

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

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Abstract

Background. The complex skeletal deformations that accompany Idiopathic Scoliosis pose a challenge to the clinician to non-invasively discriminate Idiopathic Scoliosis patients from children with no pathology. Therefore, the focus of this study is to non-invasively evaluate the position and amplitude of displacement of the pelvis, shoulders and thorax during quiet standing of Idiopathic Scoliosis patients and control subjects.

Methods. The quiet standing posture of 18 healthy adolescent females and 22 Idiopathic Scoliosis subjects was evaluated using an Optotrak 3020 position sensor over a period of 120 s, with 4 repeat trials. Outcome measures included the mean position, root mean square amplitude and range over the duration of 120 s trials for both linear and angular measures of the pelvis, thorax and shoulders. Appropriate sample times were chosen and evaluated for stability over the 120 s period, and between trial reliability was evaluated.

Findings. There was a significant difference between groups for the mean position of the shoulder blade rotation in reference to the base of support and to the pelvis. The Idiopathic Scoliosis patients had a significantly larger root mean square amplitude of anterior–posterior displacement of the T1 and S1 spinous processes in reference to the base of support. There was no difference between the sample durations to estimate the mean position of the body segments, however the root mean square increased significantly.

Interpretation. This study demonstrates that postural abnormalities are evident during quiet standing in Idiopathic Scoliosis patients.

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1. Introduction

Idiopathic Scoliosis (IS) involves 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

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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 include clinical observations made subjectively, or objectively with a plumb line, ruler and scoliometer (Cote 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,b), landmark digitisation (Le Blanc et al., 1996; Letts et al., 1988; 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 and Gorton, 2000). The premises of these techniques are to obtain a representation of body alignment from one image or photograph (Denton et al., 1992; Stokes et al., 1988), an extended scanning time of 5–15 s (Dawson et al., 1993; Jaremko et al., 2001), or through consecutive landmark digitisation over a 1–2 min period (Le Blanc et al., 1996; Letts et al., 1988; 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 anterior–posterior (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 and Hayes, 1987; Wolff et al., 1998) has been found to have excursions between 18 and 20 mm in the A/P direction, and 12–16 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 s required to obtain a stable measurement, and as high as 120 s 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 root mean square amplitude of the difference between the CoP and centre of mass (CoM) signal (Corriveau et al., 2000). These studies demonstrate the potential error that may be induced by body sway in estimating postural alignment. However apart from studies evaluating the CoP and CoM displacement, 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 was 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 was to evaluate the effect of data collection duration on the estimation of the position and orientation of the body segments.

2. Methods

2.1. 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 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 and Delaware, 1984). There was a total 18 healthy control subjects with an average age (with SD in parentheses) of 11 (2) years, mass of 39 (11) kg and height of 1.44 (0.13) m and 22 IS subjects aged 12 (2) years, mass of 42 (12) kg, height of 1.48 (0.11) m and Cobb angle of 21° (14°) who participated in this study.

2.2. Data collection

The data acquisition protocol involved the marking with a dermatographic pencil surface anatomical landmarks located on the base of support, pelvis, spine, thorax and shoulders. Only the landmarks pertinent to the present study will be described in detail here (see Figs. 1 and 2). These included, bilaterally the calcaneus, tip of the second 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 first thoracic vertebra (T1) to the first 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

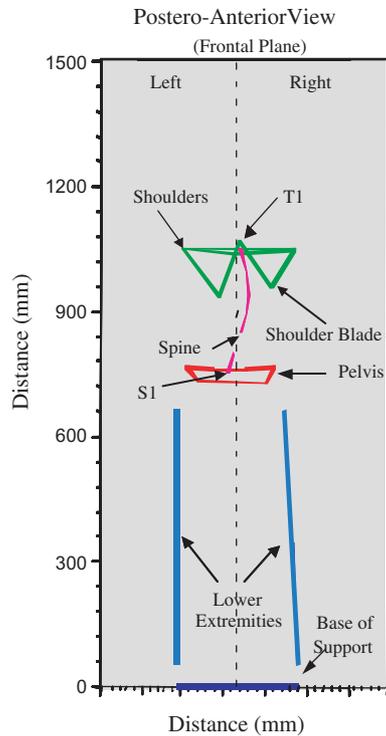


Fig. 1. Postural geometry of an Idiopathic Scoliosis patient depicting the base of support, lower extremities, pelvis, shoulders and spinous processes represented in the frontal (posterior–anterior) plane.

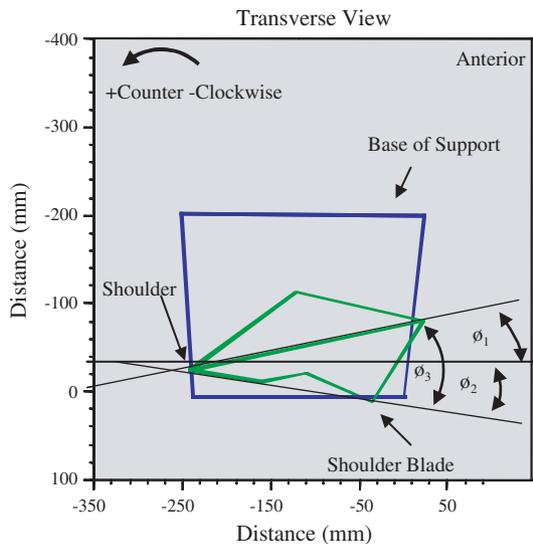


Fig. 2. The transverse view (apical) of the landmarks which define the shoulder blade (SHLDB = inferior angle of each scapula), the shoulder (SHLD = acromions), and the line of reference of the base of support, and the relative angle between the two segments ($\phi_1 = \text{SHLD}_{\text{BoS}}$, $\phi_2 = \text{SHLDB}_{\text{BoS}}$, $\phi_3 = \text{SHLD}_{\text{SHLDB}}$ ($\phi_1 - \phi_2 = \phi_3$).

(Northern Digital, Waterloo, Canada). 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 second metatarsal and malleolus) 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 m 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 s; 4 trials obtained for each subject. Between each trial, the subject was allowed to move his/her feet, or sit down to ensure that there was no accumulated fatigue through the duration of the protocol.

2.3. 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., 1998; 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 (i.e., right and left PSIS). The distance between individual bilateral points (i.e., 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 ($\text{SHLDB}_{\text{BoS}}$) and for rotation of the thoracic (Th_{BoS}), thoracolumbar (ThL_{BoS}) and lumbar (L_{BoS}) prominences.

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			Idiopathic Scoliosis		
		Avg.	-95%	+95%	Avg.	-95%	+95%
<i>Global</i>							
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 ^a
	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
<i>Relative</i>							
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 ^a
	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

^a $P < 0.05$.

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. Fig. 2 presents an example of how the angles for the SHLDB_{BoS}, SHLD_{BoS}, SHLD_{SHLDB} were calculated.

The A/P position and 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.

2.4. Statistical analysis

For each trial, the mean, RMS and range for the linear and angular measures was obtained over the duration of each 120 s. 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 s within the same trial. 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 s. 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.

3. Results

The mean position and 95% confidence intervals of the linear and angular parameters over the 120 s 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° to 3° for rotation and tilt, which was similar to the IS group, who had 2–5° of tilt (see Table 1).

The RMS and range of angular displacement over the duration of the trial (120 s) 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 1–3° 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 Fig. 3). 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. 19 mm, S1: 26 vs. 15 mm) than the control subjects.

The angular displacement of the PEL_{BoS}, SHLDB_{BoS} and SHLDB_{PEL} over time for a typical control subject is presented in Fig. 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.

3.1. Sample duration

There was no difference between the sample durations of 1 s, 15 s, 30 s, 60 s, 90 s or 120 s to estimate the mean position of the body segments. However during these

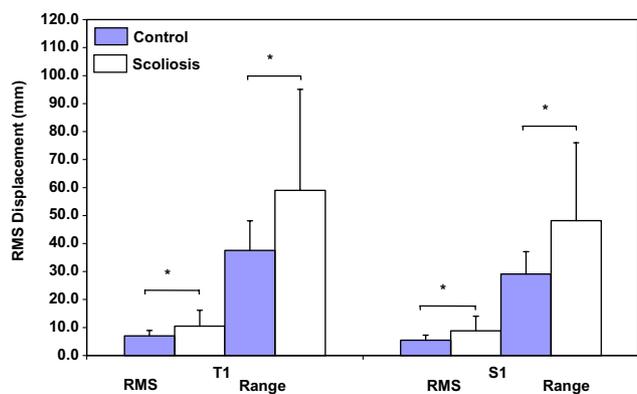


Fig. 3. RMS and range of displacement for T1_{BoS} and S1_{BoS} in the A/P direction for the IS and the control subjects (* = $p < 0.05$).

time periods a repeated measures ANOVA identified a significant increase in RMS over each period ($P < 0.05$). A 1 s sample obtained at 15 s, 30 s, 60 s, and 90 s did not reveal a significant difference in the

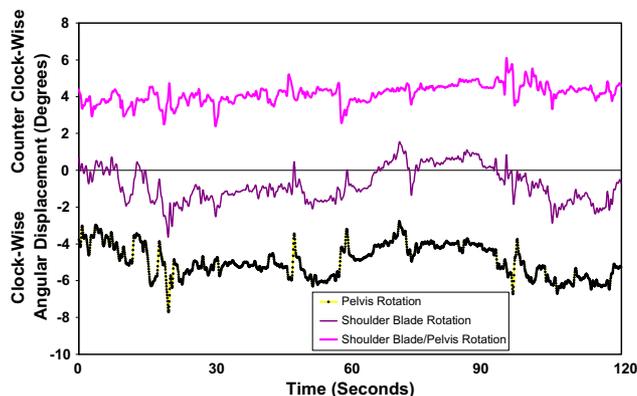


Fig. 4. The angular displacement over a period of 120 s for a control subject. The angles measured are rotation of the pelvis (PEL_{BoS}) (solid line) and shoulder blades (SHLDB_{BoS}) (solid-dotted line) in reference to the base of support, and relative rotation of the shoulder blades in reference to the pelvis (SHLDB_{PEL}) (thin line).

Table 2

The intra-class correlation coefficient (ICC) 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		
		Avg	Lower	Upper
<i>Global</i>				
Rotation (°)	PEL _{BoS}	0.92	0.86	0.96
	SHLD _{BoS}	0.92	0.86	0.96
	SHLDB _{BoS}	0.96	0.93	0.98
	Th _{BoS}	0.96	0.92	0.98
	ThL _{BoS}	0.95	0.92	0.98
	L _{BoS}	0.94	0.90	0.97
Tilt (°)	PEL _{BoS}	0.98	0.97	0.99
	SHLD _{BoS}	0.98	0.96	0.99
	SHLDB _{BoS}	0.99	0.99	1.00
A/P shift (mm)	T1 _{BoS}	0.98	0.97	0.99
	S1 _{BoS}	0.98	0.97	0.99
M/L shift (mm)	T1 _{BoS}	0.96	0.93	0.98
	S1 _{BoS}	0.95	0.92	0.97
<i>Relative</i>				
Rotation (°)	SHLD _{PEL}	0.98	0.96	0.99
	SHLDB _{PEL}	0.98	0.96	0.99
	Th _{PEL}	0.98	0.97	0.99
	ThL _{PEL}	0.92	0.86	0.96
	L _{PEL}	0.99	0.98	0.99
	SHLD _{SHLDB}	1.00	0.99	1.00
Tilt (°)	SHLD _{PEL}	0.97	0.94	0.98
	SHLDB _{PEL}	0.99	0.98	0.99
	SHLD _{SHLDB}	0.99	0.99	1.00
A/P shift (mm)	T1 _{S1}	0.98	0.96	0.99
M/L shift (mm)	T1 _{S1}	0.97	0.95	0.98

mean position between samples ($P < 0.05$). There was a strong ICC that ranged from 0.86 and 0.99 for the mean position of 4 repeat trials of 120 s each for all parameters (see Table 2). The ICC for the mean of 4 trials for 1 s ranged between 0.84 and 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 s 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: 0.44–0.76), and the highest was SHLDB_{PEL} (ICC: 0.85, CI: 0.77–0.92). For tilt in relation to the base of support the weakest ICC was for the SHLD_{PEL} (ICC: 0.82, CI: 0.72–0.90).

4. 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 IS parameters that were found to be within -13° and 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 $<5^\circ$), there was still a range of tilt between -2° and 2° , and rotation between -4° and 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 10 mm respectively. A similar presence of some degree of postural asymmetry

in normal subjects has also been suggested by previous authors (Burwell et al., 1983; De la Huerta et al., 1998; Nissinen et al., 1989). A rib hump of 1–5 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 (0.92–0.99) for the mean of 4 trials of 120 s 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 s, 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 s trial or a 120 s trial. In contrast the RMS significantly increased for all sample durations with the largest RMS at 120 s. 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 s as sample duration, good reliability was found with the ICC for the mean of 4 trials ranging between 0.84 and 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.

5. 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. There is no apparent effect of sample duration on the mean angular and linear position of body segments, however there is an effect on the RMS amplitude of displacement.

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