 3 clinicians trained specifically for this task, and should only be attempted by a clinician who has undergone proper training. Depending upon the initial state of the patient, the amplitude of the forces created by the tension of each corrective band will depend upon their two points of attachment. The tension should be sufficient to maintain the CMP, however not create any discomfort on the patient. The length and tension of each band will change in conjunction with the patients growth and change in body flexibility. However, the direction and point of force application for each type of scoliosis curve should not change through the course of treatment.

- Insert Figure 2 about here -

Statistical Analysis

Data analysis included descriptive statistics as well as two-way analysis of variance (ANOVA) for repeated measures: the two factors were 1) curve type, with four levels: thoracic, thoracolumbar, lumbar and doubles, and 2) the repeated factor BRACE, with two levels: initial status and the brace maintained corrective movement principle (BMCMP) condition. In the presence of an interaction effect, simple main effects were calculated to identify between curve type differences at the initial and the BMCMP condition, and change between with and without BMCMP conditions for the four groups. When appropriate, Sidak post hoc multiple comparisons procedure was used to locate between-groups differences. A 0.05 alpha level was used for all analyses. The variables compared between conditions were the Cobb angle and the angular and linear postural parameters described above. The data analysis was analysed for right thoracic, left thoracolumbar and right thoracic left lumbar curves. If a patient had an opposite curve such as left thoracic, the postural data was inversed (multiplied by –1). Therefor, interpretation of the data must be made in reference to a RTh, LThL and Double (right thoracic left lumbar) curve.

Results

Initial Radiological Characteristics of the Idiopathic Scoliosis patients.

The mean (± 1 SD) age at the initiation of treatment was 13 (± 1) years. Most of the patients (69), showed a Risser sign of 0, 13 patients were at Risser 1, 9 patients at Risser 2, 18 patients at Risser 3, and 2 patients at Risser 4. The patients were classified as 43 thoracic curves (41 right thoracic, 2 left thoracic), 45 thoracolumbar (14 right thoracolumbar, 31 left thoracolumbar), 8 left lumbar and 17 double curves (right thoracic left lumbar). The initial radiological characteristics for each type of curvature are presented in Table 1.

- Insert Table 1 about here -

Differences between groups and changes induced by the corrective movement principle.

The radiological and postural characteristics of the four patient curve types prior to and following the application of the BMCMP are presented in Table 1 and Table 2 respectively. For the Cobb angle, the ANOVA revealed a significant interaction effect (See Figure 3). The simple main effects revealed that regardless of the classes, the BMCMP condition was significantly lower than the initial condition ($P<0.01$). After the application of the brace induced BMCMP the mean reducibility was 28% (SD: 18) for the thoracic, 38% (SD: 21) for the thoracolumbar, 32% (SD: 11) for the lumbar and 21% (SD: 22) for the double curves. Between group pairwise comparisons identified a significant difference between the thoracic and thoracolumbar patients ($p=0.034$) at the initial condition, and between the Double and thoracolumbar ($p=0.005$) and thoracic and thoracolumbar ($p = 0.002$) groups after the BMCMP condition.

For the postural evaluations, the ANOVA revealed a significant interaction effect ($p<0.05$) for all of the parameters evaluated except for two (See Table 2).

These two parameters were the rotation of the $SHLD_{BOS}$ and rotation of the $SHLDB_{PEL}$, where there was a significant main effect for brace and for group ($p<0.05$). A pairwise comparison between groups revealed a significant difference between the thoracic and thoracolumbar patients for the rotation of the $SHLD_{BOS}$. For the rotation of the $SHLDB_{PEL}$ a difference was found between the Double curves versus the thoracic, thoracolumbar and lumbar curves, and a significant difference between the thoracic versus the lumbar and thoracolumbar curves.

- Insert Table 2 about here -

For the parameters where there was an interaction effect, post-hoc pairwise comparisons were performed to identify differences between groups at the initial status and BMCMP condition (See Table 2, Figure 3, 4, 5, 6). These differences reflect the initial unique postural characteristics for each type of curvature. The thoracic patients were significantly different to the thoracolumbar, lumbar and double for a number of parameters. These patients had a rotation in the transverse plane for the $SHLD_{PEL}$, $SHLD_{SHLDB}$ and an opposite rotation of the $SHLDB_{BOS}$ that was different from the thoracolumbar patients. They also had a lateral shift of $T1_{BOS}$ and $T1_{S1}$ that was different from the thoracolumbar and lumbar patients, and $T1_{S1}$ different from the Double patients. The patients with a Double curvature were different from the thoracolumbar for 3 parameters, and the lumbar for 2 parameters. Theis included a rotation of the $SHLDB_{BOS}$, $SHLD_{PEL}$ and $SHLD_{SHLDB}$ in the transverse plane. For the thoracolumbar patients the principal postural characteristics are most evident in the frontal plane, which include a tilt of the PEL_{BOS} that was significantly greater than the thoracic patients. For the lumbar patients, the major postural characteristics are also in the frontal plane. This includes a shift to the left of the $T1_{S1}$, with the presence of a pelvic obliquity in some patients.

- Insert Figure 3 about here –

- Insert Figure 4 about here-

- Insert Figure 5 about here-

- Insert Figure 6 about here-

The significant differences identified between groups at the BMCMP condition are also reported in Table 2. These differences reflect the unique postural position that results from the BMCMP for each type of curvature, where as the within group difference between the initial condition and the BMCMP reflect the action of the BMCMP.

Corrective Movement Thoracic Patients

The corrective movement for the right thoracic patients was characterized by a significant change in the tilt and rotation of the PEL_{BOS}, tilt of the $SHLD_{BOS}$, rotation of the $SHLD_{PEL}$, rotation of the $SHLD_{SHLDB}$, lateral shift of the shoulders, and lateral shift of the $T1_{S1}$. The main effect for BRACE also indicated a significant change in rotation of the $SHLD_{PEL}$ and $SHLDB_{PEL}$. This postural reorganization resulted in a mean 10° decrease of the Cobb angle. Figure 7 represents a typical postural geometry of a right thoracic patient following the BMCMP.

-Insert Figure 7 about here –

Corrective Movement Thoracolumbar Patients

For the thoracolumbar patients, the mean postural changes are represented by a change in the tilt of the $SHLD_{BOS}$, rotation of the $SHLDB_{BOS}$ and rotation of the $SHLD_{PEL}$. The main effect for BRACE also indicated a significant change in $SHLD_{BOS}$ rotation and rotation of the $SHLDB_{PEL}$. Figure 8 represents the postural geometry of a typical left thoracolumbar patient following the fitting of the corrective movement. These postural changes were accompanied by a mean decrease in the Cobb angle by 10°.

- Insert Figure 8 about here -

Corrective Movement Lumbar Patients

For the lumbar patients, there was a significant change in the tilt of the $SHLD_{BOS}$. The main effect for BRACE also indicated a significant change in $SHLD_{BOS}$ rotation. Figure 9 represents a typical postural geometry of a left lumbar patient following the fitting of the brace. This was accompanied by a decrease in the degree of the lumbar spinal curvature of 7°.

- Insert Figure 9 about here –

Corrective Movement Double Patients

For the patients with a double curvature, the mean postural parameters are presented in Table 2. There was a change in the rotation of the PEL_{BOS}, tilt of the $SHLD_{BOS}$, rotation and tilt of the $SHLD_{PEL}$, rotation of the $SHLD_{SHLDB}$ and lateral shift of $T1_{S1}$. The main effect for BRACE also indicated a significant change in $SHLD_{BOS}$ rotation and rotation of the $SHLDB_{PEL}$. Figure 10 represents a typical postural geometry of a patient with a right thoracic left lumbar spinal curvature after the application of the corrective movement. There was a mean decrease in the Cobb angle of 6° for the thoracic curve and 8° for lumbar and thoracolumbar curves.

- Insert Figure 10 about here -

Discussion

The objective of this article was to evaluate the acute change of an IS curve and posture that may be induced by the application of the BMCMP. The acute change is defined within the context of a change in the spine and posture immediately after the application of the BMCMP (30 minutes to 2 hours). When the BMCMP was applied to the patients there was a decrease in the amplitude of spinal curvature accompanied by postural changes that were unique to each group of patients.

Estimating the amplitude of spinal curvature using the Cobb angle [6] and how it changes overtime with the application of an external bracing system is the technique most often used to evaluate the efficacy of treatment in IS [10, 20, 25]. In the present study there was a significant decrease in the Cobb angle for all groups of patients when the BMCMP was applied. This change corresponded to a mean reducibility of 28 %, with the largest reducibility of 38 % found in patients with a thoracic curve, and the lowest of 21 % found for the patients with double curves. Emans et al., (1986) also found that there were some differences between the types of curves, with the double curves being the most difficult to change. The amplitude of this initial reducibility has been reported to be greater (50-62%) with a rigid bracing system [10, 25]. The importance of obtaining an initial reduction of the spinal curvature has been emphasised in studies that have evaluated the long term out come of rigid and non-rigid brace treatment [7, 10, 25]. In these studies, the trend identified during treatment was an initial reduction, followed by an average loss of this reduction through to follow-up [7. 10, 25]. An initial reduction of the curve of more than 50 % has been positively associated with a net correction at follow-up for rigid bracing systems [10, 25]. In a similar manner, the initial reducibility obtained using the technique described in this study has been reported to have a strong significant correlation with end of treatment outcome [7]. What is not thoroughly understood, is what is the optimal technique of applying an external brace to correct the curvature of the spine.

In the present study, a 3-D postural evaluation technique was chosen to evaluate the position and orientation of the pelvis, thorax and shoulder girdle [8]. This permits a characterization of the net geometrical configuration of IS patient posture [3, 24] as well as changes that occur in conjunction with a spinal correction [8, 37]. The initial evaluation prior to the fitting of the brace identified differences between groups that mainly included the variables of pelvic tilt, shoulder blade rotation, shoulder rotation, and lateral shit of T1 in reference to S1. Pelvic obliquity has been previously associated with spinal curvatures in the thoracolumbar and lumbar regions [21, 36, 37] which is also emphasised in the present results where the thoracic group had less obliquity than the thoracolumbar group. In contrast to the patients with a lumbar or thoracolumbar curve, the double and thoracic patients were found to have greater rotation of the shoulders, scapula and an opposite rotation between the two. Shoulder rotation of similar amplitude (average 6°) has also been noted in pre-operative thoracic patients, and attributed to be a protraction of the scapula [22]. This protraction, is hypothesised to be the result of the underlying rib hump, which in thoracic patients has been strongly correlated to the amplitude of spinal curvature [31]. The consequence is the observed opposite rotation of the shoulders in reference to the scapula that was found to be greater in the thoracic and double group than the thoracolumbar group.

The CMP was proposed as a concept for the application of a non-rigid brace in a unique manner to each type of IS. The application of this movement is dependent upon the initial state of the patient, as well as the complex interaction of soft tissue, coupled vertebral movements and the morphological characteristics of each vertebra. The effectiveness of this movement does not necessarily imply the application of large external forces, but optimal forces applied in an optimal direction for each type of scoliosis curvature. When the BMCMP was applied to the patients, there were common changes to all groups that included shoulder tilt and rotation in reference to the pelvis. Unique changes were also observed for the thoracic and double patients that included the rotation of the shoulders in reference to the scapula. However, when these changes are considered individually they reflect, the unique action of the CMP. For the thoracic patients these changes involved the opposite rotation of the $SHLD_{SHLDB}$ accompanied by a coupled movement of $SHLD_{BOS}$ tilt and lateral shift of T1 in reference to S1. Similar effects of the BMCMP on the posture of a patient with IS was also reflected in a study that found a 3° decrease in rib hump that accompanied a 9° decrease in spinal curvature [14]. For the thoracolumbar patients there was also a change in the relative rotation of the $SHLD_{PEL}$, the tilt of the $SHLD_{BOS}$ and tilt of the $SHLD_{PEL}$. Although there was a relatively small number of lumbar patients, they showed a tendency for a tilt of the $SHLD_{BOS}$. The patients with a double curvature had a significant change of the $SHLD_{PEL}$ in the transverse plane. With these postural changes, it is important to note that there was not a realignment of the patients posture to a completely normal position. This is reflected by the postural parameters that increased, such as the lateral shift of T1 and S1 for the double and thoracic patients. Since these changes are caused by the BMCMP, a longitudinal study is required to evaluate posture with and without the BMCMP from initial treatment through to follow-up. Long term studies that have evaluated a rigid brace have found some decrease in rib hump after a follow-up of 3.8 years [32], with some decrease in trunk decompensation [17].

The treatment approach that is used here is different than that utilised using rigid bracing systems. The principal mechanics associated with the reduction and stabilisation of IS curves using rigid braces involves the application of distraction and a three-point pressure approach. The efficacy of the rigid brace treatment approaches has been questioned through biomechanical analysis [1,2]. These factors reflect the non-specificity of rigid brace treatment, where there is no account for the segmental specific anatomy and mobility of the spine. The corrective movement that is favoured using the non-rigid brace focuses treatment on each specific spinal level, implicating a different action necessary for each curve type. The principles of the orthopaedic approach applied to the IS patients of this study are similar to that applied to the Pavlik harness for congenital hip dislocation of infants. This principle is based on the optimal definition of a movement that will favour correction, normal growth and development and discourage aggravating movements to the pathology [13, 15, 27]. The optimal efficacy of this treatment is reported to be dependent on the early commencement of treatment, as well as good patient compliance [15].

Although, the postural evaluation techniques used in this study did identify unique postural changes with the brace, there are a couple of limitations based on this approach. Due to the size of the bolero, the thoracic, thoracolumbar and lumbar prominences, and the majority of the spinous processes with the exception of T1 and S1 could be not be identified and evaluated with the brace on the patient using this postural evaluation technique. Only anatomical landmarks that were identifiable when the brace was fitted to the patient were used. This limits the interpretation of the amplitude of induced trunk rotation to the changes observed in the scapula. A more detailed analysis of the spinal alignment, vertebral deviation, rotation and rib rotation is required to document additional radiological changes related to this treatment approach. Another question to be addressed is related to the tension in each elastic band. Since, the initial reducibility and flexibility of each patient is different, the clinician must judge the amplitude of force that is required to maintain the correction in each elastic band. It is also necessary to evaluate individually the forces exerted through the elastic bands at their origin, and insertion, but also on their contact points on the trunk. Since, these contact forces may contribute to the correction of the spinal deformity. These issues reflect the complexity of evaluating the efficacy of applying the CMP on IS patients.

The effectiveness of the CMP in changing the spinal curvature of IS patients in this study forms the basis for the application of this treatment principle with the objective of altering the natural history of the pathology. Treatment with the CMP would involve the early initiation of treatment, before the patient commences rapid growth and curve structuralisation to benefit from the important mobility of the spine at the early stage of the pathology. The relative simplicity in adapting the brace to the growth of the patient, as well as changes in mobility and flexibility facilitates adaptation of the treatment approach. The control of spine mobility during growth should limit the impact of the aggravating factors and teach the system to work properly in these modified conditions. Positive long-term result should then be expected. Future studies should evaluate the change in spinal curvature and posture over a long term period.

Conclusion

The postural changes that were quantified when the ''corrective movement principle'' was applied were unique for each type of IS spinal curvature. The amplitude of the spinal changes support the basis for the evaluation of the long term efficacy of this treatment approach.

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Table 1: Initial radiological characteristics.

Curve Type	Apex	N	Cobb angle (°)		Kyphosis (°)		Lordosis (°)	
		113	Avg	SD	Avg	SD	Avg	SD
Thoracic	T6-T11	43	30.5	8.5	26.1	10.5	51.6	10.4
Thoracolumbar	T12-L1	45	25.4	7.6	32.0	9.0	52.0	10.7
Lumbar	L2-L4	8	23.6	6.9	37.1	12.2	54.4	8.0
Double (All)		17	30.3	6.6	28.1	10.5	46.7	10.5
Thoracic	T6-T11		31.1	8.5				
Thoracolumbar	T12-L1		29.4	5.1				
Lumbar	L2-L4		29.8	7.5				

Table 2: Initial and BMCMP conditions mean values (± 1SD).

	Initial				BMCMP				Main Effect		Simple Effect		
	D	Th	ThL	L	D	Th	ThL	L	G	B	GB1	GB2	B
Cobb Angle	30 (7)	30 (9)	25 (8)	24 (7)	25 (10)	22 (10)	16 (8)	17 (8)			4	[illegible]	[illegible]
Tilt													
PEL_{BOS}	1.2 (1.3)	0.0 (2.3)	1.3 (2.1)	1.8 (1.3)	1.7 (1.7)	-0.7 (2.6)	1.8 (2.2)	1.2 (2.5)			4		[illegible]
$SHLD_{BOS}$	2.0 (3.2)	1.4 (2.2)	0.8 (2.2)	1.0 (3.5)	0.4 (2.4)	0.0 (2.2)	1.8 (2.8)	2.8 (1.7)				[illegible]	[illegible]
$SHLD_{PEL}$	0.8 (3.2)	1.3 (3.1)	-0.5 (3.2)	0.3 (3.0)	-1.3 (3.2)	0.7 (3.7)	0 (3.0)	2.0 (3.1)					[illegible]
Rotation													
PEL_{BOS}	-0.6 (2.9)	-1.2 (3.6)	0.9 (3.7)	-1.0 (1.8)	4.0 (4.1)	1.3 (3.1)	1.9 (3.7)	1.3 (3.2)					[illegible]
$SHLD_{BOS}$	2.8 (4.9)	4.1 (3.0)	0.4 (4.0)	2.0 (2.3)	-1.8 (5.1)	0.6 (4.1)	-1.6 (3.8)	-1.8 (2.6)	4	A,B,C,D			
$SHLDB_{BOS}$	-6.6 (4.3)	-5.0 (5.3)	1.3 (4.4)	0.2 (5.0)	-6.4 (3.4)	-5.0 (4.3)	-1.5 (3.9)	-2.5 (6.6)			2,3,[illegible]	[illegible]	[illegible]
$SHLD_{PEL}$	3.4 (5.0)	5.6 (2.9)	-0.5 (4.3)	2.5 (2.1)	-5.7 (7.7)	-0.9 (3.4)	-3.5 (6.1)	-1.3 (6.0)			2,4	[illegible]	[illegible]
$SHLDB_{SHLDB}$	9.4 (6.7)	9.4 (5.0)	-0.9 (5.3)	1.3 (5.0)	4.6 (4.8)	5.6 (4.1)	0.0 (4.0)	0.9 (4.7)			2,3,4, 5	[illegible]	[illegible]
$SHLDB_{PEL}$	-5.9 (4.1)	-3.7 (4.2)	0.4 (2.9)	1.2 (3.5)	-10.5 (5.1)	-6.5 (3.7)	-3.4 (5.5)	-2.4 (7.5)	1,2,3, 4,5	A,B,C			
Shift													
M/L $S1_{BOS}$	0 (13)	1 (14)	1 (11)	6 (8.6)	-4 (18)	-5 (15)	-1 (14)	13 (21)					
M/L $T1_{BOS}$	15 (14)	2 (15)	18 (14)	23 (16)	18 (19)	8 (13)	16 (15)	31 (22)			4,5	[illegible]	[illegible]
M/L $T1_{S1}$	14 (12)	-2 (13)	16 (12)	19 (11)	23 (15)	8 (13)	15 (15)	22 (7)			1,4,5	[illegible]	[illegible]

1) D≠Th; 2) D≠ThL; 3)D≠L; 4)Th≠ThL; 5)Th≠L; 6)ThL≠L

A) D; B)Th; C)ThL; D)L

G= Group, B= Brace, GB1 = Group Brace 1, GB2 = Group Brace 2, B = Brace

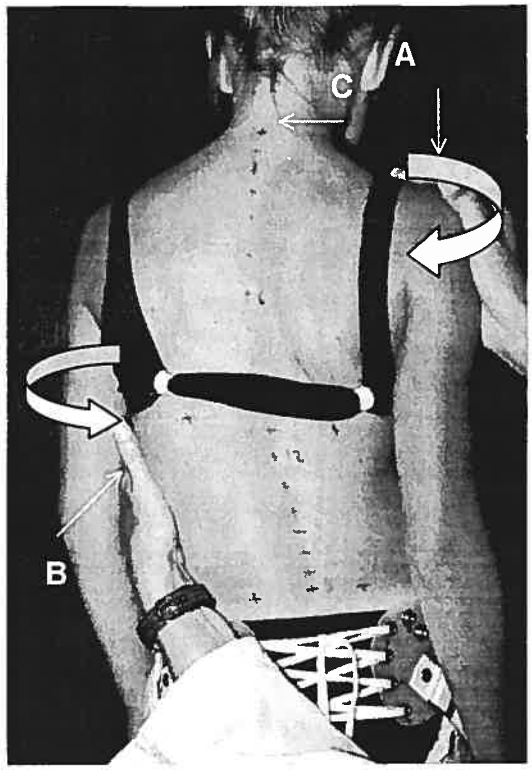

Figure 1: Corrective movement principal demonstrated on a right thoracic patient

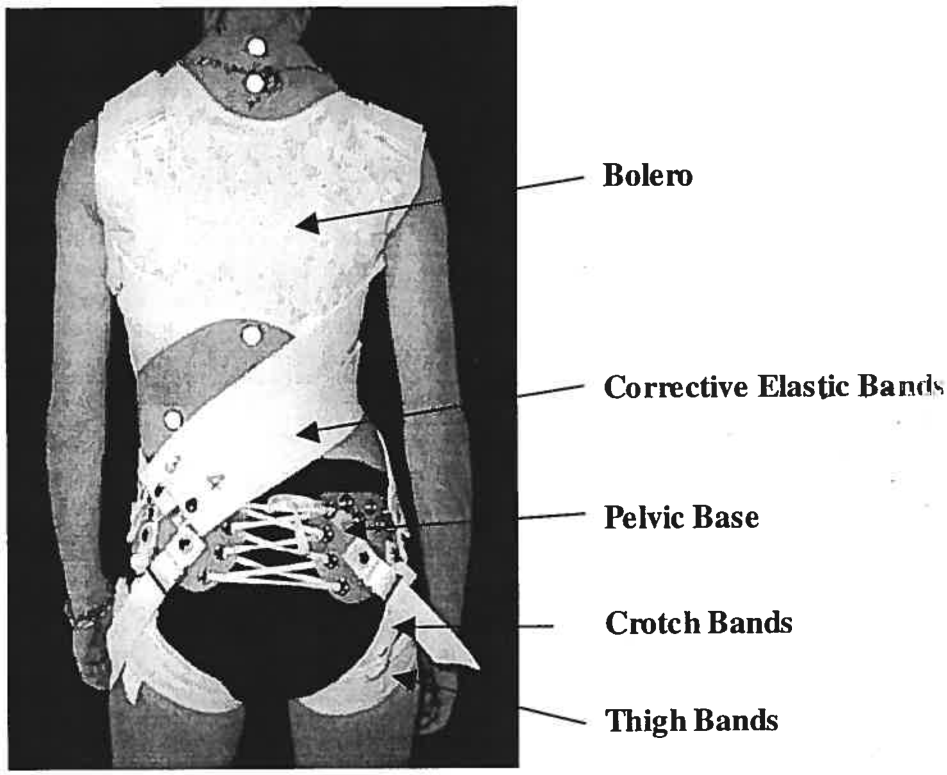

Figure 2: The corrective movement principal favorised by the SpineCor system.

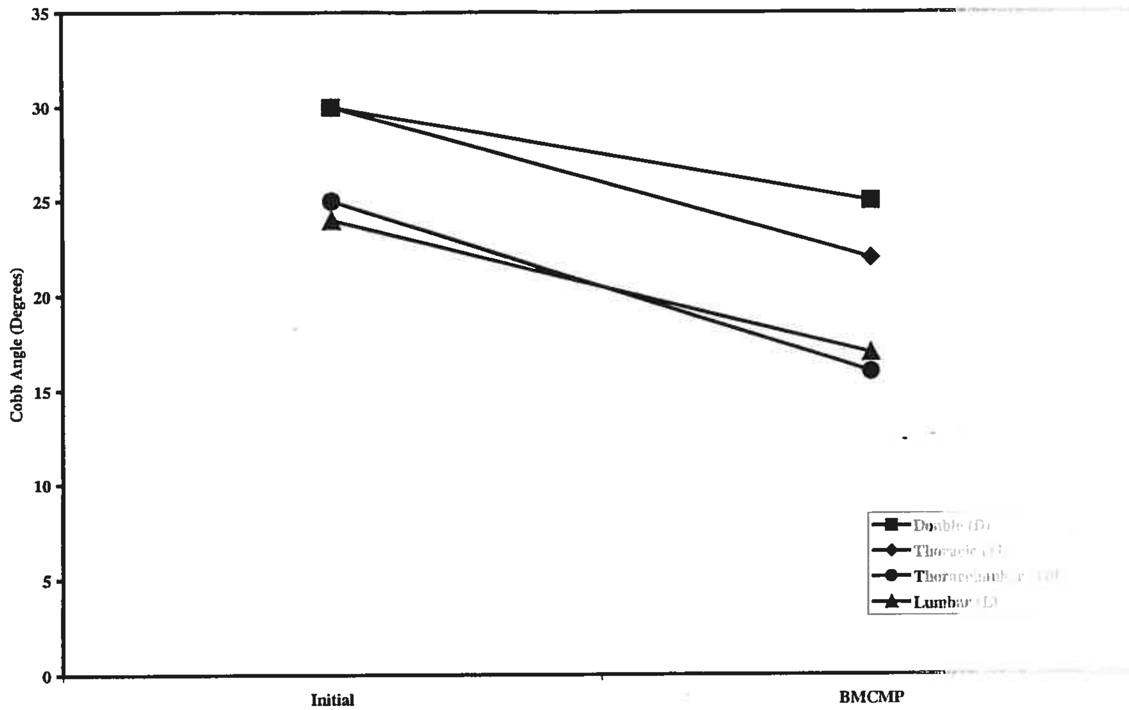

Figure 3: The amplitude of spinal curvature as measured with the angle of Cobb in the initial and brace maintained corrective movement principle (BMCMP) conditions.

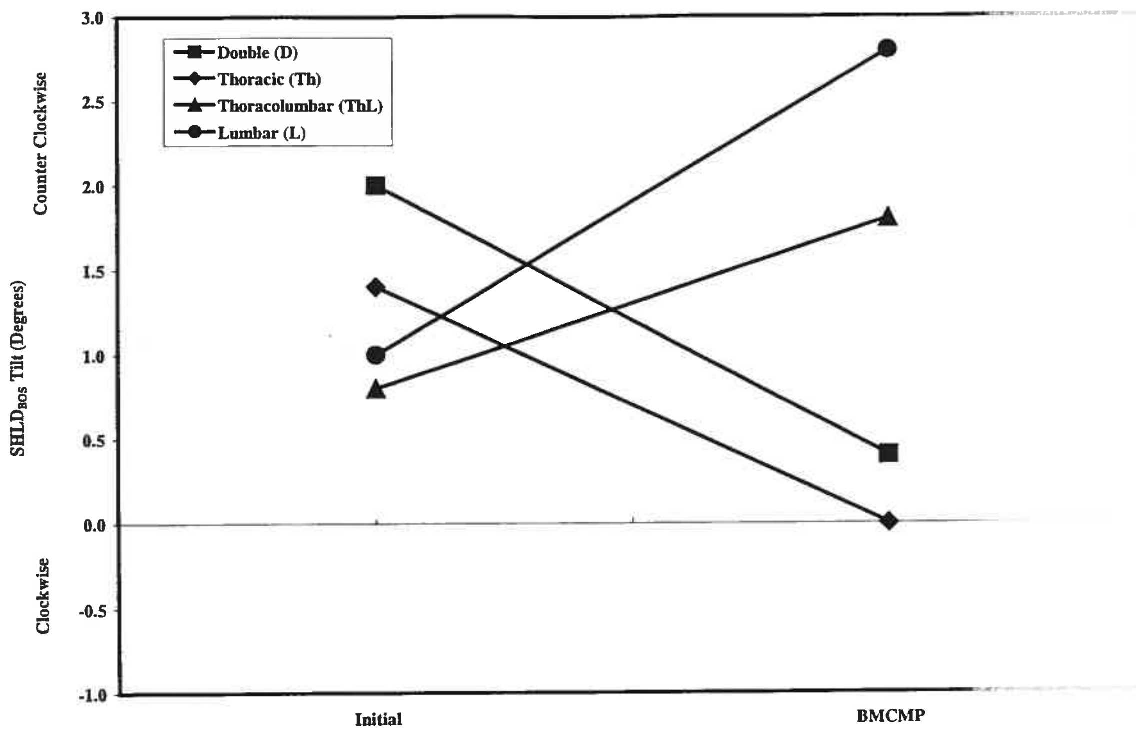

Figure 4: The amplitude of shoulder tilt in reference to the base of support ($SHLD_{BOS}$) for the initial and brace maintained corrective movement principle (BMCMP) conditions.

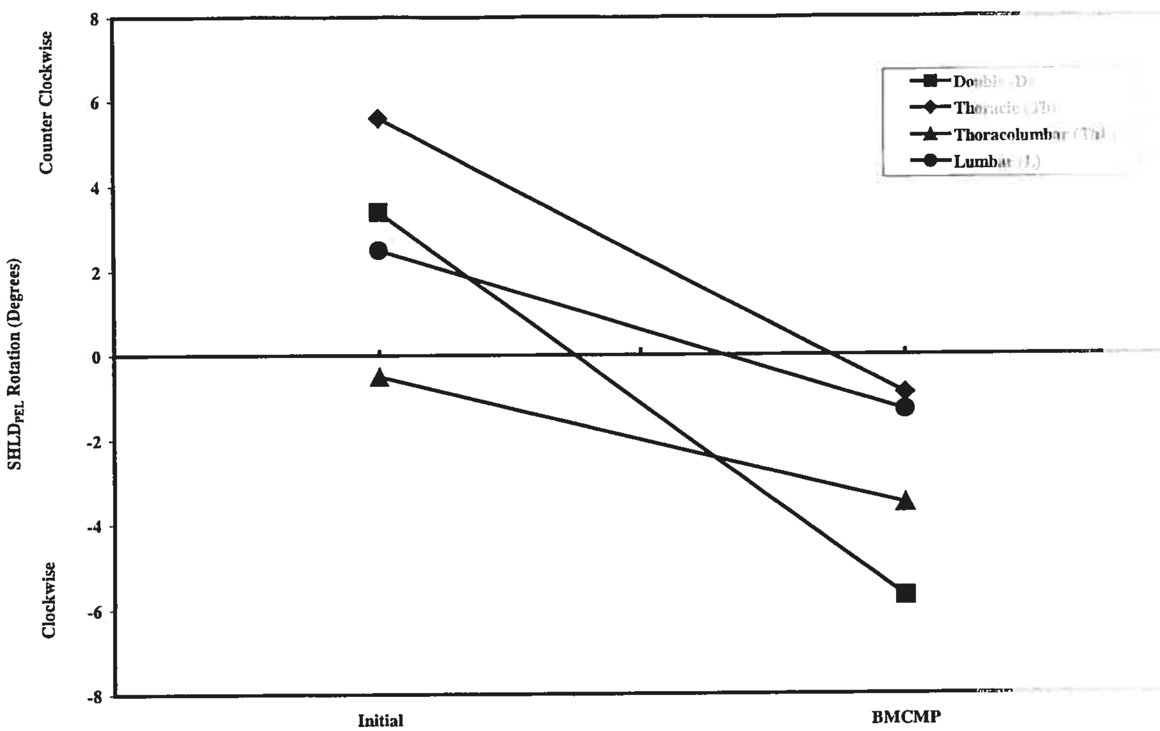

Figure 5: The amplitude of shoulder rotation in reference to the pelvis ($SHLD_{PEL}$) for the initial and brace maintained corrective movement principle (BMCMP) conditions.

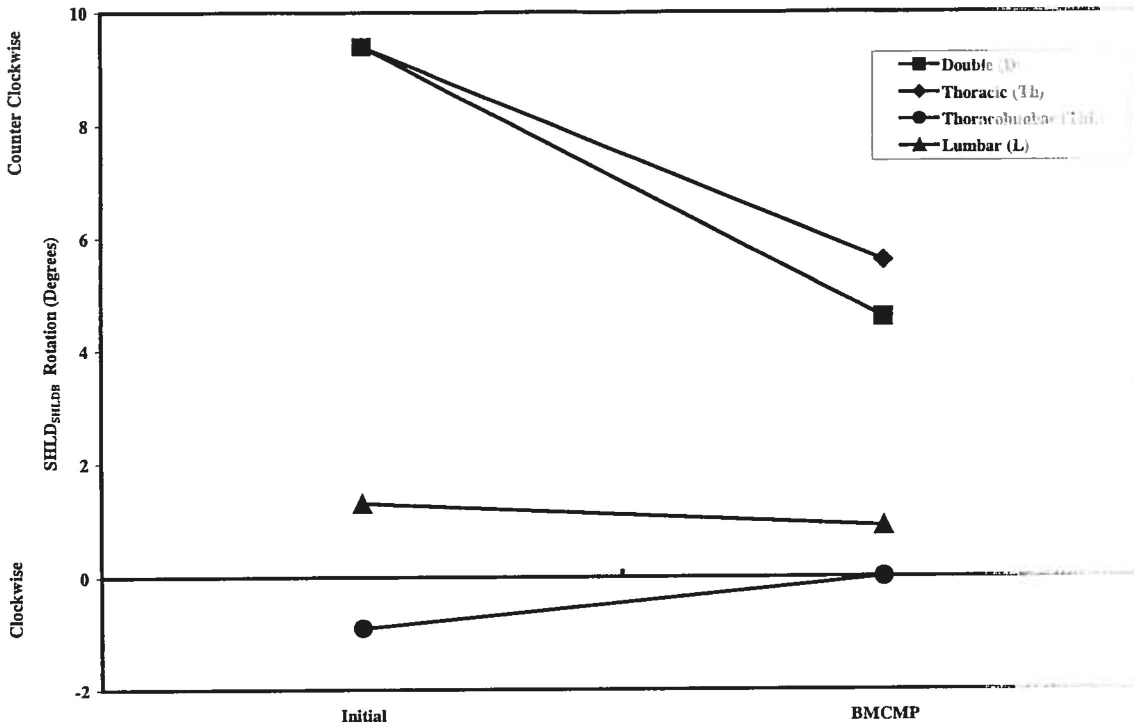

Figure 6: The amplitude of shoulder rotation in reference to the shoulder blade ($SHLD_{SHLDB}$) for the initial and brace maintained corrective movement principle (BMCMP) conditions.

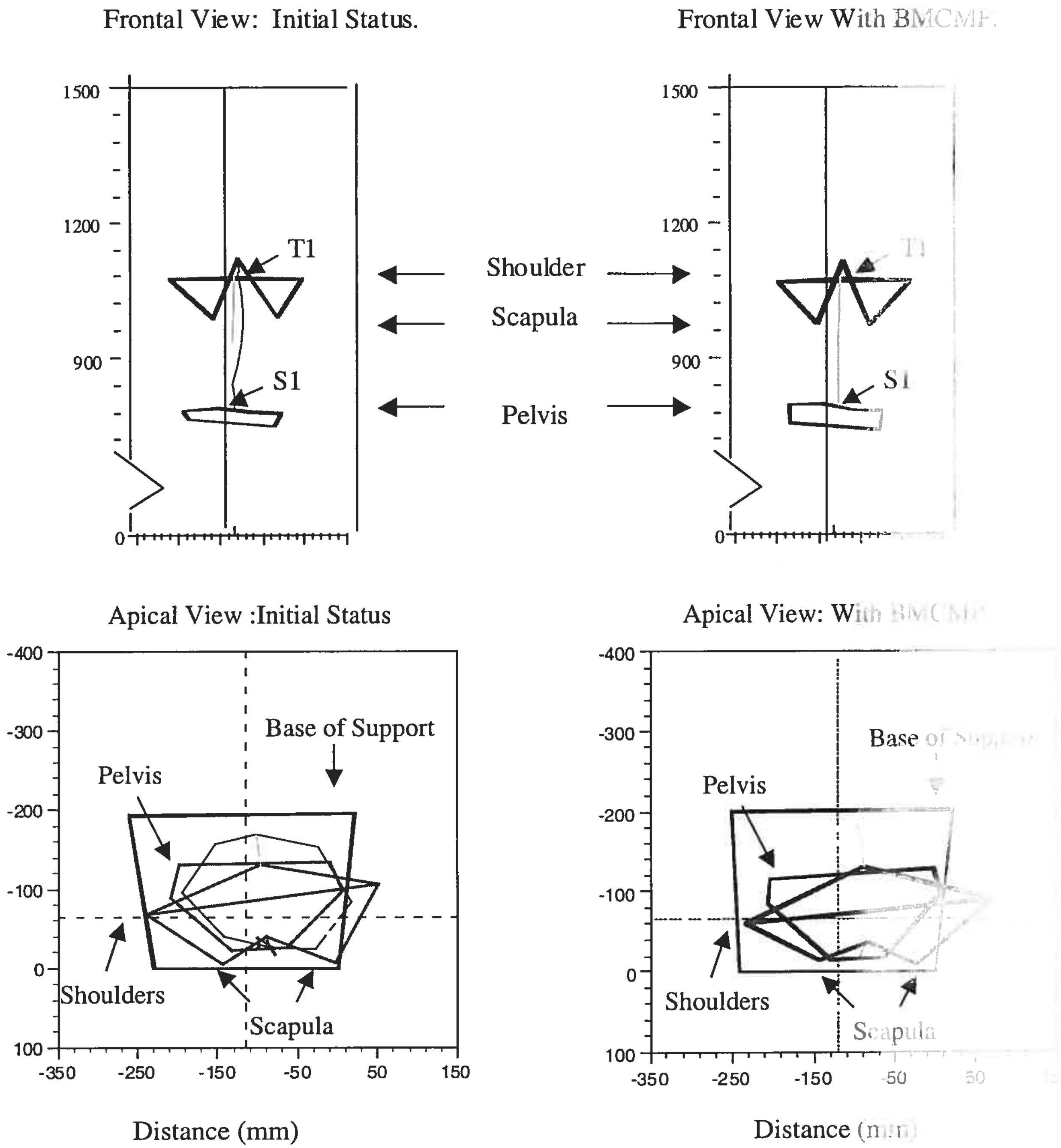

Figure 7: Apical and Posterior-Anterior view of a typical right thoracic patient without the BMCMP and with the BMCMP. Note that due to the brace the thorax could not be defined in the right graph.

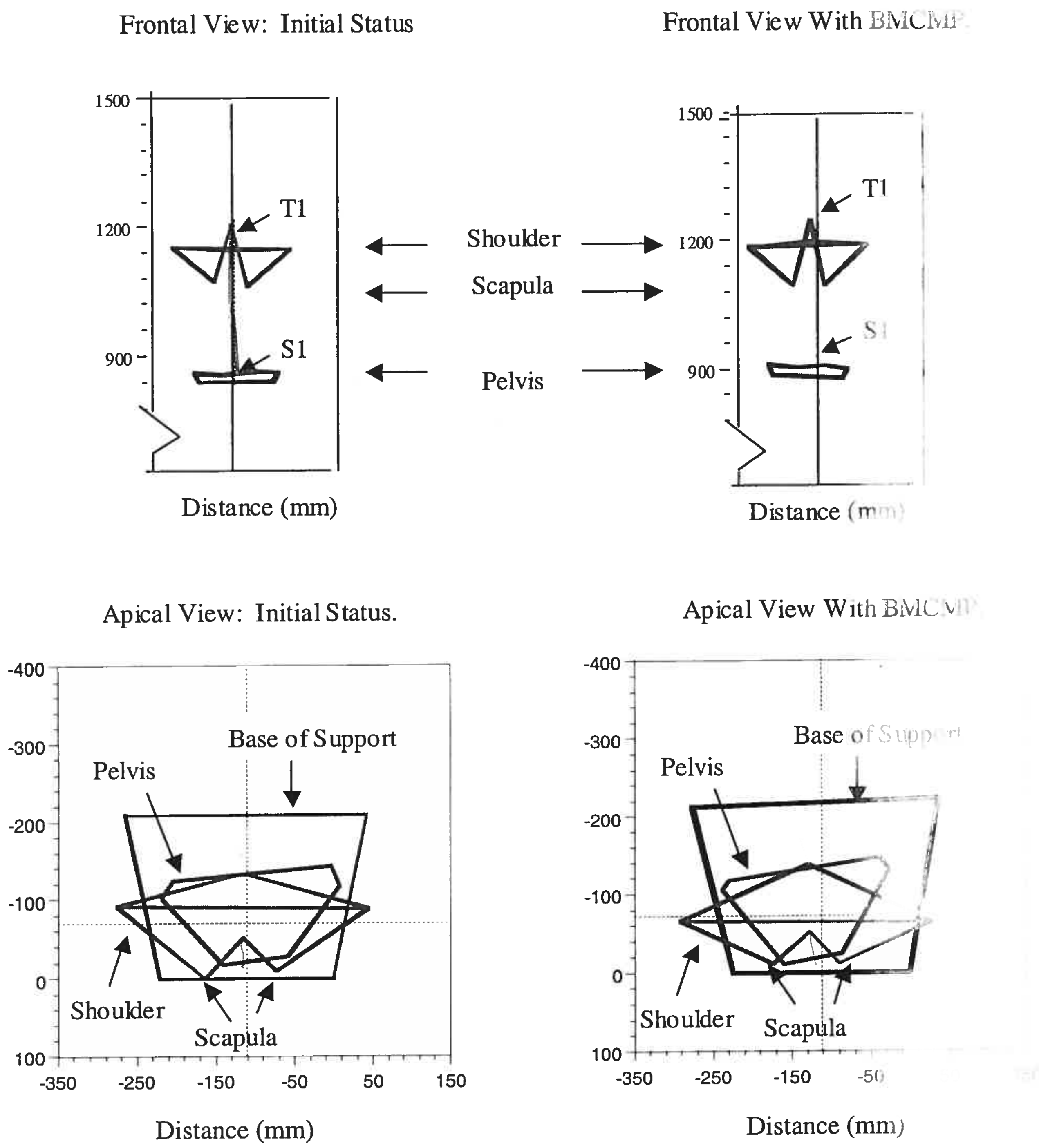

Figure 8: Apical and Posterior-Anterior view of a typical left thoracolumbar patient with and without the BMCMP.

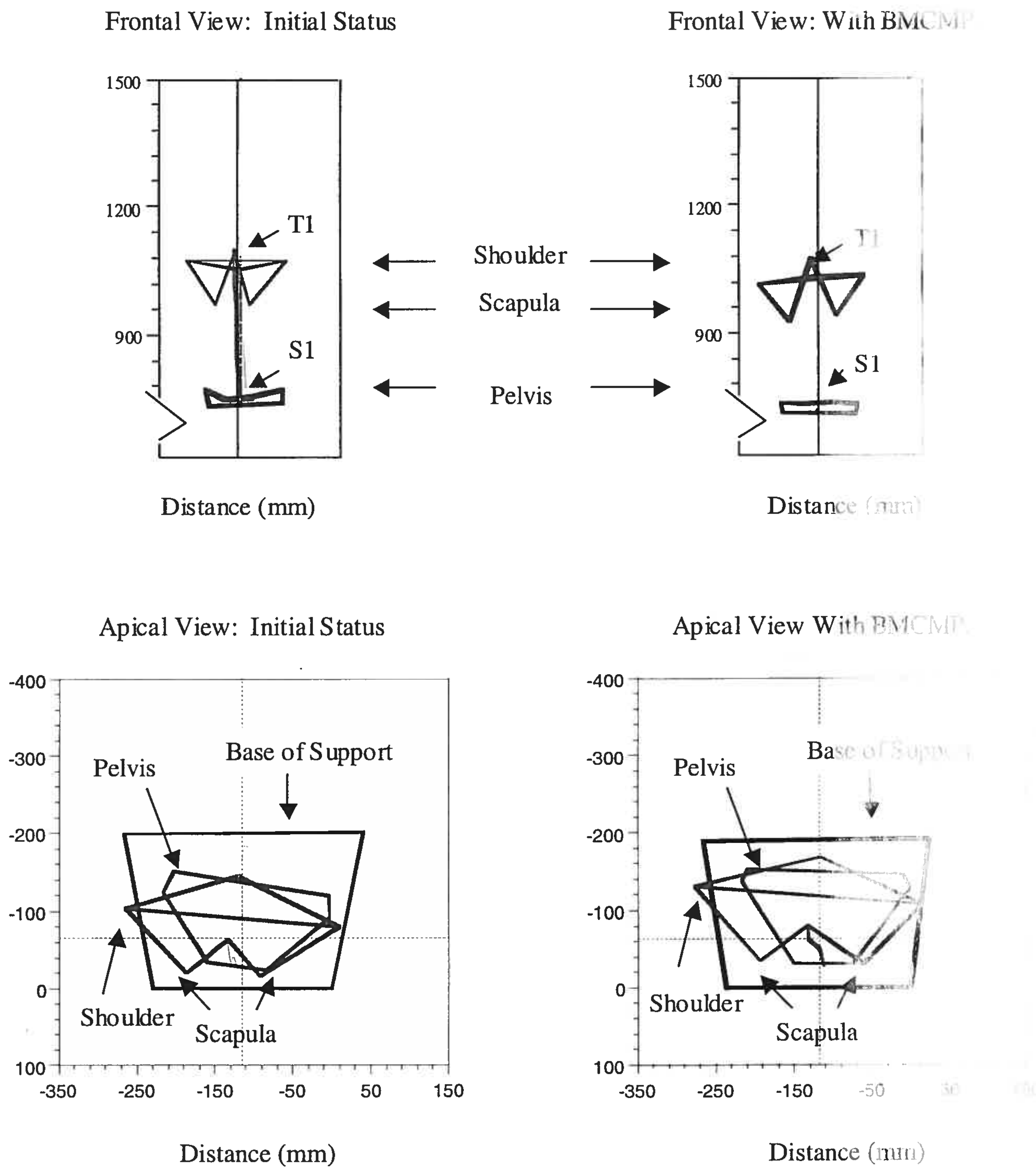

Figure 9: Apical and Posterior-Anterior view of a typical left lumbar patient, without the BMCMP and with the BMCMP

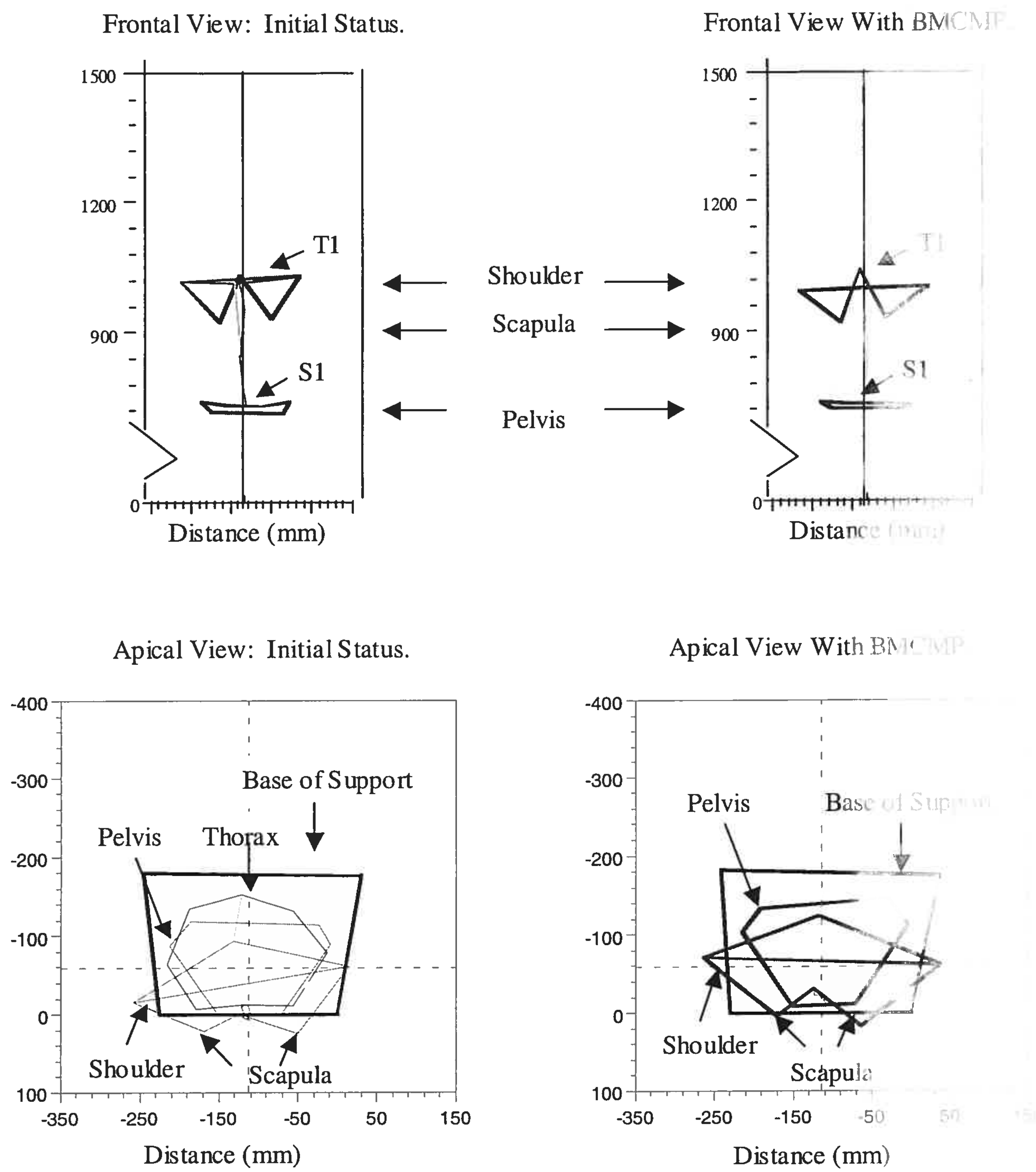

Figure 10: Apical and Posterior-Anterior view of a typical Double curve patient without and with BMCMP. Note that due to the brace the thorax could not be defined in the right graph.

Chapter VI: Manuscript #4

Estimation of the centre of mass for the study of postural control in Idiopathic Scoliosis patients: Comparison of an anthropometric and force-plate based model.

The estimation of the time and frequency characteristics of the COM has served a minimal role in understanding the natural history and aetiology of IS. This is in part due to the difficulty in obtaining an accurate and precise estimate of the position of the COM in an upright standing position. This manuscript serves to introduce a novel technique to estimate the displacement and the position of the COM in IS and control subjects.

Title: Estimation of the centre of mass for the study of postural control in Idiopathic Scoliosis patients: Comparison of an anthropometric and force-plate based model.

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Abstract

Study Design: Prospective study of 18 healthy adolescents and 22 Idiopathic Scoliosis (IS) patients.

Objectives: Quantify the position of the Centre of Mass (COM) during quiet standing using a force plate and compare this technique to the quantification of the COM with an anthropometric model.

Summary of Background Data: The movement of the Centre of Pressure (COP) in relation to the COM most accurately characterizes postural control. However, since postural deformities accompany the lateral deviation of the spine in Idiopathic Scoliosis, the use of current anthropometric models needs to be verified. Recently, a technique has been proposed and tested in healthy adults to estimate the position of the COM from force plate data. This technique has potential to be applied in a clinical setting to evaluate the postural control of IS patients.

Methods: The postural control of 18 healthy adolescents and 22 IS patients was evaluated using an Optotrak 3D kinematic system, and two AMTI force plates during quiet standing. The position of anatomical landmarks tracked by the Optotrak system served to estimate the position of the COM of both groups using an anthropometric model (COM_{anth}). The force plate served to estimate the position of the COM through double integration of the horizontal ground reaction forces (COM_{gl}). The mean position and RMS amplitude of COM_{gl}, in reference to the base of support (BOS) and the 1st sacral prominence (S1) were quantified in the Anterior-Posterior (A/P) and Medial-Lateral (M/L) directions.

Results: There was a significant difference between the control and IS patients for the displacement of the COM_{gl} in reference to the BOS in the both the A/P and M/L directions, and in the A/P direction in reference to S1. There was no difference

between groups for the mean position of the COM_{gl}, however, 63 % of the IS and 43% of the controls had a lateral position of the COM_{gl} in reference to S1 of greater than 5 mm. There was a significant difference between groups in the A/P and M/L directions for the amplitude of error between the COM_{gl} and COM_{anth} techniques.

Conclusions: Using a force plate based technique, unique differences in the position and displacement characteristics of the COM were found between IS and control subjects. The amplitude of difference between the COM_{gl} and COM_{anth} techniques in relation to these COM characteristics suggests that further research is required to optimize the estimation of the COM in adolescent and IS patients from an anthropometric model.

Key Words: Biomechanics, Posture, Idiopathic Scoliosis, Adolescent, Anthropometry, Force Plate

Key Points.

- Adolescent IS patients have greater displacement of the COM than control subjects.
- The amplitude of error between Force Plate estimation of the COM and an anthropometric model is specific to the population studied.
- The amplitude of error between the COM_{gl} and COM_{anth} techniques suggests that further development of anthropometric models is required to more accurately characterize the position and movement of the COM in IS during quiet standing.

Mini Abstract or Precis.

The Centre of Mass of adolescent Idiopathic Scoliosis patients and control subjects was evaluated using a force plate measurement technique and with an anthropometric model. The amplitude of error between the two techniques suggests that an anthropometric model is not adequate to characterize the movement of the Centre of Mass during quiet standing in Idiopathic Scoliosis patients.

Introduction

Idiopathic Scoliosis (IS) is a unique multi-faceted pathology that progresses during periods of rapid growth and development[1]. In addition to the complex 3-D curvature of the spine, vertebral[2] and thoracic[3] deformation, postural asymmetry[4], dysfunction to the proprioceptive[5-6], vestibular[7], vestibulo-spinal systems[8], and postural equilibrium[8-10] have been implicated in the characterization and aetiology of this pathology.

Estimating the position of the centre of mass (COM) has been performed on live subjects using magnetic resonance imaging[11], cross section estimation[12-14] with stereophotogrammetry, geometrical modeling[15] and in cadavers[16]. These techniques have been utilized to provide estimates of segment mass proportions and segment COM positions necessary to estimate the total body COM position often used in postural control studies[17-20]. These segment proportions have been noted to change between 4 and 20 years old[14], with only a few studies focusing on the estimation of anthropometric parameters specific to an adolescent population[12-14]. Since the spinal deformation of IS progresses from childhood through adolescence and IS is accompanied by a disturbance to postural alignment[4,21,22] and the neuromuscular systems[5-8], it is necessary to optimize the estimation of the COM displacement during quiet standing. A technique to estimate the position of the COM from the forces measured from a force plate has been proposed by King and Zatsiorsky[23]. Referred to as the "Gravity Line" (GL)[24], it was validated in adult subjects[25] and is not affected by body sway characteristics during quiet standing[23], or anthropometric estimation errors[26] as with other techniques[27,28]. This technique has potential to be a valuable clinical option to accurately assess the time and frequency characteristics of the COM in IS patients. The objective of this study is two fold. The first objective is to estimate the position of the COM using the GL (COM_{gl}) technique, and characterize the position and displacement of the COM_{gl} in adolescent IS patients and control subjects. The second objective is to compare the amplitude of error associated with the estimation of the COM from an anthropometric model (COM_{anth}) in reference to the COM_{gl} technique.

Methods

Protocol

There were 18 adolescent female control subjects (age: 11±2 years, weight 39±11 kg, height 1.44±0.13 m) and 22 IS female patients (age: 12±2 years, weight 42±12kg, height: 1.48±0.11 m, Cobb: 21±14°) evaluated in this study. In the IS group, 8 subjects had a double curve, 7 a thoracolumbar curve, and 7 a thoracic curve. Each patient read and signed an information and consent form approved by the Research Centre's Ethic's committee. The postural evaluation included the identification and marking with a water-soluble marker of 17 anatomical landmarks, located on the base of support, lower-extremities, pelvis, thorax, shoulders and head. The subjects were then evaluated for 4 trials in a quite standing position, 2 minutes for each trial, with adequate rest between each trial. An Optotrak system obtained the 3D position of the infrared emitting diodes placed on the anatomical landmarks (sampling frequency: 20 Hz), and 2 AMTI force plates (sampling frequency: 20 Hz) captured the forces and moments under each foot.

Centre of Mass

Two models were used to estimate the position of the COM. The first method (COM_{gl}) involved the estimation of the COM from force plate data based on a "zero-point to zero point integration technique"[23,25]. This technique is based on the assumption that when the horizontal force is equal to zero, the horizontal position of the COP and the COM coincide. By defining when the horizontal force is zero, the initial integration constants may be set, and a double integration of the horizontal force may be performed to estimate the position of the COM[23,25]. The second model (COM_{anth}) was based on anthropometric data proposed for children[12-14] of similar age to the population in the current study. This anthropometric data takes into consideration the location of the COM on a segment and its proportion of mass in relation to total body mass. The model included bilateral legs, and arms, trunk and head. Table 1 describes the anthropometric parameters used to define the model[14].

Equation 1 was utilized to estimate the position of the COM based on these proportions.

$$COM = \frac{m_1(x_1)+m_2(x_2)+m_3(x_3)}{m} \qquad \textbf{Equation 1}$$

Where m_1, m_2 represents the relative mass of each segment, x_1, x_2, represents the position of the segment COM relative to an arbitrary point, and m represents the total mass of the subject.

Insert Table 1 About Here.

Data Analysis

The positions of the COM_{gl} and COM_{anth}, were expressed in relation to the center of the base of support ($COM_{gl\text{-}BOS}$, $COM_{anth\text{-}BOS}$), where the medial and lateral maleolus of the right and left foot defined ankle joint centres. The mean of the right and left ankle joints defined the geometric centre located within the base of support. The COM_{gl} was also expressed in reference to the 1st Sacral Prominence ($COM_{gl\text{-}S1}$). For each trial, the mean position (mm) and amplitude of displacement (Root Mean Square: RMS, in mm) was calculated for $COM_{gl\text{-}BOS}$ and $COM_{gl\text{-}S1}$. The difference between $COM_{gl\text{-}BOS}$, $COM_{anth\text{-}BOS}$ was also obtained, and the mean absolute difference (MABD), the Root Mean Square Difference (RMSD) and maximum – minimum or range of difference (ROD) was calculated. The mean position, RMS, MABD, RMSD and ROD for each of the 4 trials[29] was averaged together for each subject and was then used to calculate the population mean and standard deviation (SD). Three series of comparisons were made. The first two compared $COM_{gl\text{-}BOS}$ and $COM_{gl\text{-}S1}$ mean position and RMS between IS and controls, and also between single and double curves. The third series compared between the IS and controls the MABD, RMSD and ROD obtained from the difference of the two models. To determine the difference between groups, an independent T-test was used with Bonferroni's correction for multiple comparisons.

Results

Position and displacement amplitude of the COM_{gl} in reference to the base of support

The $COM_{gl\text{-}BOS}$ was positioned anteriorly to the anterior-posterior (A/P) ankle axis for both the control and IS subjects by a mean 28.3 mm (Confidence Interval (CI) : 20.3 to 36.3mm), and 30.2 mm (CI: 23.1 to 37.3mm) respectively. There was a mean bias to the right from the centre of the base of support for both the IS and control subjects (3.7mm, CI: -1.1 to 8.6mm vs. 4.6mm, CI: -0.1 to 9.4mm). The RMS amplitude of the $COM_{gl\text{-}BOS}$ was significantly greater ($p<0.05$) for the IS subjects (6.7 mm, CI: 5.2 to 8.2 vs. 4.4mm CI: 3.7 to 5.2mm) in the A/P and medial-lateral (M/L) directions (2.9mm CI: 2.3 to 3.6mm vs. 2.1mm CI: 1.7 to 2.4).

Position and displacement amplitude of the COM_{gl} in reference to the 1^{st} sacral prominence

The $COM_{gl\text{-}S1}$ was positioned anteriorly to the 1^{st} Sacral prominence by a mean of 65.4 mm (CI: 58.1 to 72.5mm), and 62.3 mm (CI: 54.6 to 69.9mm) respectively for the IS and control subjects. In the M/L direction, the $COM_{gl\text{-}S1}$ was biased slightly (-1.5 mm, CI: -5.7 to 2.2 mm) for the IS patients and also for the control subjects (0.9 mm, CI: -1.9 to 3.8 mm). Ten of the 18 subjects, had a lateral shift of $COM_{gl\text{-}S1}$ in reference to S1 of plus or minus 5 mm, 6 subjects between 5 and 10 mm, and 2 subjects between 10 and 15 mm. For the scoliosis subjects, 8 of the 22 subjects had a lateral shift between plus and minus 5 mm, 8 between 5 and 10 mm, 4 between 10 and 15 mm, and 2 between 15 and 20 mm. When categorized according to single or double curves the single curves had a significantly larger lateral absolute shift of $COM_{gl\text{-}S1}$ than the control subjects and the double curves, with no difference between the double curves and the control subjects ($p< 0.05$) (See Figure 1).

Insert Figure 1 About Here.

In the A/P direction, the RMS amplitude of the difference between the COM_{gl} and S1 was significantly larger ($p< 0.05$) for the IS (2.4 mm, CI: 1.7 to 3.2 mm), than for the controls (1.2, mm CI: 0.99 to 1.4mm). In the M/L direction, the RMS of the difference between the COM_{gl} and S1 was not significantly different between groups. The IS had a mean RMS difference of 1.6 mm (1.1 to 2.0 mm), and the control subjects a mean difference of 1.2 mm (1.0 to 1.4 mm).

Difference between Models

The MABD, RMS, and ROD between the COM_{gl} and the COM_{anth} is presented in Table 2. In the A/P direction, there was a mean bias between the COM_{gl} and the COM_{anth} which was significantly different between the IS and control subjects 11.5 mm (CI: 8.4 to 14.6 mm) vs. 16.0 mm (CI: 13.6 to 18.4mm). The two groups demonstrated significant RMS amplitude differences of 0.7 mm (CI: 0.60 - 0.8 mm) vs. 1.2 (CI: 0.70 to 1.7mm) respectively. In the M/L direction, there was no difference between groups where the mean difference between models was 3.5mm (CI: 1.4 to 5.7 mm) and 3.8 mm (CI: 2.0 to 5.8mm) for the control and IS subjects. However, the two groups demonstrated amplitude differences that changed over the 120 second period which was reflected by a significant difference in the RMS of 0.5mm (CI: 0.4 to 0.5mm), and 0.8mm (CI: 0.6 to 0.9mm).

Insert Table 2 About Here.

Discussion

The objectives of this study were to apply a force plate based technique to estimate the position and amplitude of displacement of the COM in adolescent IS and control subjects, and secondly to evaluate the amplitude of error between this technique and the COM estimated by an anthropometric model. There was no difference between groups for the mean A/P position of the COM_{gl} in reference to the base of support or the 1st sacral prominence. In the M/L direction, a lateral position of the $COM_{gl\text{-}BOS}$, was common, where 66 % of the control, and 72 % of the IS subjects had a lateral deviation of the $COM_{gl\text{-}BOS}$ of greater than 5 mm. This was also true for the $COM_{gl\text{-}S1}$ where, 63 % of the IS subjects, and 43 % of the control subjects had a lateral deviation of greater than 5 mm. A categorization of subjects according to the curve type revealed that single curve subjects have a greater lateral COM deviation than control or double curve subjects.

The location of the total body COM reflects the position and orientation of individual body segments as well as the distribution of mass within and between these segments. There are a number of factors attributed to skeletal alignment which may affect the IS and control subjects differently. In the adolescent population there is a large variability in the degree of kyphosis, lordosis, and sacral tilt, which could have a significant impact on the A/P position of the COM. In the M/L direction however, lower leg length inequality, or muscle imbalance may contribute to pelvic obliquity, and possibly an imbalance in the M/L position of the COM. In the IS population, deviation of the spine has been accompanied by additional postural abnormalities which include thoracic deformation and disorientation[30], and shoulder or shoulder blade rotation[4]. Since these postural abnormalities are specific to the level and apex of the curvature, the effect on the overall COM may be different, as seen in the thoracolumbar and double curve patients in this study.

The IS subjects also had a greater RMS displacement of the $COM_{gl\text{-}BOS}$ in the A/P and M/L directions. The amplitude of body sway in IS patients, as well as adolescent control subjects has been previously evaluated. These studies have underlined that IS patients, do have different sway characteristics than control subjects[8-10], most notably by an increase in the RMS of A/P and M/L COP excursion under normal and altered sensory conditions[9]. However there are a couple of points important to highlight. Firstly, body sway has often been used synonymously with the movement of the COP as measured by a force-plate[8-10]. However, the COP and the COM are two distinct variables[17,18,19,20]. The COP is an active variable, which reflects the net output of the central nervous system, and is the variable that has been identified to control the movement of the COM[17-20]. The COM is a passive variable affected by segment position, and mass distribution within each segment. In this study the RMS amplitude of the $COM_{gl\text{-}S1}$, was greater for the IS subjects than the control subjects. This difference may reflect an active strategy employed by IS subjects to assist in the equal distribution of forces on the spine. In the M/L direction, there was no difference between groups, with upper bound confidence limits of 2.0 mm, and 1.4 mm for IS and control subjects. If taken into context of a patient or control subject who has a lateral deviation of $COM_{gl\text{-}S1}$, of greater than 5 mm, it is hypothesized that there is a large potential for asymmetrical distribution of forces on the vertebral body. Asymmetrical distribution of the forces on a vertebral body has been associated with wedging or deformation[31]. However, a more detailed study is required to accurately situate the position of the COM above each vertebral level, and evaluate its position and amplitude of displacement during quiet standing.

The mean difference between the COM_{gl} and COM_{anth}, techniques revealed a relatively large bias in the A/P direction of 11 and 16mm for the IS and control group respectively. This bias is partially due to the fact that the anthropometric model utilised markers that are placed on the surface of the skin. The amplitude of error between models, was different between groups (mean 5 mm difference), which is approximately 2.5 times larger than the observed difference between groups (2mm) for the same model. There was also a significant difference for the RMSD between models in both directions. This error accounts for 15 and 70% of the difference between groups in the A/P and M/L directions respectively. This may be attributed to a greater movement of the true position of the COM in IS patients as estimated by the COM_{gl}, which is more difficult to accurately locate and track with an anthropometric model. Although multi-segment models have been proposed[15] the most pertinent model chosen for this study was that proposed by Jensen[12,13,14]. This choice was principally based on the changes in segment mass proportions that are different between adolescents and adults. The mass proportions that are most notable to change between 4 and 20 years, is the head (20 to 6.8%), and the arms, and legs which can change from 2.6 to 3.7 % and 7.5 to 11.5 % respectively[14]. However, despite a more population specific estimation of the segment mass proportions, the amplitude of the error associated for both populations is approximately 100 % of the range of COM_{gl} in the M/L direction and 33 % in the A/P direction. The amplitude of this error will significantly decrease the sensitivity and sensibility of the anthropometric model to detecting differences within and between populations. The measurement errors associated with an anthropometric based model include the choice and identification of anatomical landmarks, the precision and accuracy of the kinematic tracking system utilized, the definition of representative body segments by these anatomical landmarks, the assignment of appropriate body segment masses, and the radius of segment COM to each segment. The accuracy and resolution of the Optotrak system used in this study was approximately 0.1 mm and 0.01 mm respectively, which represents less than 1% of the $COM_{gl\text{-}S1}$ range in the M/L direction, and therefore seen as a minor source of error in the model. Anatomical landmark detection through surface palpation is a common technique used in posture and gait studies. Inter-rator and test-retest reliability was evaluated in a population of healthy elderly and pathological patients, and found to be acceptable for the COP-COM variable[29]. Within the context of evaluating IS patients the most significant source of error is considered to be the definition of the COM of the trunk segment. The trunk represents approximately 42% of the total body mass, and therefore has the largest impact on the total movement and position of the COM. In addition to a deformation of the thoracic cage, a rotation or tilt accompanies the shoulder girdle and pelvis[4], which will significantly affect the mass distribution. Since, the axis of rotation of these deformations is not in the center of each segment, and the postural deformations are specific to both the amplitude and the type of IS, the error implicated with an anthropometric model will be unique to each type of IS patient.

Conclusion

Using a force plate based technique, unique differences in the position and displacement characteristics of the COM were found between IS and control subjects. The estimation of the COM based on the "Gravity Line" technique represents a realistic approach for the estimation of the COM of IS patients and adolescent control subjects. The amplitude of difference between the COM_{gl} and COM_{anth} techniques in relation to these COM characteristics suggests that further research is required to optimize the estimation of the COM in adolescent and IS patients from an anthropometric model.

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Table 1: COM radius, and COM proportions as proposed by Jensen (1989) and used in the present study.

	COM Fraction of Body Mass	COM Radius from Proximal
Head	0.10	0.50
Upper Trunk	0.14	0.55
Lower Trunk	0.27	0.53
Arm	0.03	0.44
Forearm - Hand	0.03	0.41
Thigh and Leg	0.16	0.37
Foot	0.02	0.42

Table 2: The mean absolute difference (MABD), RMS amplitude difference (RMSD), and Range of Difference (ROD) between $COM_{gl\text{-}BOS}$, and $COM_{anth\text{-}BOS}$.

		Control		Scoliosis		
		Avg (mm)	SD	Avg (mm)	SD	p
MABD	A/P	11.7	6.6	16.3	5.5	0.021
	M/L	3.5	4.0	3.9	3.9	0.98
RMSD	A/P	0.7	0.2	1.0	0.5	0.009
	M/L	0.5	0.1	0.7	0.3	0.001
ROD	A/P	4.7	1.5	7.0	1.1	0.035
	M/L	3.1	0.9	5.0	0.7	0.003

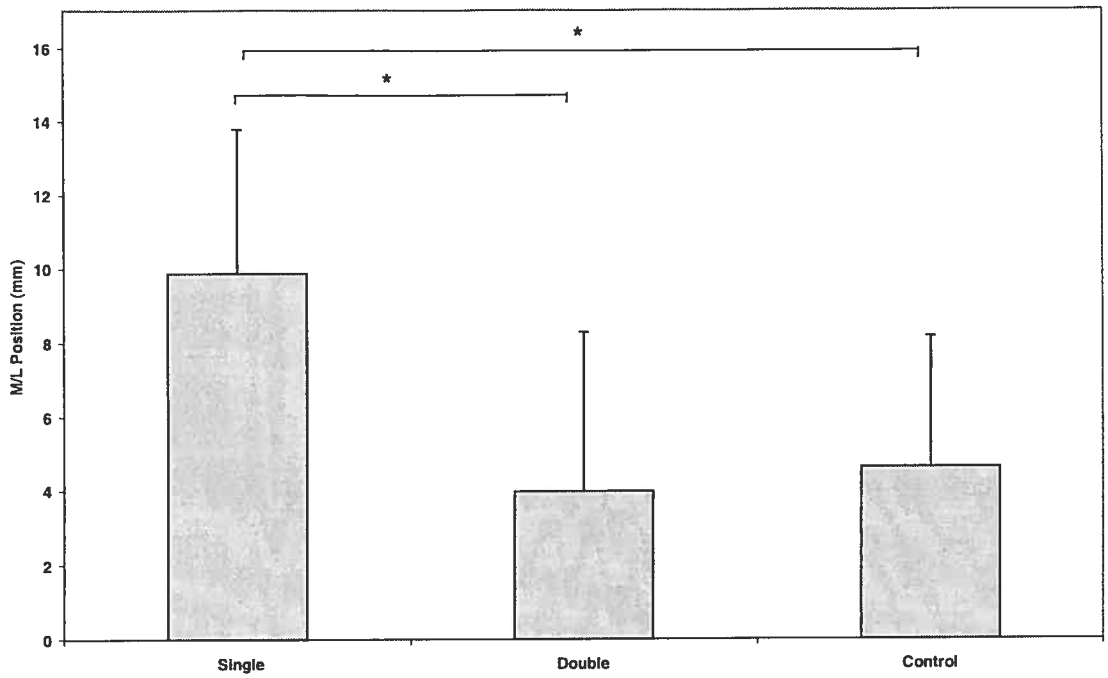

Figure 1: Mean M/L position of the COM_{gl-S1} for Single, Double and Control subjects (*p<0.05).

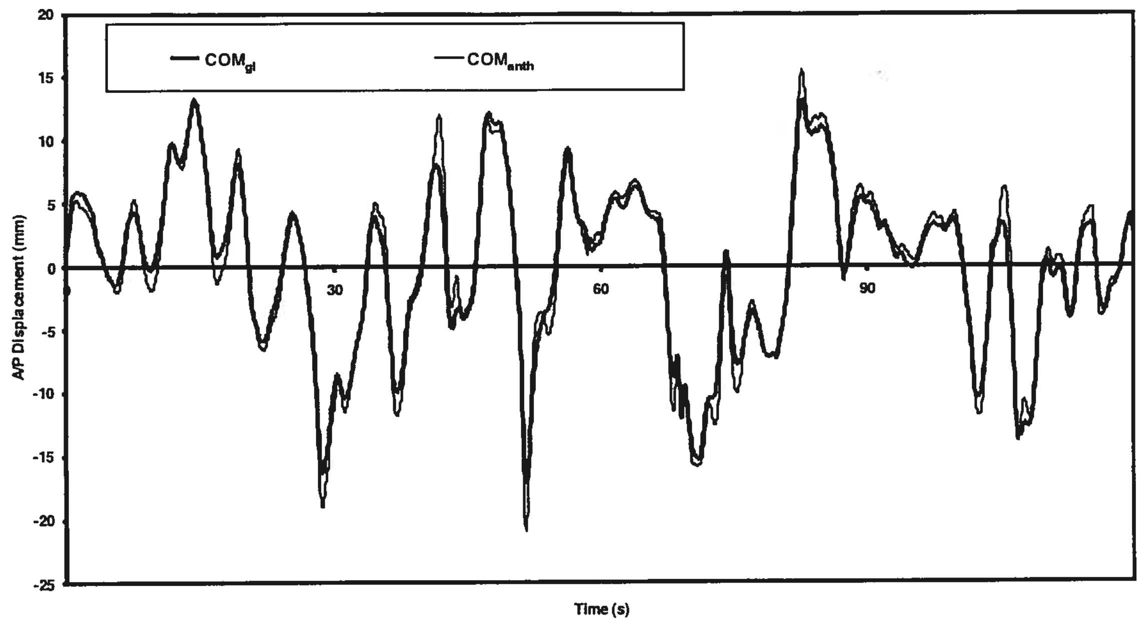

Figure 2: The COM_{gl}, and COM_{anth} in the A/P direction for a typical IS patient.

Chapter VII: Manuscript #5

Postural control in adolescent Idiopathic Scoliosis and control subjects.

Dysfunction to postural control has been associated to the aetiology of IS. However this has for the most part been evaluated through the displacement of the COP. Postural control can more effectively be assessed through evaluating the displacement of the COP in relation to the COM (COP-COM) within the context of an Inverted Pendulum model. This manuscript focuses on evaluating the postural control strategies of IS patients and control subjects.

Title: Postural control in adolescent Idiopathic Scoliosis and control subjects.

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Abstract

Objective: The objective of this study was to evaluate the postural control of adolescent Idiopathic Scoliosis and control subjects during quiet standing. Fifteen healthy adolescent female, (age: 11±2 years) and 15 subjects with Idiopathic Scoliosis (age: 12±2 years, Cobb angle: 15±10°) were recruited from the Community and an Orthopaedic outpatient clinic. **Methods:** The postural control of each participant was evaluated using 2 AMTI force platforms and an Optotrak system. The Centre of Pressure (COP), Centre of Mass (COM) and COP-COM signal, and correlation between the horizontal acceleration of the COM and COP-COM were calculated from the forces and moments of the force plates. Infrared emitting diodes served to provide the 3D body segment co-ordinates necessary to estimate ankle, hip and neck angles in the A/P and M/L planes. **Results:** In the A/P direction, a two way repeated measures ANOVA revealed a significant group (IS vs. control), and level (ankle vs. hip vs. neck) effects, however no significant interaction effect was detected. In the M/L direction, a significant level effect was determined. The IS subjects had a significantly greater RMS amplitude of the COP, COM and COP-COM in the A/P and M/L direction. The correlation between the COM_{acc} and COP-COM (A/P: -0.73 vs. -0.72 IS, M/L: -0.65 vs. -0.70) was not different between groups. **Conclusion:** The postural control of IS subjects with a small Cobb angle during quiet stance is challenged in both the A/P and M/L directions as demonstrated by a greater COP-COM signal. Both the IS and control subjects demonstrated a tendency to behave as an Inverted Pendulum, however, the significantly greater angular movement about the hip and neck reflects a postural control strategy where the principle axis of rotation is not the ankle joint.

Keywords: Postural Control, Idiopathic Scoliosis, Maturation, Kinematics, Biomechanics

Introduction

Maturation of postural control from child hood to adult hood has been associated with an age related decrease in postural sway (Riach and Hayes 1987), a refinement of compensatory balance adjustments (Shumway-Cook and Woollacott 1985) and a gradual shift from vision dependence to integrated multi-sensory balance control (Foudriat et al., 1993). This natural transition, thought to be complete by the age of 7 years in normal children, may be disturbed in patients with Idiopathic Scoliosis (IS). This patient population has demonstrated dysfunction to the proprioceptive (Cook et al., 1986; Keesen and Crowe 1992), vestibular (Jensen and Wilson 1979), vestibulo-spinal systems (Salhstrand 1979), with an observable difference in body sway characteristics (Lidstrom et al., 1988; Sahlstrand 1978).

For the most part, postural control during quiet standing in adolescent control and IS subjects has been evaluated through the movement of the Centre of Pressure (COP) (Lidstrom et al., 1988; Riach and Hayes 1987; Sahlstrand 1978). However, the COP has been identified as the variable that controls the movement of the COM (Jian et al., 1993; Halliday et al., 1998). The difference between these two variables (COP-COM) has been identified as the ''error'' signal of the postural control system during quiet standing, and it's strong relationship with the horizontal acceleration of the COM serving the basis for the validation of the inverted pendulum model of quiet standing (Winter et al., 1998; 2001). The displacement of the Centre of Pressure (COP), is primarily controlled by the ankle dorsi and plantar flexors in the anterior-posterior (A/P) direction, and by the hip abductors and adductors in the medial-lateral (M/L) direction (Winter et al., 1996). However, recent studies have implied that angular movement of the trunk during quiet standing, is superior to the total angular movement about the ankle joint (Allum et al., 2001; 2002; Aramaki et al., 2001). This segmental movement may be particular pertinent to adolescent and IS patients since growth and development continues through adolescence with changes in skeletal geometry, alignment (De la Huerta et al., 1998), segment mass distribution, and mass proportions (Jensen 1989). It is during these phases of rapid growth and development that the adolescent with spinal column deviation is at greatest risk of progressing (Lonstein and Carlson 1984). The primary objective of this paper is to evaluate the postural control of adolescent IS and control subjects.

Material and Methods

Subjects

Fifteen healthy female adolescent subjects with no known orthopaedic or neurological pathology were recruited from the local community (age: 11 ± 2 years, weight 42 ± 11 kg, height 1.47 ± 0.12 m). The absence of IS was confirmed through measuring the amplitude of trunk deformation with a scoliometer (< 4 °), with the legs straight, and the subject in a forward bending position. The 15 IS female subjects (age: 12 ± 2 years, weight 40 ± 9kg, height: 1.47 ± 0.10 m, Cobb: 15 ± 10°) were recruited by an orthopaedic surgeon at an outpatient clinic. IS was confirmed through a posterior-anterior X-ray obtained during their regular follow-up. None of the patients had prior treatment for IS. Each subject gave informed consent, after receiving an explanation of the experimental protocol and reading an information and consent form previously approved by the Research Centre's Ethic's Committee.

Experimental Protocol

All subjects underwent the following experimental protocol. After changing into non-obstructive clothing, anatomical landmarks were detected and marked with a water-soluble marker on the base of support, the lower extremities, the pelvis, thorax, shoulder girdle, spine, and head. For the purpose of this study, only the landmarks specific to the parameters evaluated will be described. These landmarks include bilaterally, the medial and lateral maleolus, greater trochanter, acromion, and tragus of ear. After placing infra-red emitting diodes on the landmarks, the subjects were asked to stand barefoot with each foot on one of two AMTI force platforms with the center of their heels 28 cm apart, and the external border of the feet at a 15° angle from the A/P axis. The subject was asked to look straight ahead, with their eyes open and maintain a quiet standing position for a trial duration of 120 seconds. Four repeat trials were obtained for each subject with adequate rest in between each trial. During each trial, the AMTI force platforms collected the forces and moments under each foot in synchronization to the infra-red emitting diodes captured by an Optotrak 3020 position sensor (Sampling Frequency: 20 Hz).

Data Analysis

The data was collected in a global reference system where X defined A/P, Y defined M/L and Z defined vertical, aligned to the centre of the right force platform. Prior to calculation of the parameters all data was low-pass filtered with a fourth-order Butterworth dual pass filter (cut off frequency 3 Hz). The choice of cut-off was based on a residual analysis that was performed across all subjects for the 3-D co-ordinates as well as the forces and moments of the force platforms.

Segment angles were calculated in the frontal and sagittal planes as described by Winter 1990. To simplify the analysis in each plane, the right and left sides were averaged together and three segments were defined. The first segment (leg) is the lower extremity defined by the malleolus and the greater trochanter. The second segment (trunk) defined by the trochanter and acromion, and the third segment (head) is defined by the acromion and the tragus of the ear. The joints were represented by the ankle, hip and neck.

The COM was estimated using a 'zero-point to zero point integration' technique proposed by King and Zatsiorsky (1990). The net center of pressure (COP) was calculated as a weighted average of the individual COP of the right and left feet (Equation 1.).

$$COP = COP_r * (Fz_r / (Fz_r + Fz_l) + COP_l * (Fz_l /(Fz_r + Fz_l) \qquad \textbf{Equation 1}$$

Where, COP_r, Fz_r and COP_l, Fz_l represents the individual center of pressure and vertical force for the right and left feet respectively. The difference was then calculated between COP and the COM (COP-COM). Then, the acceleration of the COM was calculated (COM_{acc}), and correlated with the COP-COM signal.

The average, Root Mean Square (RMS) and range of the COM, COP, COP-COM displacement and each segment angle was calculated for each individual trial. The average of 4 trials (Corriveau et al., 2001) was calculated and used to construct each group mean and standard deviation. A repeated measures ANOVA was used to compare the ankle to the hip, and neck angles. A student's t-test with Bonferroni's correction for multiple comparisons was used to compare differences between groups for the COM, COP and COP-COM signals in the A/P and M/L directions.

Results

In the A/P direction results revealed a significant group and level effect for the RMS amplitude of segment angle. No significant interaction effect was found, and a post-hoc analysis identified a significant difference between all levels ($p<0.05$). The ankle angle had the smallest RMS in both the A/P and M/L directions, with the hip angle approximately 2 times greater and the neck angle approximately 3 times greater ($p<0.05$) (See Table 1). These differences were also present when the range of segment angle was evaluated across each trial. In the A/P direction, the ankle angle had a mean range of 1.6° (CI: 1.4° - 1.7°) and 2.3°(CI: 1.9° - 2.7°) for the control and IS subjects respectively. At the hip this was greater with a respective mean range of 4.2° (CI: 3.5° - 4.9°), and 5.2° (CI: 4.5° - 5.9°), and at the neck it was 5.3° (CI: 4.4° - 6.3°) and 6.0° (CI: 5.4° - 6.6°) for the control and IS subjects. The angular displacement over the data collection period is displayed for one IS patient in Figure 1.

- Insert Table 1 About Here. -

- Insert Figure 1 About Here. -

In the M/L direction a repeated measures ANOVA revealed a significant level effect for the RMS amplitude of segment angle. As in the A/P direction, the ankle angle had the smallest RMS amplitude, with greater hip and neck angles (see Table 2). An evaluation of the range of segment angles over the duration of each trial revealed no significant difference between group or level.

- Insert Table 2 About Here. -

The displacement of the COM for a typical IS subject is presented in Figure 2. It is observed that the COP oscillates to either side of the COM in order to maintain the COM within the base of support.

-Insert Figure 2 About Here. -

The RMS amplitude for the COP, COM and COP-COM are presented in Figure 3 and 4. There was a significantly greater RMS for the IS group than for the control group for all variables accept for the COM in the M/L direction. The correlation between the COM_{acc} and the COP-COM distance for A/P and M/L directions are presented in Table 2. There was no significant difference between the control or the IS groups for the correlation between COM_{acc} and the COP-COM distance.

- Insert Figure 3 About Here. -

- Insert Figure 4 About Here. -

Discussion

The objective of this study was to evaluate the postural control of adolescent IS and control subjects. This was performed through initially characterizing the angular motion about the ankle, hip, and neck, and secondly, evaluating the movement of the COP and COM and relating the COP-COM difference to the horizontal acceleration of the COM. It was found that there was greater relative motion between the hip, and neck than about the ankle joint, with a significant difference between groups in the A/P and the M/L direction. The IS subjects had a significantly greater RMS amplitude of the COP, COM, COP-COM difference, with a similar correlation between the horizontal acceleration of the COM, and the COP-COM difference.

A positive correlation between the horizontal acceleration of the COM, and the COP-COM difference has supported the theory of the Inverted Pendulum model during quiet stance (Winter 1998, 2001). Where the ankle joint is the principal axis of rotation in the A/P direction with movement controlled by the ankle plantar-dorsi flexors, and in the M/L direction, activation of the hip abductors and adductors controls a load-unload strategy of the lower limbs(Winter 1996). Recently, Rietdyk et al., (1999), has suggested that despite segmental movement, the Inverted pendulum model is still valid in the presence of an externally applied perturbation to the trunk. In this study, a question is raised as to whether or not adolescent children, and IS patients behave as an inverted pendulum model during quiet stance as reported in adult subjects. This is supported by two important findings. The first is the moderate relationship between the COM_{acc} and COP-COM of -0.73 and -0.65 for the control subjects, and -0.72 and -0.70 for the IS patients in the A/P and M/L directions respectively. This accounts for less than 50 % of the explained variance. The second is related to the greater segmental motion at the hip and neck, which was 3 to 4 times that of the ankle joint. This relationship is weaker than the -0.91 and -0.75 reported in adult control subjects (Winter et al., 2001) during quiet stance, and in adult subjects under perturbed conditions (Rietdyk et al., 1999). There was no difference between groups for the correlation between the horizontal acceleration of the COM and COP-COM. Since both groups of subjects demonstrated considerable variability, (range of -0.61 to -0.81 in A/P, and -0.50 to -0.80 in M/L), it is hypothesized that a number of factors may contribute to this relationship. The factors may be general to both groups and related to the overall maturation of the neuromuscular system, and affected by secondary factors such as growth of specific body segments, growth velocity, age and maturity indexes. The factors may also be specific to unique aspects of the IS pathology. This may include structural changes related to the deformation and disorientation of vertebra that may contribute to a decreased mobility of the spinal column. A deficit in the proprioceptive system may be another source of this increased mobility. IS patients have been found to have more difficulty in reproducing joint angles, as well as having greater thresholds to detect knee motion. (Barrack et al., 1984; Cook et al., 1986). In the presence of dysfunction to the proprioceptive and vestibular systems, it is hypothesised that the CNS may actively permit a larger amplitude of sway, benefiting from an increased flow in the visual field, compensating for the deficit in the proprioceptive input.

The amplitude of body sway in IS patients, as well as adolescent subjects has been previously evaluated. These studies have underlined that IS patients, do have different sway characteristics than control subjects (Lidstrom et al., 1988; Sahlstrand et al., 1978; 1979). However, there are a couple of distinctions that are important to highlight. Firstly, body sway has often been used synonymously with the movement of the COP as measured by a force-plate. However, the COP and the COM are two distinct variables. The COP is an active variable, which reflects the net motor output of the central nervous system, and is the variable, which has been identified to control the movement of the COM (Winter et al., 1998; 2001). The COM is a passive variable whose net position is affected by the position of body segments in space and the distribution of mass throughout the body. The significant difference between the COP-COM in the A/P and M/L directions found in this study, underlines the uniqueness of the COP and COM, and that their interaction represents a unique aspect of postural control that is different between IS patients and healthy adolescent control subjects. However, it is unclear within the context of this study what aspect of IS may be the source of this increased difference.

Conclusion

The postural control during quiet stance of IS subjects with a small Cobb angle is challenged in both the A/P and M/L directions as demonstrated by a greater COP-COM signal. Both the IS and control subjects demonstrated a tendency to behave as an Inverted Pendulum, however, the significantly greater angular movement about the hip and neck reflects a postural control strategy where the principal axis of rotation is not the ankle joint.

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Table 1: Angular measurements in the sagittal plane. (Avg = Average, SD = Standard Deviation).

		Ankle (°)	Hip (°)	Neck (°)	Group	Segment
Control	Avg	0.3	0.8	1.0	*	*
	SD	0.1	0.2	0.2		
Scoliosis	Avg	0.5	1.1	1.3		
	SD	0.2	0.5	0.6		

* $p<0.05$

Table 2: Angular measurements in the frontal plane (Avg = Average, SD = Standard Deviation).

		Ankle (°)	Hip (°)	Neck (°)	Group	Segment
Control	Avg	0.1	0.4	0.6		*
	SD	0.1	0.1	0.1		
Scoliosis	Avg	0.2	0.5	0.7		
	SD	0.1	0.2	0.3		

* $p<0.05$

Table 3: The correlation between the COM_{acc} and COP-COM, for control and Idiopathic Scoliosis patients.(Avg = Average, SD = Standard Deviation).

		Correlation COP-COM vs. COM_{acc}	
		A/P	M/L
Control	Avg	-0.73	-0.65
	SD	0.05	0.07
Scoliosis	Avg	-0.72	-0.70
	SD	0.06	0.07
	p	0.48	0.97

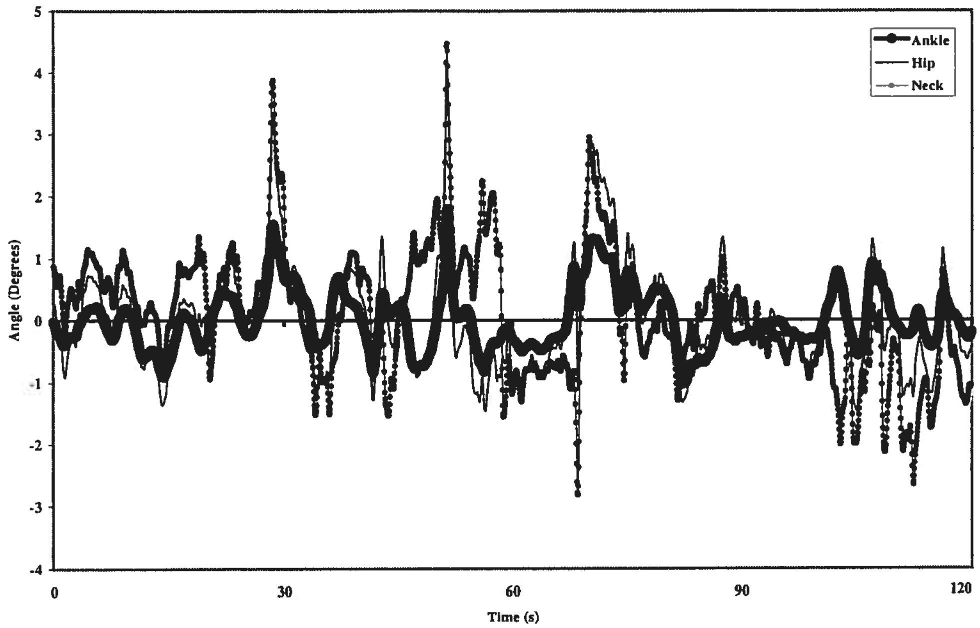

Figure 1: The ankle, hip and neck angle in the A/P direction with the bias removed for a typical IS patient. The solid thick dotted line represents the ankle, the thin line the hip, and the thin dotted line is the neck.

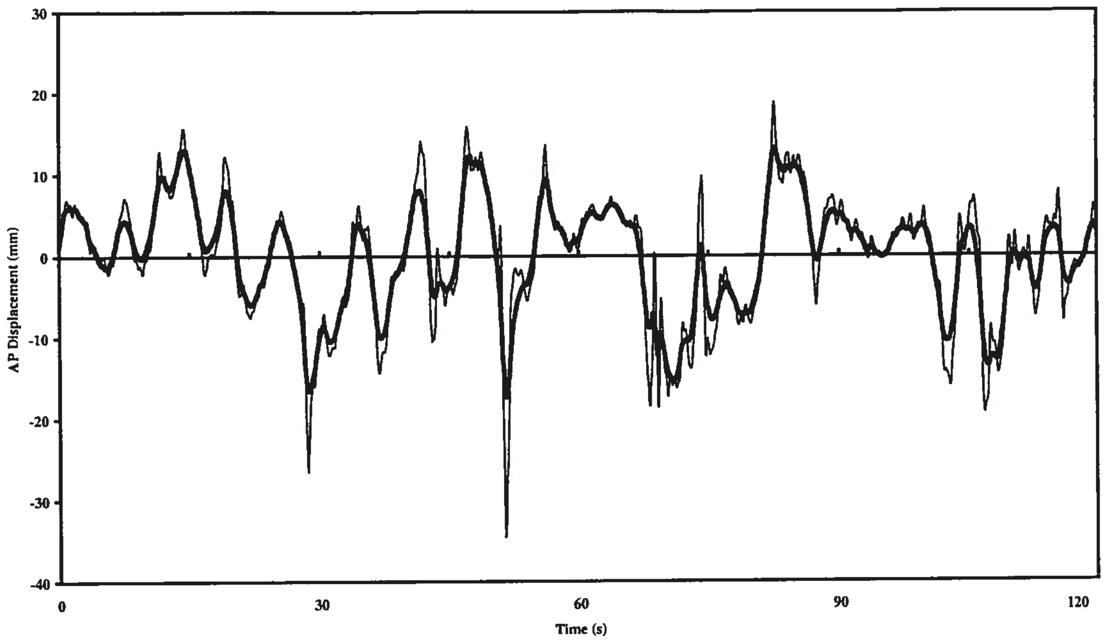

Figure 2: The COP and COM in the A/P direction for a typical IS patient. The solid thick line is the COM and the light thin line is the COP.

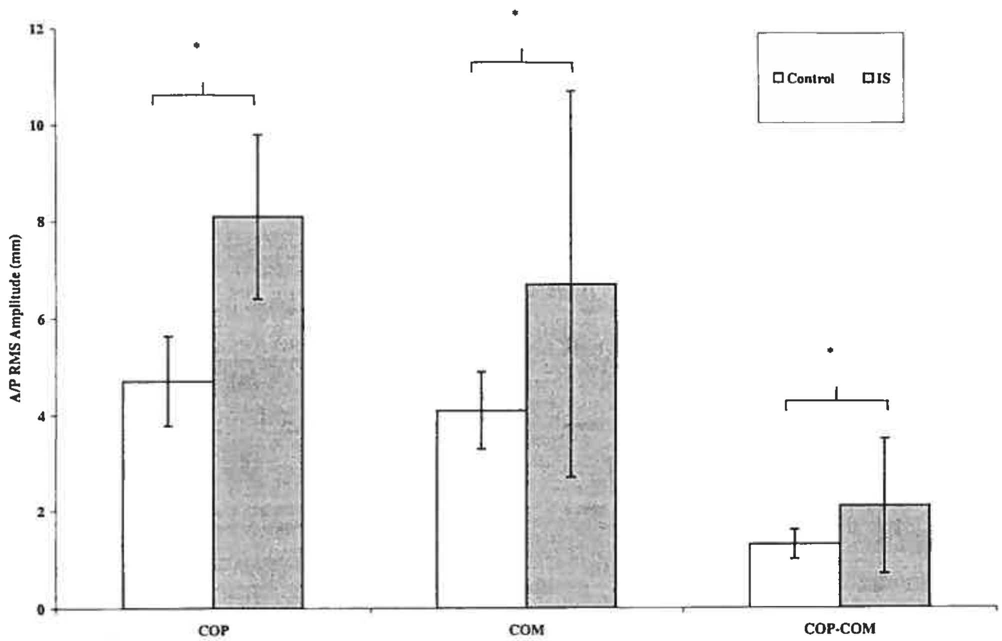

Figure 3: RMS amplitude (mm) of COP, COM and COP-COM displacement in the A/P direction. Solid bars define the IS group, light bars represent the control group. A significant difference ($p<0.05$) is identified as an asterisk.

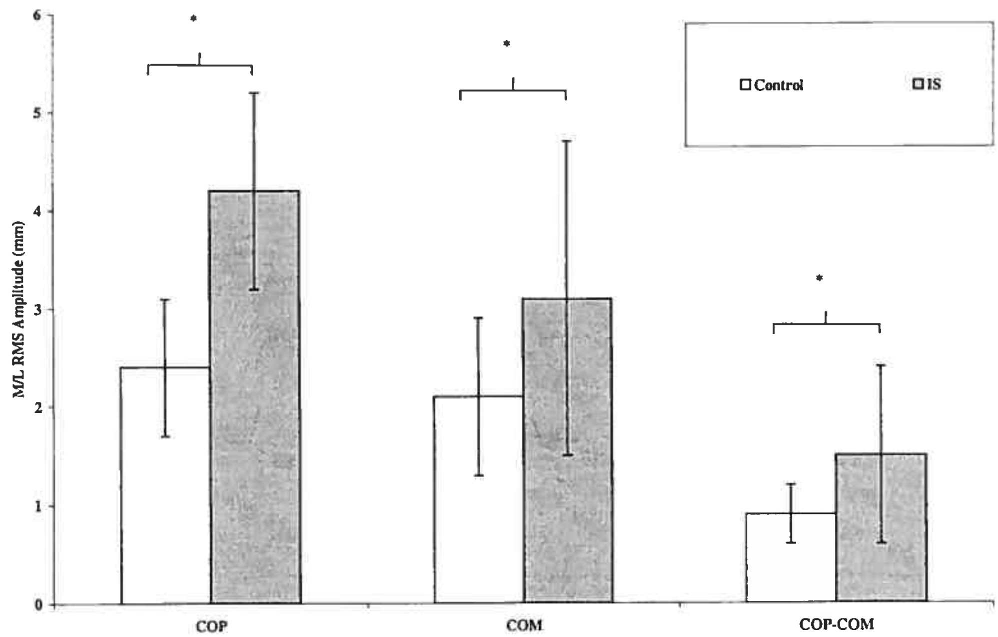

Figure 4: RMS amplitude (mm) of COP, COM and COP-COM displacement in the M/L direction. Solid bars define the IS group, light bars represent the control group. A significant difference (p<0.05) is identified as an asterisk.

CHAPTER VIII: General Discussion

The general objective of this thesis was to identify postural alignment and postural control parameters that would assist in the assessment and treatment of IS. This specifically involved applying two approaches for the postural assessment of IS. The first is a postural alignment model, and implicates assessing the position and orientation of the body segments in space. The second, is the evaluation of postural control through implementing a novel technique to estimate the COM in IS patients and control subjects.

There has been considerable research devoted to quantifying in 2-D (Carman et al., 1990; Cobb 1948, Morrissy et al., 1990) and 3-D (Delorme et al., 1999, Stokes et al., 1987) the amplitude of spinal curvature, as well as the orientation (Stokes et al., 1986; Stokes et al., 1988) and deformation of individual vertebra (Aubin et al., 1998) and the thorax (Danserau & Stokes 1988; Stokes et al., 1989). These methods have been used to precisely characterize the complex nature of the spinal deformity, and track its evolution without and with treatment. However, due to the potential negative consequences to the health of the patient with repeated x-ray exposure, simpler non-invasive postural assessment techniques have been developed. The emphasis of non-invasive techniques to evaluate the posture of IS patients has for the most part been focused on identifying patients that require surveillance or treatment using one indice of trunk rotation (Bunnell & Delaware 1984), or to predict the amplitude of spinal deformity (Jaremko et al., 2001; 2002a; 2002b; 2002c). The direction of this research has contributed to the understanding of the relationship between postural abnormalities and the underlying spinal deformity through regression analysis. However, there has been little emphasis on quantifying individual postural characteristics associated with the overall impression of postural distortion or asymmetry (Raso et al., 1998) to improve the characterization of IS patient posture prior to and during treatment. The first three objectives of this study were designed to assist in the identification of postural alignment parameters specific to the type of IS curvature and the acute changes that occur when a non-rigid brace is applied to the patient. The fourth objective of this thesis focused on the application of a novel technique to estimate the position of the COM of IS patients. The importance of applying this novel technique is underlined by the complex deformations of the spine and thorax that characterise IS. Through the application of this technique an evaluation of postural control may be peformed through the assessment of the displacement of the COM in relation to the COP.

8.1 Angular and linear displacement of the pelvis and shoulder girdle during quiet standing in control and Idiopathic Scoliosis patients.

The evaluation of spinal deformity (Stokes et al., 1988), back surface asymmetry (Denton et al., 1992) and postural alignment (De la Huerta et al., 1988; Le Blanc et al., 1996) of IS patients has been the focus of a number of studies. The premises of these techniques are to obtain a representation of the bodies skeletal configuration through one image or photograph (Denton et al.,1992; Stokes et al., 1987), an extended scanning time of 5 to 15 seconds (Dawson et al., 1993; Jaremko 2001;2002a,b,c), or through consecutive landmark digitisation over a 1 to 2 minute period (Le Blanc et al., 1996; Letts et al., 1998; Mior et al., 1996, Zabjek et al., 1999). The first manuscript of this thesis is the first study that has investigated the amplitude of displacement of segmental angular measurements of rotation and tilt in the transverse and frontal planes during quiet standing. In the current study, it was found that the average RMS displacement of the angular and linear measures was found to be inferior to 1° and 10 mm respectively. This displacement is similar to the variability noted in previous studies with different data acquisition techniques. The within and between session variability of similar parameters using a shorter data acquisition time has been found to be 12.5 mm, and 5.4 mm for A/P and M/L shift, and 2.8° and 1.4° for rotation and tilt respectively (De la Huerta et al., 1998). Goldberg et al. (2001) who studied IS patients found 15 mm, and 8 mm variability obtained with repeated samples with the patient in the same position and repositioning of the patient using a surface topography technique. The sequential digitisation of anatomical landmarks has also found average between evaluator variability of 1-1.8° for parameters of rotation and tilt (Dao et al., 1997). The variability attributed to the repeated measurements of these patients has been attributed to either body sway or to the positioning of the patient (Goldberg et al., 2001; Zabjek et al., 1999).

Subtle asymmetries of the skeletal system are relatively common, with a clinical prevalence of rib hump between 1 and 5 mm estimated to be as high as 61 %. A lower leg length inequality has been found to have a clinical prevalence of 4.8 %, and as high as 47.9 % for the left leg and 22.8 % for the right leg measured radiographically in patients with a rib hump of at least 6mm (Nissinen et al., 1989). In the present study it was observed that the majority of control subjects also had a postural deviation. A deviation in rotation was found to have standard deviation of 1-3°, and tilt from 1 to 2°, and a M/L shift of T1-S1 of up to 6 mm. The characteristics of this control population are similar to those reported by De la Huerta et al., (1998).

8.2. Postural alignment characteristics specific to the type of spinal curve.

Although numerous studies have investigated the relationship between back surface asymmetry and the amplitude of Cobb angle (Liu et al., 2001), very few have actually investigated the association of specific postural characteristics with specific types of spinal curvatures (Inami et al., 1999). Liu et al., (2001) found that the Q angle (angle of spinal curvature based on spinous process positions), T1-NC (natal cleft), and T1-S1 angles were the most valuable for classifying single curves by curve amplitude, with Q angle and kyphosis the most valuable for double curves. However, Liu et al (2001) did not partition the single and double curves according to curve type. Inami et al., (1999) identified a greater POTSI index for thoracic and thoracolumbar curves than double curvatures. The 6 individual measurements (3 back surface frontal asymmetry and 3 height differences) that compose the total score also found individual differences between curves. Although the asymmetry indexes are measured relative to the pelvis, and are specific to the level of the shoulders, axila and trunk, only the lateral shift of C7 to the centre line defined by the pelvis, is similar to the shift of T1-S1 evaluated in this thesis. In the present study the thoracolumbar patients were characterized by postural alignment deviations in the frontal plane, the thoracic patients with postural deviations in the transverse plane, and in the deviations in the frontal plane, the double patients a combination of frontal and sagittal plane deviations.

8.3 Postural alignment changes induced by a non-rigid brace.

The goal of treating IS is to alter the natural history of curve evolution. The application of a rigid brace has been found to have a 74 % probability of stabilisation or improvement, which was significantly greater than no treatment (34 %) and 33 % with electrical stimulation (Nachemson & Peterson 1995). A recent review of patients treated with the non-rigid brace SpineCor, found a slightly greater cumulative probability of success at four years of combined treatment and follow-up of 0.92 and 0.88 for curves less than and greater than 30° respectively (Coillard et al., 2003). For rigid bracing systems, the amplitude of the initial in brace correction of greater than 50 %, has been associated with a final curve correction of 7° (Olafsson et al., 1995), with an initial reducibility of 8-10% associated with a poor post-treatment result (Noonan et al., 1996). This average reducibility is greater than that reported for the non-rigid brace (Coillard et al., 2003), and the reducibility found in this study. However, despite a smaller initial reducibility, the general pattern of curve evolution is the same as with other bracing systems. The typical pattern of treatment for both the rigid and non-rigid braces has been noted to include an initial reduction of the spinal curvature in brace followed by an average loss of this reduction by the end of treatment and during follow-up (Coillard et al., 2003; Emans et al., 1986). The average decrease in spinal curvature at follow-up was found to be slightly higher for the non-rigid brace (Coillard et al., 2003) in comparison to the other rigid bracing systems (Emans et al., 1986; Lonstein & Winter 1994). It is therefore recognised that the in-brace correction is difficult to maintain until the end of treatment and the technique with which the brace is applied may contribute to the final correction or stabilisation of the spinal curvature.

In this thesis, the non-rigid brace was applied in a different manner for each type of spinal curvature with an initial reducibility of 28% (SD: 18) for the thoracic, 38% (SD: 21) for the thoracolumbar, 32% (SD: 11) for the lumbar and 21% (SD: 22) for the double curves. This reduction in spinal curvature was accompanied by unique postural changes. The parameters most noted to change included the rotation and tilt of the shoulders, and shoulder blades in reference to the pelvis, and rotation of the shoulders in reference to the shoulder blades. There are few studies that have reported the amplitude of change in postural parameters when a rigid or non-rigid brace is applied. Griffet al., (2000), noted a decrease in thoracic rib hump of 2.4° for a change of 7.4° for the thoracic region of single and double curvatures when treated with the same non-rigid brace as utilised in this study. Although a positive correlation of 0.59 and 0.69 were found with and without the brace, there was a low correlation with the amplitude of change between these two conditions. Goldberg et al., (2001) evaluated changes in back surface parameters obtained from surface topography before and after 1 year of follow-up. A significant but weak correlation was found between a change in Cobb angle and the Suzuki hump sum which is a quantification of surface rib hump (0.48 and 0.42 respectively), as well as a significant change in at least one of the Quantec spinal parameters. The Quantec spinal parameters are a series of measurements such as surface spinous process angles, or rib hump angles obtained from a surface scan of the back. The weak correlation between postural change and a change in spinal curvature may be due to two factors. The first is related to the small range of change in both spinal and postural parameters, which results in a weak correlation. The second is hypothesized to be related to the manner in which the neuromuscular system adapts uniquely for each patient with the application of a brace.

The clinical benefit of quantifying postural alignment of IS patients is related to two factors. Firstly it is non-invasive, so there is no limitation in the frequency of evaluation. Secondly, it also provides a quantitative perspective of postural alignment in three planes of reference for the pelvis, trunk and shoulders. These two aspects are an improvement over traditional radiographic techniques. Traditional radiography is limited by the potential harmful health effect of repeated exposure to radiation, therefore limiting the number of evaluations that can be performed. The position and orientation of the pelvis and shoulders is also difficult to obtain from 2-D radiography, therefore limiting the overall impression of a patients posture.

However, the limitation of this technique is that it provides an indication of the overall postural alignment and does not implicate the time and frequency components related to posture in quiet standing. The time and frequency components of posture during quiet standing can provide deeper insight into mechanisms responsible for postural control.

8.4 Estimation of the centre of mass and evaluation of postural control

The position of the COM has been estimated using measurements performed directly on cadavers (Dempster & Gaughran 1967), and live subjects using a stereophotogrammetry (Zatsiorsky & Seluyanov 1983; 1985), cross-sectional modelling of body segments (Jensen 1978; Jensen 1986; Jensen 1989), medical imaging techniques (Pearsall et al., 1996) and force plates (Benda et al., 1994; Caron et al., 1997;. King & Zatsiorsky 1997; Morasso et al., 1999; Shimba 1984; Zatsiorsky & King 1998). Of these models, anthropometric measurements proposed by Dempster & Gaughran 1967, as well as modified segment proportions (Winter et al., 1996); have been principally used to estimate the displacement of the COM during quiet standing in adults (Winter et al., 1996; 1998; 2001). However, mass proportions of the head and arms and legs are noted to change between the ages of 4 and 20 years (Jensen 1989). Therefore the adult based anthropometric models are inappropriate to be applied to a younger population. The anthropometric proportions proposed by Jensen (1978; 1986; 1989) provides a more population specific estimation of the COM. However they have not been evaluated for their accuracy to estimate the position of the COM during quiet standing. Through comparison with other force plate techniques, the 'Gravity Line' technique has been identified as an encouraging technique to estimate the displacement of the COM (Lafond et al., in press; Lenzi et al., 2003). This is due to the independence of the technique to errors caused by anthropometric parameters (Lafond et al., in press; Lenzi et al., 2003). There have been a limited number of studies that have compared the COM estimated with anthropometric body segment parameters to the COM estimated from a Force Plate. In this thesis, this is the first time to the author's knowledge that a comparison between anthropometric and the 'Gravity Line' technique has been performed in adolescents and IS patients. The differences between the two techniques was characterized by a mean bias in the position of the COM in the A/P direction, and a RMS amplitude difference of 0.7 and 1.2 mm, in A/P and 0.5 to 0.8 mm in the M/L direction which was greater for the scoliosis than the control subjects respectively. This amplitude of difference was greater than that previously reported by Zatsiorsky & King (1998) in adult subjects who reported a mean difference of 0.3 mm for the RMS displacement, and a strong correlation of 0.88 between the 'gravity line' COM estimation and anthropometric estimation of the COM in adult subjects. This increased error is suspected to be caused by the complex nature of spinal deformation accompanied by postural deviations of the shoulders, pelvis and thorax.

The mean bias found in the A/P position of the COM estimated using anthropometric parameters was expected. This bias has also been recognised by previous authors, as being constant to each subject during the same data collection period. This difference is attributed to the identification of anatomical landmarks on the surface of the skin, which is not close to the joint centre of the segments involved. This leads to a bias in the A/P direction. To overcome this bias, it is removed from the signal prior to comparing the COM displacement with the COP displacement (Winter et al., 1996; 1998; 2001).

The principal advantage of utilising the ''gravity line'' technique to evaluate IS, and adolescent controls is that it provides an accessible means of estimating the position of the COM in a clinic that has access to a Force Plate. Since it does not require landmark detection, or the placement of opto-electronic markers, the preparation time for the patient is decreased significantly. This technique could be combined to estimate the position of the COM and compared simultaneously with 2D or 3D radiography. This provides a means of directly comparing vertebral position, in relation to the COM, and provide the basis to address the problem of vertebral wedging.

The assessment of body sway in IS and adolescent subjects has most often been quantified through measuring aspects of the COP related to sway area (Chen et al., 1998; Nault et al., 2002, Sahlstrand et al., 1978), sway radius (Chen et al., 1998), and sway amplitude (Chen et al., 1998), where the IS were found to have greater amplitudes than control subjects. This is in agreement to the results in this study where both the COM and COP demonstrated greater RMS displacement in the IS patients than the control subjects. However, it is important to distinguish between these two variables. The COM is considered to be the passive variable, who's position is affected by a weighted sum of the position of all of the body segments. On the other hand the COP is considered as the ''control'' variable, responsible for maintaining the COM within the base of support. However, consideration of the COP-COM can provide an indication of the efficacy of the postural control system. In this study, the IS patients were found to have a greater RMS difference of the COP-COM variable in both the A/P and M/L directions. This significantly greater difference in the A/P direction is in agreement with Nault et al., (2002) who found an average RMS amplitude of 1.0 mm for IS, and 0.8 mm for control subjects. However, Nault et al., (2002) did not find any difference in the M/L RMS amplitude of the COP-COM. This difference may be attributed to the technique utilised to estimate the position of the COM. Nault et al., (2002), utilised a technique developed by Caron et al., (1997) to estimate the position of the COM. This technique has been found to be sensitive to body segment parameters (Lenzi et al., 2003) and has significantly greater differences in adults in comparison to kinematic methods than the ''Gravity Line'' technique utilised in this study (Lafond et al., in press). This may contribute to a greater error in the estimation of the COM, and there fore more difficult to identify differences in the M/L direction where the amplitude of RMS difference is smaller than in the A/P direction.

To our knowledge the sixth manuscript of this thesis is the first study that investigated the correlation between the horizontal acceleration of the COM with the COP-COM difference in adolescent IS patients and control subjects. This correlation has been found to be very strong (-0.91 A/P and -0.75 M/L) in adult subjects and has been used to validate the inverted pendulum model (Winter et al., 2001. Rietdyk et al., 1999). The inverted pendulum model implies that the principal axis of rotation for the COM is about the ankle joint axis in the A/P, and the hip joint in the M/L directions (Winter et al., 1996). In this study it was found that the correlation was weaker (-0.73 A/P and -0.65 M/L) with a more pronounced difference in the A/P direction. It is possible that this weaker relationship is due to the maturity of the neuromuscular system. There have been numerous authors that have suggested that the neuromuscular system is already mature between the ages of 8 and 12 (Riach & Hayes 1987, Forssberg & Nashner 1982; Woollacott et al., 1987). Motor-response patterns to an external perturbation have been found to have adult like muscle activation patterns between the ages of 7 –12 (Forssberg & Nashner 1982; Woollacott et al., 1987). However, this reflects the reaction of the body to an external perturbation of larger amplitude, than the smaller fine motor adjustments need to control the COM during quiet standing. In this study, it was found that the IS patients had a greater relative RMS amplitude of angular displacement of the hip than the control subjects. This mobility of the hip was also reflected by greater relative RMS amplitude of displacement between the COM and the 1st Sacral prominence. This aspect of relative segmental motion during quiet standing has not been previously evaluated, in adolescent or control subjects. Segmental motion is normally observed under the conditions of an external perturbation, where dependent on the amplitude and the source of perturbation, either an ankle or a hip strategy is utilised (Horak & Nashner 1986; Rietdyk et al., 1999). Rietdyk et al., (1999) found that despite external perturbations applied to the trunk in adult subjects, there was still a significant positive correlation between the horizontal acceleration of the COM and the COP-COM difference. It was hypothesised by that despite the presence of angular movement that was greater at the hip than the ankle in the presence of an external perturbation, the strong correlation still validated the theory of the inverted pendulum. The results of this present study suggest a similar notion. The correlation although not as strong still reflects an Inverted Pendulum mode of postural control in adolescent subjects. However, the greater relative angular displacement at the hip for the IS patients reflects a pathological aspect of IS. It is hypothesised that this observed difference might be related to 3 factors. Firstly, this may be the result of decreased mobility of the spinal column as a result vertebral wedging and vertebral disorientation that results in greater mobility at other joints. Secondly, it may be a consequence of a deficit in the proprioceptive system. This aspect has been noted previously, where IS patients have been found to have greater thresholds to detect knee joint motion, and more difficulty in producing joint angles (Barrack et al., 1984; Cook et al., 1986). As a result it is more difficult for IS patients to control the hip joint motion. Thirdly, this may be an active strategy employed by the patient to attempt to redistribute the forces on the vertebral bodies to prevent vertebral wedging. However, if this were the case, it would have been expected that the same increased joint movement would have been observed in the M/L direction as well. Therefore further research is required to determine if these observations are an active strategy or a result of a deficit to the proprioceptive system.

8.5 Limitations of the Present Research

This thesis investigated aspects of postural alignment and postural control in IS patients. IS is a difficult population to study since there are a number of factors that are implicated in the aetiology, multiple risk factors for progression, as well as the unique natural history that is associated with each type of spinal curvature. In consequence, a large number of IS patients is required such that age, maturity, gendre and type of spinal curvature may be accounted for. This is important when considering the initial postural characteristics of the IS patients and also the changes that occur with treatment. For example, it is possible that the nature of the relationship between the spinal deformation and the type of spinal curvature may be different for smaller spinal deviations than 15°, and in larger spinal deformations of the spinal column. Prior treatment with a rigid brace may also affect the nature of this relationship, since the natural evolution of postural alignment that accompanies the spinal curvature would be altered.

The initial pre-treatment postural alignment characteristics and changes induced by a non-rigid brace were evaluated in a group of IS patients with a Cobb angle between 15° and 45° who had not received any prior orthopaedic treatment. The technique used to evaluate the postural alignment in this study was based on the identification of surface anatomical landmarks to assess postural alignment, and the estimation of the amplitude of spinal deformation using the Cobb angle (Cobb, 1948). The limitation of using this apporach is that it does not provide direct information regarding the position and orientation of individual vertebra or of the thorax. This aspect may be of interest when evaluating the efficacy of a treatment approach for IS patients, and should be considered in future studies.

This research also identified that the RMS difference of the COP-COM variable, and relative movement of the hip in the A/P direction is greater in IS than in Control subjects. Within the context of this study it was not clear if this is an aetiological factor of IS, or an observable effect of the proprioceptive deficits found in the IS population. A larger population of IS patients is required to be followed over a longer period of time so progressive vs. non-progressive IS patients may be identified.

The systems used in this research were two optoelectronic systems, a sonar-based digitisation system, and a force plate measurement system. The principal advantage of both opto-electronic systems is the ability to obtain accurate and precise 3-D positions of active or passive markers in 3D space in real-time. However, the limitation of regularly using these systems in a clinical environment is the overall cost, expertise required to operate the systems, as well as the time required to place the active/passive markers on the patients. The sonar-based system was chosen as a clinically applicable tool due to it's low cost, simple set up and operation, and flexibility in transportation and utilisation in a variety of clinical environments. The major disadvantage of the sonar-based system is its susceptibility to poor functioning in environments where there is significant air current. Since, the 3-D position is estimated from the time a sound is emitted from the digitisation probe, to its reception by three receivers, temperature, humidity, and airflow will affect this propagation time, and therefore affect the 3D accuracy and precision of the system. A calibration device is capable of accounting for temperature and humidity changes, however air current can only be minimised by controlling the room in which the system is used. Although there was a strong agreement between the stereo-video graphic system and the sonar-based system, attention should be paid to patients who demonstrate considerable postural sway.

8.6 Future Studies

This research has investigated specific aspects of postural alignment and postural control of IS patients and provides the basis for future investigations into optimizing the evaluation, treatment and understanding of the aetiology of IS. The scope of future investigations includes the following:

1) With an increasing number of IS patients evaluate the influence of curve amplitude on the postural characteristics and the observable changes with the non-rigid brace.

2) Evaluate the influence of gendre, maturity level and curve amplitude on the immediate changes induced on the spine and posture of all of the IS scoliosis patients.

3) Evaluate the predictive value of the initial postural changes obtained with the fitting of the brace with the final treatment outcome.

4) Compare the position of the COM estimated from a force plate with the position and orientation of the vertebra obtained from 2D and 3d radiological evaluations.

5) In a prospective study evaluate the COP-COM variable and categorize the IS patients according to curve type, curve amplitude as well as the progressive vs. non-progressive.

CHAPTER IX: Conclusion

This thesis contributes to the current knowledge of IS through the identification of postural alignment parameters that assist in the characterization IS patients according to the type of spinal curvature, the unique changes induced by a BMCMP, and unique aspects of postural control. This entailed using novel, non-invasive techniques to quantify the position and displacement of the COM in relation to the COP and quantify the alignment of individual body segments in a population of IS patients and control subjects.

The identification of surface anatomical landmarks located on the base of support, pelvis, shoulder blades and shoulder's served as the basis for the quantification of their angular/linear position and displacement in the frontal, transverse and sagittal planes. This approach combined with an opto-electronic recording system provides a reliable quantitative means of assessing postural alignment providing both global measurements in reference to the base of support and relative measurements between body segments. The principal differences between IS and control subjects was found to be the A/P RMS displacement of T1 and S1, and the mean rotation of the $SHLDB_{BOS}$ and the $SHLDB_{PEL}$. Although the RMS angular displacement is similar between the IS and control subjects, there was a large variability in scoliosis patients for the mean angular positions, making it difficult to clearly differentiate them from the control subjects. This variability in the postural alignment characteristics of the IS patient population is primarily attributed to the presence of different types of spinal curvatures and makes it more difficult to characterize the postural alignment of IS patients when evaluated as one group.

The importance of categorizing IS patients according to their type of curvature was underlined with the presence of numerous between group differences. The most notable of these differences were found in the frontal (tilt and lateral shift) and transverse planes (rotation). The LThL and D patients had a similar left lateral shift of the shoulders that was opposite to the right lateral shift of RTh patients. However, conversely, the RTh and D patients had similar counter-clockwise tilt of the $SHLD_{PEL}$ and $SHLDB_{PEL}$ that was opposite to the clock-wise tilt of LThL patients. In the transverse plane the RTh and D patients also demonstrated similar but greater clock-wise rotation of the SHLDB, counter clock-wise rotation of the SHLD and counter-clockwise rotation of the $SHLD_{SHLDB}$ than the LThL patients. These differences underline the unique postural characteristics of each type of spinal curvature and underlines the importance of using multiple parameters to characterize the posture of IS patients. Performing this type of postural evaluation with a sequential digitisation technique to quantify the tilt of body segments is clinically more applicable than a video based approach. However a change in the order of landmark digitisation should be considered in order to optimize the calculation of segment rotation, and minimise the effect of postural sway.

The application of a unique BMCMP to IS patients according to their type of curvature was accompanied by a decrease in the amplitude of spinal curvature and unique changes to postural alignment. The change in SHLD tilt, SHLD rotation, and rotation of the $SHLD_{SHLDB}$ reflects the unique BMCMP applied to each type of spinal curvature. The RTh and D patients had a similar increase in SHLD tilt, and decrease in $SHLD_{SHLDB}$ rotation accompanied by a decrease in SHLD rotation. The rotation of the SHLD decreased for the RTh, and changed direction from counter-clockwise to clock-wise for the D patients, and to a lesser degree for the LThL patients. The LThL patients in contrast to the RTh and D patients had a decrease in SHLD tilt with no change in SHLD rotation in reference to the shoulder blades. Although these changes reflect the immediate effect of the BMCMP on posture alignment and curvature of the spine, further research is required to evaluate the postural changes that occur over the duration of treatment.

The complex 3-D nature of the postural deviations found in IS patients challenges researchers in obtaining an accurate estimation of the COM using an anthropometric model. This was reflected within the present study when a significantly larger difference was found for the IS than the control subjects when the two models were compared. This increased error is primarily attributed to the simplification of the trunk in estimating the COM that does not account for the complex nature of pelvis, shoulder, and shoulder blade rotation and tilt often found in IS patients. Estimation of the COM using the force plate based technique is independent of the anthropometric and geometric characteristics of the patient. Therefore, the latter technique represents a viable clinical option for evaluating the postural control of IS patients. Through estimating the COM using the force plate technique, a greater RMS COP-COM difference was found for IS patients in both the A/P and M/L directions. Although this difference indicates a challenged postural control system in IS patients, its source may be attributed to two factors. A comparison of the RMS displacement of the body segments between IS and control subjects revealed a significantly greater segmental mobility in the sagittal plane. This increased segment mobility may be attributed to the difficulty the postural control system experiences in controlling the complex postural deformations of the trunk and spinal column. An additional contributing factor is the developing postural control system in both IS and control subjects that is emphasised through the moderate correlation found between the COM_{acc} and the COP-COM signal.

Within the scope of this thesis a number of parameters which reflect postural alignment and control were found to detect differences between IS patients and control subjects, between groups of IS patients, and before and after the application of a BMCMP. These results underline the importance of applying a comprehensive postural evaluation to understand the complex deformation and evolution of IS. These results provide the basis for future research that should focus on further application of these techniques to quantify the postural changes that occur over the duration of treatment and further investigate the role of postural control dysfunction in the aetiology of IS.

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Appendix 1

CONSENT FORM

Project Title: MULTICENTER TRIAL PROTOCOL
Dynamic Corrective Brace (DCB)

Investigators: Dr. Christine Coillard
Dr. Hubert Labelle
Dr. Benoit Poitras
Dr. Charles H. Rivard

Summary of the project:

Your attending physician has found it necessary to evaluate your scoliosis and eventually suggests that you take part in a prospective protocol for the evaluation of the D.C.B. (Dynamic Corrective Brace). The effects of this brace, which have been evaluated in over 70 patients since 1993, must be compared to a control group. The targeted population is a group of scoliotics presenting a small idiopathic scoliosis curve with a Cobb angle between 15° and 30°. These patients are not currently being provided with active treatment, most orthopedists are waiting for a 30° angle to prescribe a rigid brace. This brace is also more easily acceptable than other rigid braces. The objective of this project is to gather detailed information concerning the effects of the D.C.B. on the geometry of the spinal column, the postural geometry, the growth and the neuromuscular system of the scoliotic patient. You will be randomly assigned to one of two groups that are being studied: the group treated with the D.C.B or the untreated control group.

Your follow-up is carried out at variable intervals throughout the treatment. It is performed in the presence of an orthopedist and includes routine clinical and x-ray examinations. Supplementary anthropometric, postural and neuromuscular evaluations, including a physiotherapy examination and an evaluation of the mobility of your back, are also carried out during your treatment.

At the time of the initial evaluation, two additional x-rays are taken: one in a lying position to evaluate the reducibility of the curve and another to help us measure your bone age. The follow-up includes only the standard scoliosis x-rays and the supplementary evaluations which are surface and stereovideographic measures that are absolutely not invasive. Therefore, each visit is slightly longer than a regular visit.

The protocol acknowledges that any aggravation of 5 degrees or more of your Cobb angle results in your withdrawal from the protocol. Your attending physician will then suggest a more appropriate type of treatment for your condition.

Project Title: MULTICENTER TRIAL PROTOCOL
Dynamic Corrective Brace (DCB)

INFORMED CONSENT:

I/my child declare that I have full knowledge of the information provided to the patients and the parents concerning this Dynamic Corrective Brace evaluation. All my questions concerning this project were answered to my satisfaction.

I am aware that at any time, I will be allowed to withdraw from this protocol, without prejudice regarding all of my rights for treatment. Should there be an aggravation of more than 5° of the Cobb angle in either groups, this will result in my withdrawal from the study, which will enable my attending physician to modify the treatment.

I understand that the results of this study can eventually be published and that this information may be shared between researchers, but that my confidentiality will be respected at all times.

______________________________	______________________________
Signature of the parent	Date
______________________________	______________________________
Signature of the subject	Date
______________________________	______________________________
Signature of the tutor	Date

APPROUVÉ LE COMITÉ D'ÉTHIQUE
DATE 18/2/[illegible]
[redacted]

APPROUVÉ LE COMITÉ D'ÉTHIQUE HÔPITAL SAINTE-JUSTINE
26-07-99
DATE
[redacted]

CONSENT FORM

Project Title: **MULTICENTER TRIAL PROTOCOL**
Dynamic Corrective Brace (DCB)

Investigators: **Dr. Charles H. Rivard**
Dr. Christine Coillard

Summary of the project:

Your attending physician has found it necessary to evaluate your scoliosis and eventually suggests that you take part in a prospective protocol for the evaluation of the D.C.B. (Dynamic Corrective Brace). The effects of this brace, which have been evaluated in over 136 patients since 1994, must be compared to other rigid braces results. The targeted population is a group of scoliotic patients presenting a medium idiopathic scoliosis curve with a Cobb angle between 31° and 45° (inclusively). The SpineCor brace is more easily acceptable than other rigid braces. The objective of this project is to gather detailed information concerning the effects of the D.C.B. on the geometry of the spinal column, the postural geometry, the growth and the neuromuscular system of the scoliotic patient. Please note that you have no obligation towards this protocol study and that alternative treatments for the idiopathic scoliosis are available.

Your follow-up is carried out at variable intervals throughout the treatment. It is performed in the presence of an orthopaedist and includes routine clinical and x-ray examinations. Supplementary anthropometric, postural and neuromuscular evaluations and an evaluation of the mobility of your back, are also carried out during your treatment.

At the time of the initial evaluation, two additional x-rays are taken: one in a lying position to evaluate the reducibility of the curve and another to help us measure your bone age. The follow-up includes only the standard scoliosis x-rays and the supplementary evaluations which are surface and stereovideographic measures that are absolutely not invasive. Therefore, each visit is slightly longer than a regular visit.

The protocol acknowledges that any aggravation of 5 degrees or more of your Cobb angle results in your withdrawal from the protocol. Your attending physician will then suggest a more appropriate type of treatment for your condition.

It is clear that this consent form does not reduce nor eliminate in any way the responsibility of the researchers and the promoter of this research towards any accident that may occur during the study.

Project Title: **MULTICENTER TRIAL PROTOCOL**
Dynamic Corrective Brace (DCB)

APPROUVÉ LE COMITÉ D'ÉTHIQUE
HÔPITAL SAINTE-JUSTINE
26.07.9?
DATE
SIG[redacted]

INFORMED CONSENT:

I/my child declare that I have full knowledge of the information provided to the patients and the parents concerning this Dynamic Corrective Brace evaluation. All my questions concerning this project were answered to my satisfaction.

I am aware that at any time, I will be allowed to withdraw from this protocol, without prejudice regarding all of my rights for treatment. Should there be an aggravation of more than 5° of the Cobb angle, this will result in my withdrawal from the study, which will enable my attending physician to modify the treatment.

I understand that the results of this study can eventually be published and that this information may be shared between researchers, but that my confidentiality will be respected at all times.

It is understood that by signing this form, I do not renounce to my legitimate rights nor those related to my child.

____________________ Signature of the parent	____________________ Date
____________________ Signature of the subject	____________________ Date
____________________ Signature of the tutor	____________________ Date

---

You can call anytime at: 514-345-4839 and someone will assist regarding any question you may have related to the project.

In addition, all subjects can call the ombudsman of the Hôpital Sainte-Justine (telephone: 514-345-4749) in order to get information related to their rights as participants to a research project.

APPROUVÉ PAR LE COMITÉ D'ÉTHIQUE
HÔPITAL SAINTE-JUSTINE
DATE 23 [redacted]

CENTRE
DE RECHERCHE
DE L'HÔPITAL
SAINTE-JUSTINE
Le centre hospitalier universitaire mère-enfant

Université de Montréal

Feuille d'information

Titre du projet : Contrôle postural chez les patients scoliotiques : maturation neuromusculaire et implications sur la progression des courbures vertébrales. *Postural control in scoliotic patients: neuromuscular maturation and implications to curve degeneration.*

Responsable du projet : Dr. François Prince

Collaborateurs :

Dr. Christine Coillard

Dr. Charles-H. Rivard

Commanditaires : Aucun

Résumé du projet:

Nous sollicitons votre collaboration pour participer à un projet de recherche effectué par des membres du service d'orthopédie de l'Hôpital Sainte-Justine et du département de kinésiologie de l'Université de Montréal. Nous nous intéressons à la compréhension du contrôle postural en période de croissance chez des patientes atteintes de scoliose idiopathique (déviation latérale de la colonne vertébrale). Nous sommes à la recherche de jeunes filles âgées entre 8 et 18 ans, afin d'établir des comparaisons entre les populations scoliotiques et non scoliotiques. L'examen postural est réalisé au Centre de réadaptation Marie-Enfant situé au 5200, Bélanger Est, à Montréal. Les données sont recueilles à l'aide de deux plates-formes de forces, et d'un système cinématique. Pour ce faire, les sujets doivent porter un maillot de bain noir (deux pièces) que nous fournissons. Cet examen dure moins d'une heure et sera effectué à deux reprises dans un intervalle de 4 mois. L'examen consiste en une détection des repères anatomiques réalisée à l'aide d'un crayon dermographique, à coller à l'aide de ruban auto-collant double-face hypo-allergène les marqueurs nécessaires et à faire l'acquisition des données avec le système Optotrak.

Avantages et bénéfices :

La participation à ce projet est sur une base volontaire. Le consentement d'un parent/tuteur est nécessaire, ainsi que la présence d'un adulte

P… amour des enfants

3175, Côte-Sainte-Catherine
Montréal (Québec)
H3T 1C5
Téléphone: (514) 345-4691
Télécopieur:(514) 345-4801
Cour. électronique:

APPROUVÉ HÔPITAL SAINTE-JUSTINE
DATE 23 juil.
[redacted]

responsable lors de l'évaluation. Il y aura une compensation financière de 50$ associée à la participation aux deux séance de collecte de projet. En participant à cette étude le patient bénéficiera d'un traitement et une analyse de sa scoliose plus détaillés que ce qui est offert dans le cadre de l'examen clinique traditionnel des patients scoliotiques. De plus, le patient aura la chance de participer à une étude réalisée avec des technologies de pointe dans un cadre scientifique et le parent/tuteur aura la chance d'obtenir des informations rigoureuses sur la scoliose idiopathique. Grâce aux résultats obtenus dans cette étude, le clinicien aura le choix d'offrir un suivi médical plus rigoureux du patient scoliotique et contribuera à traité la scoliose idiopathique plus efficacement.

Inconvénients et les risques :

Cet examen ne comporte aucun risque et aucune procédure invasive (radiographie, prise de sang, etc....) n'est requise. Pendant vos évaluations s'il y a des indications que vous avez une scoliose, vous serez averti et le numéro de téléphone d'une clinique orthopédique vous sera donné. La scoliose idiopathique est une maladie progressive de la colonne vertébrale. L'absence de traitement augmente significativement le risque d'aggravation de la scoliose, un traitement chirurgical en cas de courbures sévères peut être nécessaire.

Comment la confidentialité est-elle assurée ?

Tous les renseignements obtenus sur vous dans le cadre de ce projet de recherche seront confidentiels, à moins d'une autorisation de votre part ou d'une exception de la loi. Pour ce faire, ces renseignements seront mis sous clé. Les dossiers sous étude seront conservés aux archives de l'Hôpital Sainte-Justine.

Cependant, aux fins de vérifier la saine gestion de la recherche, il est possible qu'un délégué du comité d'éthique de la recherche, des représentants de Santé Canada, de la Food and Drug Administration aux Etats-Unis et des organismes commanditaires consultent vos données de recherche et votre dossier médicale.

Par ailleurs, les résultats de cette étude pourront être publiés ou communiqués dans un congrès scientifique mais aucune information pouvant vous identifier ne sera alors dévoilée.

APPROUVÉ PAR LE COMITÉ D'ÉTHIQUE HÔPITAL SAINTE-JUSTINE
DATE 23 juil 0
[redacted]

Responsabilité des chercheurs :

Dans l'éventualité où vous seriez victime d'un préjudice causé par les procédures requises par le protocole de recherche, vous recevrez tous les soins que nécessite votre état de santé et qui sont couverts par les régimes d'assurance-hospitalisation et d'assurance-maladie. En signant ce formulaire de consentement, vous ne renoncez à aucun de vos droits prévus par la loi.

Conflits d'intérêts :

Les chercheurs et collaborateurs n'ont aucun intérêt suffisamment important qui pourrait influencer l'exercice objectif a leur jugement professionnel.

En cas de questions ou des difficultés, avec qui peut-on communiquer?

Pour plus d'information concernant cette recherche, contacter le chercheur responsable de cette étude à l'Université de Montréal, le Dr. F. Prince au 514) 343-7784.

Pour tout renseignement sur vos droits à titre de participant à ce projet de recherche, vous pouvez contacter l'ombudsman de l'hôpital Sainte-Justine au (514) 345-4749.

APPROUVÉ PAR LE COMITÉ
HÔPITAL SAINTE-JUSTINE
DATE 23

Titre du projet: Contrôle postural chez les patients scoliotiques [redacted] maturation neuromusculaire et implications sur la progression des courbures vertébrales. *Postural control in scoliotic patients : neuromuscular maturation and implications to curve degeneration.*

CONSENTEMENT ET ASSENTIMENT:

Je/mon enfant affirme avoir pris connaissance de l'information aux patients et aux parents concernant le projet de recherche intitulé : "Contrôle postural chez les patients scoliotiques : maturation neuromusculaire et implications sur la progression des courbures vertébrales". Les responsables présents ont répondu de façon satisfaisante à toutes mes questions au sujet de ce projet d'évaluation.

Je suis conscient qu'à tous moments, il me sera permis de me retirer de ce protocole d'évaluation sans aucun préjudice à l'égard de mes droits au traitement.

Je comprend que les résultats de cette étude pourront éventuellement être publiés et que cette information pourra être échangée entre les chercheurs, mais, que la confidentialité de mon dossier sera respectée en tout temps.

______________________________ _________________

Consentement du parent, tuteur — Date

______________________________ _________________

Assentiment de l'enfant — Date

______________________________ _________________

Signature du témoin — Date

FORMULE D'ENGAGEMENT DU CHERCHEUR

Le projet de recherche a été décrit au participant ainsi que les modalitées de sa participation. Un membre de l'équipe de recherche a répondu à ses questions et lui a expliqué que la participation est libre et volontaire. Je m'engage à respecter ce qui a été convenu dans le formulaire de consentement.

______________________________ _________________

Signature du chercheur — Date

Appendix 2