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Directed versus non-directed standing postures in adolescent idiopathic scoliosis: its impact on curve magnitude, alignment and clinical decision making

Authors: [1]Prudence Wing Hang Cheung, BDSc (Hons), PhD

[1]Hei Lung Wong

[2]Damian S L Lau, MSc, PDipDR

[1]Jason Pui Yin Cheung, MBBS, MMedSc, MS, PDipMDPath, MD, MEd, FHKAM(orth), FRCSEd(orth), FHKCOS

Affiliations: [1]Department of Orthopaedics and Traumatology, The University of Hong Kong, Pokfulam, Hong Kong SAR, China;

[2]Department of Radiology, Duchess of Kent Children's Hospital, Hong Kong, Sandy Bay, Hong Kong SAR, China.

Address for Correspondence: Jason Pui Yin Cheung

Department of Orthopaedics and Traumatology,

The University of Hong Kong

5/F, Professorial Block, Queen Mary Hospital

102 Pokfulam Road, Pokfulam, Hong Kong SAR, China

Phone: (852) 2255-4581

Fax: (852) 2817-4392

Email: cheungjp@hku.hk

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Key Points

- A novel study using low-dose biplanar radiography to investigate postural variation and its clinical impact in adolescent idiopathic scoliosis.
- Discrepancy in major curve Cobb angle (>5º) from postural variation occurred in 22.2% of the study cohort, with shoulder imbalance and pelvic obliquity as indicators for inaccurate Cobb angle representation.
- Under- or over-estimation of major curve Cobb angle at 25º or 40º resulted from postural variation can result in missing the appropriate timing for brace initiation or surgical consideration.

- Single Cobb angle measurement should not be the sole basis for management decision making, but close examination of overall alignment and trend of curve progression should be performed.

Structured Abstract

Study Design

Prospective study

Objective

To investigate the difference in major curve Cobb angle and alignment between directed and non-directed positioning for adolescent idiopathic scoliosis (AIS) and to evaluate implications on treatment decision-making.

Summary of Background Data

Proper positioning of patients with spinal deformities is important for assessing usual functional posture in standing, so management strategies can be customized accordingly. Whether postural variability affects coronal and sagittal radiological parameters and the impact of posture on management decisions remain unknown.

Methods

Patients with AIS presenting for initial consultation at the tertiary scoliosis clinic were recruited. They were asked to stand in two positions: passive, non-directed position; and directed position by the radiographer. Radiological assessment included major and minor Cobb angle, coronal balance, spinopelvic parameters, sagittal balance and alignment. Cobb angle difference >5º between directed and non-directed positioning was considered clinically impactful. Patients with or without such difference were compared. Over- or under-estimation of the major curve (at 25º or 40º) by non-directed positioning were examined due to relevance to bracing and surgical indications.

Results

This study included 198 patients, with 22.2% experiencing Cobb angle difference (>5º) between positioning. The major curve Cobb angle was smaller in non-directed than directed positioning (median difference: -6.0º, upper and lower quartile: -7.8, 5.8), especially for

curves ≥30º. Patients with a Cobb angle difference had changes in shoulder balance (p=0.007) when assuming a directed position. Non-directed positioning had 14.3% of major Cobb 25º underestimated and 8.8% overestimated, whereas 11.1% of curves >40º were underestimated.

Conclusion

Strict adherence to a standardized radiographic protocol is mandatory for reproducing spine radiographs reliable for curve assessment, as a non-directed position demonstrates smaller Cobb angles. Postural variation may lead to over-, or under-estimation, of the curve size relevant for both bracing and surgical decision-making.

Key Words: Adolescent idiopathic scoliosis, posture, postural variation, Cobb angle, alignment

Level of Evidence: II

Introduction

Biplanar stereoradiography is becoming the standard for patients with spinal deformities due to the advantages of three-dimension reconstruction and reduced radiation exposure.[1-4] Proper positioning for radiographs is important to assess patients' usual functional posture in standing so that management strategies can be tailored to the standing alignment.[5] Standing upright with the arms slightly forward and elbows bent with fists on clavicles is one of the possible positions to achieve better visibility of the sagittal alignment.[6] However, the lack of a rigid jig allows postural variability despite instructions from radiographers. A guiding device has been developed for conventional posteroanterior (PA) spine radiographs,[7] but it has not gained popularity and was not designed for biplanar stereoradiography. Visual cues or verbal instructions can be followed by some but not all patients, especially those of younger age. Whether the natural posture of the patients affects coronal and sagittal radiological parameters remains unknown. Since patients acquire their relaxed posture during daily life rather than the directed position for spine radiographs, differences between non-directed posture and directed positioning may lead to Cobb angle and balance variations that result in different treatment recommendations. Thus, understanding the impact of posture on evaluation of curve magnitude and alignment can aid in clinical decision-making and treatment planning.

This study aims: i) to investigate whether there is any clinically significant differences in coronal Cobb angle (>5º) between directed and non-directed positioning during whole spine radiographs in adolescent idiopathic scoliosis (AIS) and the extent of such difference; ii) to define what presenting Cobb angles are most susceptible to differences resulting from postural changes; iii) to observe the changes in balance and alignment between directed and non-directed positioning; and iv) to examine whether the observed discrepancy may affect decision-making for bracing referral or for consideration of surgery.

Patients and Methods

Study Design

This was a study of patients with AIS who presented for their *first* consultation at a tertiary referral scoliosis specialist clinic during the period of April to October 2020. Patients who were referred from the territory-wide school screening program[8] were included for recruitment via convenience sampling. The referral criteria were based on the forward bending test with scoliometer measurement of angle of trunk rotation (ATR) of ≥15º, Moiré topography with ≥2 Moiré lines and Cobb angle ≥20° on a conventional spine radiograph taken from a general clinic. Patients were examined to have no leg length discrepancies, which are known to shift of the centre of pressure in standing position and increase the Cobb angle.[9] Patients with leg length discrepancies were excluded. This study was approved by the local ethics committee with patient and parental written informed consent obtained.

Radiographic imaging

As part of the first consultation routine, each patient received whole body, head-to-toe radiographs, using the EOS® imaging system (EOS Imaging, Paris, France), and a left hand and wrist radiograph for bone age assessment. The biplanar design of the EOS system allows simultaneous frontal and lateral images to be taken at a low-dose radiation protocol adjusted for paediatric and adolescent patients as per manufacturer instructions.[10] This results in EOS images having lower radiation dosage than conventional, film-based PA and lateral spine radiographs by 13 and 15 times respectively.[10,11] Patients were asked to stand in a non-directed passive posture, then followed by a standardized protocol on patient's positioning.

For non-directed positioning, patients were asked by the radiographer to 'stand naturally with hands lifting up and look straight ahead'. For directed positioning, the radiographer gave standardized verbal instructions: 'Stand as straight as possible and place both palms on the wall in front, relax your shoulder and have your chin up.' **(Figure 1)** The radiographer then confirmed that patients' arms were raised with both hands rested on the radiation detector at the level just above shoulders, and the position of the pelvis was with minimal rotation as required.

Radiographic measurement

Radiological parameters were measured by two independent readers using the DICOM-based Radworks 5.1 (Applicare Medical Imaging BV, Zeist, The Netherlands) computer software program. Both raters were blinded to patient's clinical data and whether the image was non-directed or directed. Coronal Cobb angles of the major and minor curves,[12] and coronal balance parameters including trunk shift, radiographic shoulder height, pelvic obliquity and C7-central sacral vertebral line (C7-CSVL) deviation (**Figure 2**). Sagittal parameters were also examined, including sagittal vertical axis (SVA) deviation, cervical sagittal alignment from C2 to C7, thoracic kyphosis from T5 to T12, lumbar lordosis from L1 to S1, and spinopelvic parameters (pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS)).

Outcome measures

Data collection was performed on the day of consultation. Demographic and growth data included age, sex, body height (cm), arm span (cm) and weight (kg), age of menarche, skeletal maturity using Risser staging which consists of Stage 4+ referring to the capping of the iliac crest apophysis prior to its complete fusion graded as Stage 5.[13] The curve type indicating the location of the major curve based on the apex as thoracic (T11 and above) or lumbar (T12 and below), and treatment prescribed were also recorded. Primary outcome measures were the difference in major curve Cobb angle between directed and non-directed postures, and alignment profile changes between positioning. A Cobb angle difference of >5º was defined as clinically impactful to account for measurement error,[14,15] whereas differences in coronal and sagittal balance, cervical, thoracic and lumbar alignment parameters and spinopelvic parameters were assessed. Secondary outcome measures included the prevalence rate of major curve Cobb angle changes between the two positions: from ≥25º (in directed positioning) to <25º (non-directed positioning), and from <25º (directed) to ≥25º (non-directed). The prevalence rate of changes of Cobb angle between positioning for major coronal Cobb angle >40º was also observed. The thresholds of 25º and 40º were selected for the evaluation of whether clinical decision-making for brace initiation[16] or the consideration of surgical correction[17] were required.

Statistical Analysis

Normality was assessed using the Shapiro-Wilk test. Major curve Cobb angles in directed and non-directed standing postures were compared using Wilcoxon signed-rank test, with stratification based on major Cobb angle at directed positioning. Further analysis involved dividing the study cohort into patients with or without major curve Cobb angle difference >5º between positioning. Intergroup comparison of coronal balance, sagittal balance and sagittal spinal and spinopelvic alignment parameters were conducted through Wilcoxon signed-rank tests. The relationships between cervical, thoracic and lumbar parameters were assessed using Spearman's correlation and point-biserial correlation tests, with correlation coefficient (r_s) indicating the strength of relationship as weak (<0.39), moderate (0.40 to 0.59), strong (0.60 to 0.79) and very strong (0.80 to 1.00).[18] The inter-rater and intra-rater reliabilities for directed and non-directed Cobb angles were assessed using intraclass correlation coefficient

(ICC).[19] All analyses were performed using SPSS version 28.0 (IBM SPSS Inc., Chicago, IL) and G*Power version 3.1.9.7 (Heinrich-Heine-Universität Düsseldorf). A p-value of <0.05 was considered statistically significant.

Results

There were 244 patients suitable for inclusion, with a total of 198 patients (66.2% girls) recruited. They were studied with their profile characteristics presented in supplementary table 1, Supplemental Digital Content 1, http://links.lww.com/BRS/C162. There were 54% of the whole study cohort with major curve Cobb angle of <25º, 36.9% with curves of 25º to 40º, and 9.1% with a major Cobb angle of >40º. Approximately 5.6% were recommended for surgery and 17.7% were prescribed with bracing at the first consultation.

Significantly smaller major curve Cobb angle with non-directed positioning

Non-directed positioning presented with significantly smaller major Cobb angle than directed position, specifically for Cobb angles of 30º to <35º (p=0.001), 35º to <40º (p=0.004), and curves ≥40º (p=0.081) (**Table 1**). In **table 2**, 22.2% of the whole cohort experienced major Cobb angle differences between positioning, with non-directed positioning presented with median of 6.0º *smaller* major Cobb angle than directed positioning (p=0.044). The prevalence rate of Cobb angle difference was highest for curves ≥40º (38.9%), followed by 30º to <35º (38.5%) and 35º to <40º (27.3%). The Cobb angle differences correlated weakly to the curve magnitude at presentation in directed positioning (r_s=0.214, p=0.002), and to the curve type (r_s=0.149, p=0.036).

Changes in balance and alignment between positioning

Between directed and non-directed positioning, patients who exhibited difference in major curve Cobb angle had less trunk shift (-4.7 left of CSVL to minimal -0.3, p=0.068), shoulder balance had changed from left side elevated (non-directed) to right side elevated (directed) (median difference of -2.3mm, p=0.007), and C7-CSVL deviation became less to the left side after directed positioning (median difference of -2.1mm, p=0.095) (**Table 3**). Differences of trunk shift and C7-CSVL deviation were marginally short of statistical significance due to group size, as the median value of differences were larger than the other group without Cobb angle difference. Patients without Cobb angle difference also had differences in coronal parameters but of lesser degree with less truncal shift to the left of CSVL by a median of -0.7mm, from balanced shoulder to 1.5mm elevated right shoulder, and reduced C7-CSVL deviation to the left by 1.1mm. These patients had maintained shoulder balance (from 0.5mm to 1.6mm after instruction), as compared to patients with Cobb angle difference having their shoulders higher on the left (non-directed) than the right side (mean values -0.9mm to 2.7mm) (**Table 3**).

For sagittal profile and balance in supplementary table 2, Supplemental Digital Content 2, http://links.lww.com/BRS/C163, patients with Cobb angle difference had SVA shifted to less positive by median difference of 9.9mm of SVA (p=0.011) after directed positioning versus lesser difference of 4.0mm (p=0.048) in patients without Cobb angle difference. Patients with Cobb angle difference also demonstrated less lumbar lordosis (p=0.001), less SS (p<0.001) and more PT (p=0.056) in non-directed than directed position (**Figure 3**). Patients without Cobb angle difference were significantly less kyphotic at C2-C7 (p=0.003) and at T5-T12 (p<0.001) after being instructed.

Major curve Cobb angle difference correlated to pelvic tilt, sacral slope and pelvic obliquity

In **table 4**, major curve Cobb angle difference between positioning was found moderately correlated to pelvic tilt (r_s=-0.383, p<0.05) and sacral slope (r_s=0.316, p<0.05) in non-directed positioning. These were not found in patients without Cobb angle difference, whose major curve Cobb angle difference correlated with pelvic obliquity in directed posture (r_s=0.191, p<0.05). Pelvic obliquity in non-directed positioning for patients with Cobb angle difference correlated to curve type (r_s=0.310, p<0.05), while C7-CSVL deviation and curve type (r_s=-0.423, p<0.001), and SVA deviation with C2-C7 alignment (r_s=0.324, p<0.05) were also correlated. These were not found in patients without Cobb angle difference, whose C2-C7 alignment correlated with thoracic kyphosis (r_s=0.299, p<0.001) and lumbar lordosis (r_s=0.161, p<0.05) instead. Significant relationships were found between trunk shift and curve type, SVA and LL, and TK and LL for all patients (**Table 4**).

Underestimation of major curves of 25º or >40º by non-directed posture

In **table 5**, non-directed positioning had 14.3% of patients with major Cobb angle of 25º underestimated (13/91, 69.2% lumbar curves) whereas 8.8% (8/91, 75.0% lumbar curves) of patients had overestimation of the curvature. For the surgical consideration threshold for Cobb angles >40º, 11.1% (2/18 lumbar curves) of these curves were represented as <40º when in non-directed posture.

The inter-rater reliabilities for directed and non-directed Cobb angles were found excellent (Cronbach's α: 0.97 and 0.98 respectively), while intra-rater reliability was good and excellent (Cronbach's α for directed and non-directed Cobb angle: 0.81 and 0.97). Overall inter-rater and intra-rater (Cronbach's α: 0.94 to 0.99 and 0.93 to 0.99 respectively) reliabilities of other radiological parameters were excellent.

Discussion

Postural variation may be contributing to changes in radiological parameters,[20] which is important for the assessment of whether any scoliotic curve progression has actually occurred over time. As of this writing, there is a lack of evidence that *changes* in postural position can lead to changes in the radiological parameters of AIS. Also, the amount of difference in curve magnitude and alignment, and its impact on treatment decision-making have yet to be explored. With the advantage of low-dose whole body imaging, this novel study reveals that there are clinically impactful differences in Cobb angle between non-directed and directed standing postures in AIS, with an overall incidence of 22.2% in this study cohort. Non-directed posture tends to present a smaller Cobb angle, with a median of 6º difference, as well as with differences in trunk shift, shoulder balance and C7-CSVL deviation. A major Cobb ≥30º is susceptible to such Cobb angle differences. Due to the under-, or over-estimation, of curve magnitude from postural variation, a total of 23.1% of major curves ≥25º could have brace initiation or observation inappropriately. For large curves >40º, postural variation can still have an impact through underestimation.

From a practical standpoint, the absolute Cobb angle is crucial for the diagnosis of idiopathic scoliosis and for management indications. A standardized radiographic protocol is necessary for reproducible imaging and positioning of the spine.[21] Only this can allow for valid monitoring of curve progression through serial radiographs. This is particularly important for patients undergoing bracing as the detection of curve progression relies heavily on the Cobb angle on radiographs with or without an orthosis.[22] However, it is important to recognize that a non-directed position can be more reflective of the functional balance posture, as a relaxed body posture is what the patient adopts in daily life.[23] Based on the characteristics of patients who demonstrated major curve Cobb angle difference between positioning, it is suggestive that shoulder imbalance and pelvic obliquity are the key parameters which influence Cobb angle and spinopelvic parameters. When comparing non-directed to directed positioning, shoulder imbalance changing from left to right side elevation, significantly increased LL, reduced PT and increased SS, significant correlations of major curve Cobb angle difference with PT and with non-directed SS are found *only* in the patients with Cobb angle difference >5º. Their pelvic obliquity at directed position did not correlate with Cobb angle difference, unlike those patients without curve differences between positioning. The importance of global coronal balance should be emphasized as it is one of major treatment outcome measures.[24] Shoulder imbalance leads to cosmetic disfigurement and is influenced by the proximal thoracic curve.[25] Medial shoulder height asymmetry is created by the upward tilt of proximal ribs and T1, and correlates well with upper thoracic curve size.[26] Lumbar lordosis, SS and PT had significant differences at directed positioning confirming that the pelvis position is subjected to changes in posture. This coincides with the fact that PT and SS are position-dependent, as they depend on the angular position of the sacrum/pelvis in relation to the femoral heads which change with positioning and posture.[27] The relationship of PT and SS are also affected by lumbosacro-pelvic flexion and extension, and whether the pelvic position is in a balanced or retroverted position, Supplemental Digital Content 3, http://links.lww.com/BRS/C164.

There is coupling between coronal and sagittal alignment,[28-31] and sagittal balance and spinopelvic balance are important aspects to be restored in scoliosis surgery.[32] After assuming a directed position, the larger difference of SVA deviation with more negative C2-C7 alignment and increased lumbar lordosis and SS in patients with Cobb angle difference are in contrast with more reduction of thoracic kyphosis in patients without Cobb angle difference between positioning. The directed position has less thoracic kyphosis, which can be related to paraspinal muscle contraction, spine and trunk muscle loading.[33] Posture changes relate to one's ability to control postural and functional balance, which varies between individuals with different occupations.[34] It is unknown whether some patients have inherently larger differences between passive, natural posture and their instructed active upright position. Also, it is uncertain if AIS compromises the ability to deliver such postural change between non-directed and instructed positioning. The presence of the scoliotic curve, its location and magnitude of curvature can affect spinal muscle tone and asymmetry[35] in the immediate region.

One of the important findings is the under- and over-estimation of Cobb angles which are critical for clinical decision-making. The rate of underestimation in the non-directed posture (<25º but ≥25º in directed position) implies that 14.3% of the patients would have missed the appropriate timing for brace initiation and bearing the potential consequence of curve progression, whereas 8.8% of these patients would be treated with unnecessary bracing according to the established criteria of the Scoliosis Research Society for bracing (major curve magnitude between 25° and 40°, Risser stage ≤2, <1 year post-menarche and without previous treatment).[36] The importance of timely bracing has always been emphasized, whereas inappropriate bracing can lead to poor health-related quality of life.[37] Thus, bracing should be prescribed carefully with clinicians being aware of the parameters found for inaccurate representation of Cobb angle in this study. For the consideration of adulthood progression risk with potential surgery for Cobb angles >40º,[38,39] 11.1% of the patients would have had a different conclusion based solely on the Cobb angle measured in non-directed posture. This may lead to drastic changes in our prognostication, such as post-brace weaning curve progression,[40,41] and explanations to patients and their families. Our findings also illustrate that any decision-making in AIS should not be devoid of meticulous scrutiny of the radiological evidence. Clear trends of continuous progression should be identified through repeated imaging before surgery is offered in these patients. A single Cobb angle measurement may be highly influenced by a poor standing posture and this may be modifiable with radiographer's instruction and balance training. A patient who presents with Cobb angle of 45° should be carefully monitored for continuous progression risk before offering surgery.[42] As a rule of thumb, single Cobb angle thresholds are not recommended for decision-making as it can be influenced by non-functional positioning like directed posture. Different radiographs may be taken with variable positioning thus standardization of technique is important.

The main limitation of this study is the inability to quantify the deviation of positions in relaxed postures from directed positions which may be variable depending on patient's inherent posture and muscle balance. We also do not know the degree of exercise or balance training in our patients prior to this assessment. Some patients may be inherently more capable of maintaining a balanced posture than others. Nevertheless, this reflects the true nature of our patients in the clinic without directed standing. In addition, the association of curve flexibility with the changes observed is unknown. Whether these factors will influence the overall outcome of brace or surgical treatment is also unclear and warrant future study.

In conclusion, strict adherence to a standardized radiographic protocol is crucial to maintain a comparable point of assessment. Shoulder imbalance and pelvic obliquity need to be examined carefully as they can be indicators for inaccuracies in Cobb angle presentation. Patients with major curve ≥30º are more susceptible for Cobb angle discrepancies if standing postures deviate from the radiographic protocol. Single Cobb angle measurement should not be the sole basis for management decision-making and the overall alignment and posture of the patient should be taken into consideration. Both clinicians and radiographers should be vigilant for pelvic and upper limb positioning during imaging to deliver accurate and reproducible radiographs which are essential for diagnosis and decision-making in AIS.

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Figure 1. Patient at directed positioning.

Figure 2. An example of two posteroanterior biplanar radiographs in non-directed (left) and directed (right) positioning. Coronal parameters include the Cobb angle of major and minor curves, trunk shift (TS), shoulder balance (SB), pelvic obliquity (PO), and C7-CSVL deviation. Note the reduction in Cobb angles, less C7-CSVL deviation and TS, greater SB and PO with directed standing.

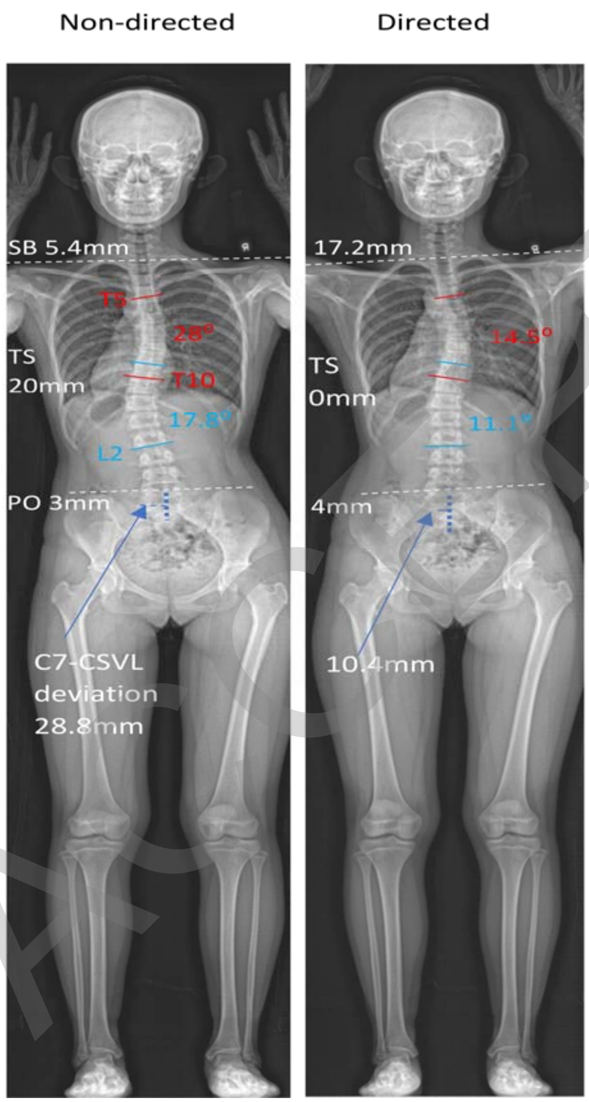

Figure 3. Schematic diagram on the summary of differences between patients with or without major curve Cobb angle difference between positioning (D: Directed; ND: Non-directed). Those with Cobb angle difference between standing postures lead to less sagittal vertical axis

(SVA) deviation, more lumbar lordosis (LL), less pelvic tilt (PT) and greater sacral slope (SS) changes in directed standing (red box). Those without Cobb angle difference has less kyphosis in cervical alignment and thoracic kyphosis with directed standing.

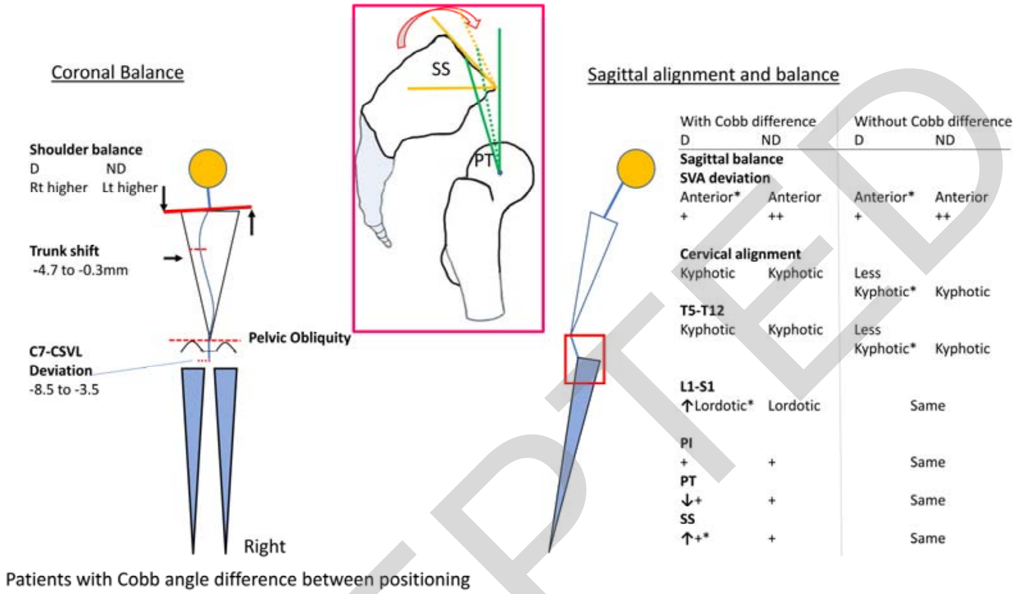

Table 1. Comparison of major curve Cobb angle in directed and non-directed positioning based on stratification of the Cobb angle in directed positioning

Cobb angle in directed positioning	Directed positioning	Non-directed positioning	p-value^	ND < D	ND > D	ND = D	Difference in absolute values Median (95% CI)
	Median (IQR)			No. of patients			
10º to <20º	16.1 (4.1)	16.0 (6.20)	0.388	24	29	2	2.1 (1.4 – 3.0)
20º to <25º	22.2 (2.2)	21.5 (4.3)	0.259	28	24	0	2.4 (1.3 – 2.7)
25º to <30º	27.2 (2.5)	26.4 (4.7)	0.141	20	14	2	2.4 (1.4 – 3.4)
30º to <35º	32.6 (1.9)	29.1 (6.0)	0.001*	22	3	1	4.7 (2.1 – 5.3)
35º to <40º	37.6 (4.6)	33.7 (3.3)	0.004*	10	1	0	3.8 (0.8 – 6.3)
≥40º	46.4 (13.7)	46.4 (10.8)	0.081	12	6	0	4.2 (1.2 – 5.9)
Whole cohort	23.8 (12.1)	23.3 (10.5)	< 0.001*	116	77	5	2.5 (2.1 – 3.0)

^ Wilcoxon signed-rank test

ND: Non-directed positioning, D: directed positioning, IQR: Interquartile range, CI: confidence interval

Table 2. Prevalence of clinical difference of major curve Cobb angle (>5º) between directed and non-directed positioning

Cobb angle in directed positioning	Cobb angle difference (>5º) n (%)					
	Yes			No		
10º to <20º	11 (20.0%)			44 (80.0%)		
20º to <25º	6 (11.5%)			46 (88.5%)		
25º to <30º	7 (19.4%)			29 (80.6%)		
30º to <35º	10 (38.5%)			16 (61.5%)		
35º to <40º	3 (27.3%)			8 (72.7%)		
≥40º	7 (38.9%)			11 (61.1%)		
Whole cohort	44 (22.2%)			154 (77.8%)		
Cobb angles, degrees Median (IQR), mean	Directed	Non-directed	Difference [Non-directed – Directed] Median (lower, upper quartile)	Directed	Non-directed	Difference [Non-directed – Directed] Median (lower, upper quartile)
Major curve	29.1 (14.7), 29.4	25.0 (10.4), 27.3	-6.0 (-7.8, 5.8)	22.8 (9.3), 25.0	22.7 (9.1), 24.4	-0.8 (-3.4, 1.1)
Minor curve (first)	23.6 (13.7), 25.3	22.1 (14.8), 24.9	-1.5 (-3.6, -0.4)	17.9 (14.5), 20.5	18.8 (14.2), 19.8	-1.0 (-2.6, 0.1)
Minor curve (second)	22.3 (19.9), 24.4	28.4 (17.9), 24.6	-1.3 (-2.1, 1.5)	15.3 (6.1), 16.2	14.3 (9.8), 16.9	0.6 (-2.5, 2.1)

n: number, IQR: interquartile range

Table 3. Comparison of coronal balance in patients with and without major curve Cobb angle differences between positionings

	Patients with Cobb angle difference (> 5º) n = 44				Patients without Cobb angle difference (≤ 5º) n = 154			
	Directed	Non-directed	p-value ^	Difference [Non-directed - Directed] Median (lower, upper quartile)	Directed	Non-directed	p-value ^	Difference [Non-directed - Directed] Median (lower, upper quartile)
Parameters - Median (IQR), mean								
Coronal balance								
Trunk shift, mm	-0.3 (22.5), -2.9	-4.7 (23.1), -5.0	0.068	-1.7 (-6.9, 3.2)	-6.4 (16.0), -5.3	-6.9 (16.4), -6.3	0.048 *	-0.7 (-5.1, 2.9)
Shoulder balance, mm (negative sign = left side higher than right)	0.7 (16.0), 2.7	-0.2 (12.9), -0.9	0.007 *	-2.3 (-7.2, 1.5)	1.8 (10.5), 1.6	0.0 (10.2), 0.5	0.020 *	-1.5 (-4.7, 2.3)
Pelvic Obliquity, º	1.0 (2.8), 0.8	1.0 (2.0), 1.0	0.165	0.2 (0.0, 1.0)	1.0 (2.0), 0.9	1.0 (2.0), 0.9	0.314	0.0 (0.0, 0.3)
C7-CSVL deviation, mm	-3.5 (19.6), -6.7	-8.5 (23.5), -9.4	0.095	-2.1 (-8.3, 4.4)	-8.5 (16.3), -8.0	-11.6 (18.2), -9.9	0.022 *	-1.1 (-6.7, 3.4)

^ Wilcoxon Signed Rank Test
IQR: interquartile range, CI: confidence interval

Table 4. Correlation tests between cervical, thoracic and lumbar parameters in directed and non-directed positioning

Parameters	Patients with major curve Cobb angle difference between positionings (n = 44)		Patients without major curve Cobb angle difference between positionings (n = 154)	
	Directed^	Non-directed^	Directed^	Non-directed^
Major curve Cobb angle difference (non-directed – directed) and Pelvic incidence (PI)	-0.179	-0.132	0.006	0.114
Major curve Cobb angle difference and Pelvic tilt (PT)	-0.407**	-0.383*	0.122	0.053
Major curve Cobb angle difference and Sacral slope (SS)	0.253	0.316*	-0.104	-0.045
Major curve Cobb angle difference and Trunk shift	-0.104	-0.158	-0.136	-0.074
Major curve Cobb angle difference and Shoulder balance	-0.026	0.159	-0.059	-0.026
Major curve Cobb angle difference and Pelvic Obliquity	0.082	0.085	0.191*	0.123
Major curve Cobb angle difference and C7- CSVL	-0.158	-0.183	-0.051	-0.111
Major curve Cobb angle difference and curve type▲	-0.278 (p=0.068)		0.035 (p=0.667)	
PI and curve type▲	-0.197	-0.291	0.045	0.061
PT and curve type▲	-0.031	-0.169	0.010	-0.024
SS and curve type▲	-0.198	-0.141	0.045	0.092
Trunk shift and curve type▲	-0.465**	-0.365*	-0.261**	-0.266**
Shoulder balance and curve type▲	-0.016	0.072	-0.109	-0.087
Pelvic Obliquity and curve type▲	0.236	0.310*	0.129	0.122
C7-CSVL and curve type▲	-0.423**	-0.295	-0.144	-0.194*
SVA and C2-C7 alignment	0.324*	0.423**	0.126	0.057
SVA and TK	-0.245	-0.257	-0.071	-0.143
SVA and LL	-0.493**	-0.640**	-0.229**	-0.192*
C2-C7 alignment and TK	0.173	-0.322*	0.299**	0.371**
C2-C7 alignment and LL	-0.173	-0.262	0.040	0.161*
TK and LL	0.503**	0.417**	0.486**	0.483**

^ Spearman's rho, ▲Point-biserial correlation test, * p <0.05, ** p <0.001, ___ significant relationships found in one group but not the other

Table 5. Matched pairs comparison of directed versus non-directed positioning with a threshold value of major curve Cobb of 25º and 40º

Directed position with major curve Cobb angle of ≥25º	Non-directed position major curve Cobb angle <25º but ≥25º at directed position	Non-directed position with major curve Cobb angle ≥25º but <25º at directed position
91/198 (46.0%)	13/91 (14.3%) 9 Lumbar 4 Thoracic	8/91 (8.8%) 6 Lumbar 2 Thoracic
Directed position with major curve Cobb angle > 40º	Non-directed major curve Cobb angle < 40º but > 40º at directed position	
18/198 (9.1%)	2/18 (11.1%) 2 Lumbar	