Reliability and Effect of Arm Positions Used During Imaging on Spinal Alignment Parameters in Healthy and Adolescent Idiopathic Scoliosis Populations

By

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Abstract

Adolescent idiopathic scoliosis (AIS) is a 3D spine disorder with lateral curvature, vertebral rotation, and sagittal changes. AIS affects 2-3% of the adolescent population. Adolescents with progressive idiopathic scoliosis receive numerous x-rays throughout their treatment, exposing them to harmful radiation throughout growing years. Particularly in young children, increased exposure to radiation has been shown to increase the incidence of cancer. Clinicians detect progression in frontal curves using radiographs around every 6 months during growth, and with new low-dose imaging technology, the arms must be elevated when capturing the sagittal view to visualize the vertebrae. Raising the arms has been shown to affect spinal sagittal angles. It is unclear which arm positions lead to spinal alignment measurements which minimize the effects on the spine and are the closest representatives of the habitual posture. Additionally, it is unknown whether such positions could allow scoring skeletal maturity which require hand exposure possibly above the shoulders. 3D Ultrasound (3DUS) is a safe method to assess arm positions without any radiation exposure.

This study aimed to, foremost, synthesize and review the literature on this topic. Additionally, this study aimed to determine the test-retest reliability of 3DUS imaging results in three standing positions; find a standing posture used to acquire simultaneous frontal and lateral radiographs that best equate to habitual standing posture; and to identify whether any of the arm positions that minimize spinal alignment changes could allow for skeletal maturity assessment.

To test if different arm positions change spinal alignment in healthy volunteers and volunteers with AIS, 3DUS was used to measure the angle of vertebral rotation (AVR), frontal, and sagittal curve angles in ten different positions: 1)habitual standing, 2) arms supported at 60^{o} of shoulder flexion *(local EOS positioning)*, 3) fingers to clavicles, 4) fingers to chin, 5) fingers to zygomatic, 6) fingers to eyebrows, 7) shoulders abducted 90º hands open with thumb on shoulder, 8) hands on wall, 9) hands on block, and 10) hands unsupported. Three positions (1,3,8) were re-tested for reliability analysis. Separate group by position mixed model ANOVAs compared the effect of arm positions among groups. Separate repeated measures ANOVA explored the comparison of the effect of the 10 positions among male participants.

Our systematic review screened 1332 abstracts and 33 full texts. Data was extracted from 7 studies. Common positions were habitual standing, fists on clavicle, and active (arms raised unsupported). Kyphosis, lordosis, and sagittal vertical axis (SVA) were most measured. Meta-analysis showed significantly decreased kyphosis (SMD= 0.8º, 95%CI= 0.5,1.1) and increased lordosis (SMD= -1.2º, 95%CI= -1.6,-0.9) when clavicle was compared to standing. Significant posterior shifts in SVA were shown in clavicle compared to standing (MD= 30.6mm, 95%CI= 23.9,37.3) and active compared to clavicle (MD= -2.0mm, 95%CI= -3.4,-0.6). Frontal and transverse parameters were rarely studied (1 study).

Reliability ($ICC_{3,1}$) with standard error of measurement (SEM) was calculated for test-retest acquisition and measurements by one evaluator blinded to the test measurement when completing the retest in 43 females and males with AIS. Reliability of frontal and sagittal parameters in the three positions were adequate for research use (ICC>0.70). AVR measurements and all measurements in the hands on wall position were most reliable and adequate for individual use (ICC>0.90).

Ninety females with and without AIS with mean age, height, and weight of 17±4years, 162±6cm, and 55±10kg, and ten males with AIS (16±3 years, 174±11 cm, and 63±13 kg), were included for comparison of arm positions. Maximum curve angle showed group by position interactions. Female with AIS single-curve showed larger curves in standing in all positions excluding hands on blocks ($p>0.05$). Sagittal parameters did not show group by position interactions, but position pairwise comparisons showed decreases in kyphosis in arms abducted 90° and increases in lordosis in fingers to cheeks/eyebrows ($p>0.05$). AVR twist was not significantly affected by changes in position. Males with AIS showed comparable results to females, but no significant differences were detected.

Overall, US imaging produces reliable measurements for frontal, sagittal, and transverse spinal parameters in common standing positions. Arm position comparisons show there is not one position representative of habitual standing posture for all group compared. None of the positions that expose the hands fully represent standing among all groups. When arms are raised, decreases in max curve angle were shown in those with single-curves, and decreases in kyphosis and increases in lordosis were found for all groups. These findings may inform clinicians which arm positions are best to adopt when capturing frontal and sagittal radiograph images.

Preface

This thesis is an original work by Brianna Fehr. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name "3DUS examination of the effect of arm position on the spine alignment", Study ID No. PRO00111881, September 20, 2021.

"Systematic Review of Imaging Comparisons of Spinal Alignment among Standing Positions in Healthy Adolescents or Adolescents with Idiopathic Scoliosis – SOSORT 2023 Award Winner" has been published by The European Spine Journal as part of this thesis (DOI 10.1007/s00586-023-07815-0) [1].

The literature review in chapter 2, as well as the data analysis in chapters 4 and 5 are my original works. I was responsible for the data collection, image analysis, extraction, and the statistical analysis for all chapters, as well as the composition of this document.

Dr. Eric Parent, the principal investigator and primary supervisor for this project, was involved through the initial study design, data collection, and manuscript edits of all chapters.

Dr. Edmond Lou, a co-supervisor, was involved in the design of the ultrasound image analysis program, technical support with the ultrasound system, and edits to the submitted manuscript in chapters 4 and 5.

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Thank you to the Women in Scholarship, Engineering, Science and Technology (WISEST) program, the High School Youth Summer Research (HYRS) program, Kinesiology student practicum, and the Undergraduate Research Initiative programs at the University of Alberta for providing generous programs for students to explore science and research. Namely, for giving Aislinn Ganci, Ana Vucenovic, Sarah Bruha, Miran Qazizada, Annika Visser, Janie Pollard, Linh Du, Arju Neupane, and Susana Dokiburra a place to build their research knowledge.

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LIST OF ABBREVIATIONS

3D: Three-dimensional

3DUS: Three-dimensional Ultrasound

AIS: Adolescent idiopathic scoliosis

ANOVA: Analysis of variance

APP: Anterior pelvic plane

AVR: Axial vertebral rotation

AVT: Axial vertebral translation

AXIS: Appraisal tool for cross-sectional studies

CI: Confidence interval

CINAHL: Cumulated Index to Nursing and Allied Health Literature

COL: Center of lamina

CSVL: Central sacral vertical line

CVL: Central vertical line

DMS: Digital maturity scale

EBSCO: Elton B. Stephens Company

EOS: EOS imaging system

GPS: Global positioning system

HRQOL: Health-related quality of life

ICC: Intraclass correlation coefficient

LEV: Lower end vertebrae

MIAS: Medical Image Analysis Software

MRI: Magnetic resonance imaging

NOS: Newcastle-Ottawa scale

ODI: Oswestry disability index

PA: Posterior-anterior

PHV: Peak height velocity

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

PROSPERO: International Prospective Register of Systematic Reviews

RASO: Relative anterior spinal overgrowth

SEM: Standard error of measurement

SF-36: Short form-36 questionnaire

SOSORT: Society on Scoliosis Orthopaedic and Rehabilitation Treatment

SPSS: Statistical Package for the Social Science

SRS: Scoliosis Research Society

SRS-22: Scoliosis Research Society-22 questionnaire

SRS-24: Scoliosis Research Society-24 questionnaire

SVA: Sagittal vertical axis

UEV: Upper end vertebra

US: Ultrasound

CHAPTER 1: INTROUCTION

Background

It is standard practice for patients with AIS to have radiographic imaging done about every 6 months during growth to monitor curve progression [2]. Diagnostic imaging is used to inform decisions about appropriate treatment. Recurrent radiation exposure has been shown to increase the incidence of cancer, especially in young children [3]. New low-dose stereo-radiograph technology has been introduced to health care centres as an alternative to standard x-rays. This low-dose technology captures frontal and sagittal images simultaneously and requires the arms to be raised in order to visualize all vertebrae. Ideally, radiograph images provide reliable skeletal maturity assessment in order to determine growth remaining in patients. The most reliable maturity indicator, Sanders scoring, requires the fingers to be shown in the frontal image [4]. Unfortunately, raising the arms has been shown to affect sagittal angles like kyphosis and lordosis [5–12]. There is no current standardized arm position that best equates to habitual standing for patients to adopt when being imaged, therefore, possibly providing inaccurate radiograph measurements. 3D Ultrasound (3DUS) imaging is a safe, radiation-free method used to acquire images of the spine in frontal, sagittal, and transverse planes.

Objectives:

This project aimed to review all current literature on this topic, test the reliability of spinal alignment measurements obtained with our 3DUS imaging image analysis, and use this 3DUS imaging to compare spinal alignment in 10 standing positions to find a standardized position for patients during radiography that represents habitual standing measurements. Further, some of the images compared to habitual standing were investigated because they would allow exposing the hands for skeletal maturity assessment. I hypothesized that the current literature, as well as our own data, would show that as the arms are raised above the shoulders, this would have the largest impact on sagittal parameters by decreasing kyphosis measurements and increasing lordosis measurements. Additionally, I anticipated to reach adequate test-retest reliability coefficient estimates for research and individual inferences using our 3DUS spinal alignment measurements.

The following thesis sections consist of:

Chapter 2 which is a summary of the current literature on adolescent idiopathic scoliosis and key studies establishing the context leading to the investigation of this thesis.

Chapter 3 is a published systematic review of the literature currently published effect of arm position on spinal parameters. This manuscript was awarded one of two SOSORT 2023 award consisting of the open-access publication fee in the European Spine Journal.

Chapter 4 is a research manuscript on the test-retest reliability of frontal, sagittal, and transverse spinal parameter ultrasound measurements to assess the spine in three standing position – habitual standing, fingers to clavicle, hands on wall.

Chapter 5 is a research paper on the effect of ten different standing positions on fontal, sagittal, and transverse spinal alignment parameters.

Lastly, Chapter 6 is a final discussion on the entirety of this research, with future research recommendations and clinical implications.

CHAPTER 2: GENERAL LITERATURE REVIEW

Adolescent Idiopathic Scoliosis

Adolescent idiopathic scoliosis (AIS) is defined as a structural, lateral, rotated curvature of the spine that typically arises in children around the age of puberty [13]. Children with a spinal curvature less than a Cobb angle of 10° should not be given the diagnosis of scoliosis, as spinal curves under 10° are considered a normal variant. The prevalence of curves more than 10° is approximately 1-3% of the population, with larger curves being more rare [14]. Adolescents with idiopathic scoliosis can receive numerous x-rays throughout their treatment, exposing them to harmful radiation throughout their growing years. Particularly in young children, this increased exposure to radiation has been shown to increase the incidence of cancer [3]. New technology has been created to reduce the radiation exposure during an x-ray. Most notably, EOS imaging has shown to decrease the dose of radiation during an x-ray up to 50% compared to standard spine radiographs [15]. In a clinical setting, spinal parameters are usually measured from a single frontal radiographic image obtained in an upright, standing posture [15]. It is necessary to have the arms elevated during lateral radiographs to avoid the bones of the arms overlapping with vertebral bodies. Sagittal views of the spine are necessary to measure parameters such as kyphosis and lordosis in scoliosis patients but is unclear how different arm elevation positions affect spinal alignment measurements.

Diagnostic Examination for Scoliosis

The diagnosis of idiopathic scoliosis is one of exclusion. Idiopathic scoliosis is diagnosed if other causes such as vertebral malformation, neuromuscular disorder, and syndromic disorders have been ruled out [13]. The four principal lesions that are associated with idiopathic scoliosis and must be ruled out are Chiari malformation, syrinx, diastematomyelia, and tethered cord. [15] The age of the patient is important to note because children in their first decade of life have a higher risk of associated neural lesions and must be screened with an MRI. The age of a child also aids in determining the risk of progression [16].

Another factor to consider when evaluating a patient for scoliosis is their sex. Males have a lower prevalence of scoliosis than females, presenting in only 0.5-1% of the population [17]. Females also present a higher risk for scoliosis progression, more than six times more than that of males [14] Males with idiopathic scoliosis should be followed later into their growing years, as it has been shown that larger curves progress for a longer period compared to females [18]. The female to male ratio with AIS ranges from 1.5:1 to 3:1 and increases substantially with age. The prevalence of curves with higher Cobb angles is substantially higher in girls. The female to male ratio rises from 1.4:1 in curves from 10° to 20° up to 7.2:1 in curves greater than 40° [19].

When ruling out neuromuscular diseases, doctors can also evaluate the patient's gait. For example, ataxia may produce an antalgic gait. Pain can also be a sign of neuromuscular disease, which could warrant an MRI [16]. Secondary signs of scoliosis can include truncal distortion and include a rib or flank prominence, shoulder elevation, flank flattening or indentation, scapular rotation or elevation, and iliac crest prominence or elevation [16] Iliac crest asymmetry should prompt an evaluation of the lower limbs for length discrepancies [16]

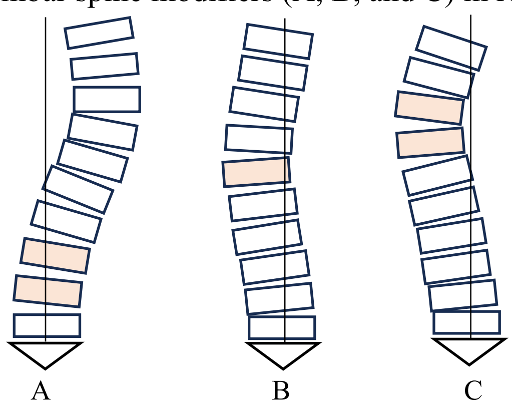
Patients are generally screened with an Adams' forward bending test and a scoliometer. For this test, the patient bends forward until the spine is horizontal, knees fully extended and upper limbs hanging. In thoracic scoliosis with the apex of the curve to the right, the patient's right side will be prominent and can be measured in degrees using the scoliometer [20]. The Scoliosis Research Society recommends a scoliometer reading between 5^0 and 7^0 as a threshold for radiography referral [21]. A definitive diagnosis cannot be made without measuring the Cobb angle on a standing coronal radiograph [13].

Idiopathic Scoliosis Classification

Idiopathic scoliosis has been categorised based on the age of onset. These categories are termed infantile (0-3 years), juvenile (4-9 years) and adolescent for 10 years and older [14] The Scoliosis Research Society (SRS) has described a classification system of non-idiopathic scoliosis that can be used to rule out any other diagnoses. These diagnoses can fall under the following broad categories: congential scoliosis, neuromuscular, and syndromic [22]. Each category includes different diagnoses that must be ruled out before diagnosing AIS. Congenital scoliosis is caused by malformation of the vertebrae, affecting every 1 in 1000 live births [23]. Neuromuscular scoliosis is caused by insufficiency of active muscle stabilizers of the spine, and prevalence varies depending on the condition. For example, patients diagnosed with cerebral palsy, where nearly 20% of these patients are also diagnosed with neuromuscular scoliosis [19]. A much more rare type of scoliosis is classified as syndromic. This means that scoliosis can occur as part of many genetic and non-genetic syndromes. An example of this would be a patient diagnosed with Marfan syndrome [14].

The Lenke classification system is meant to guide surgical decisions and begins with an evaluation of each of the three major spine regions that may develop an operative curve: Proximal Thoracic (apex between T2-T5), Main Thoracic (apex between T6-T11/T12), and Thoracolumbar/Lumbar (apex between T12-L1 and L1/L2-L4, respectively). The major curve is identified as the largest Cobb angle. Other smaller curves present are noted as minor. All major curves are deemed structural, and minor curves can be confirmed structural if the bending radiograph curve measurement remains above 25^0. The system has designated three lumbar curve patterns as lumbar modifiers A, B, or C, and similar to the King classification, these lumbar modifiers are based on the position of the Central Sacral Vertical Line (CSVL) to the apex of the curve [24]. Figure 1 shows the differences in lumbar modifiers A (CSVL line lies between the pedicles at the lumbar apex), B (CSVL touches the apical vertebral pedicle), and C (CSVL does not touch any part of the apical vertebral body or pedicle).

Figure 1. Lumbar spine modifiers (A, B, and C) in relation to the CSVL.

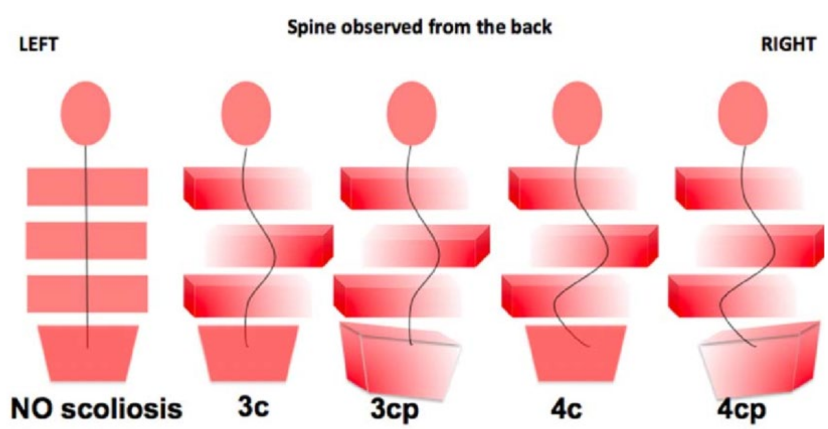


Lastly, unique to Lenke's classification, a sagittal thoracic modifier based on the T5-T12 Cobb measurement on the standing lateral radiograph is included. When this kyphosis Cobb angle measures less than 10°, a minus (-) or hypokyphotic sagittal modifier is designated. When it is between 10° and 40°, an 'N' or normal kyphotic modifier is designated. Finally, when it is ≥40°, a plus (+) or hyperkyphotic modifier is added. Overall, the Lenke system combines the curve type, the lumbar modifier, and the sagittal thoracic modifier for a complete scoliosis curve classification consisting of 6 curves patterns with modifiers [24].

Although the Lenke Classification system is reliable, there are limitations. The largest being that side bending radiographs must be aquired and are typically only taken if surgical treatment is being considered [24]. This system also allows for 42 total curve patterns which increases the already complex nature of any orthopeadic surgeon's job. Lastly, the Lenke system is not used to classify curve types for patients with AIS who are not considering surgery as a treatment option, and is therefore not realiable to use in non-operative cases [24].

Schroth curve types are another classification system, more commonly used for rehabilitation purposes, as opposed to King and Lenke, which are more focused on classification for surgical purposes. The Schroth classification curve types are: 3c, affecting the thoracic spine without a pelvis imbalance, 3cp, which is a thoracic dominant curve with an imbalanced pelvis on the thoracic concave side, 4c, which is a thoracolumbar/lumbar dominant deformity without a pelvis imbalance, and lastly, 4cp, which is a thoracolumbar/lumbar dominant curve with a pelvis imbalance to the lumbar concave side, as shown in Figure 2 [25]. Similar to Schroth, the Rigo Classification system was developed in order to define specific principles of correction required for proper brace design and fabrication. Viewing the patient from the front and in forward bending allows for the diagnosis of four basic types called: (I) three curves, (II) four curves, (III) non three-non four and (IV) single lumbar or thoracolumbar. After confirming this diagnosis with a radiograph, it is necessary to choose a particular sub-type that will determine the brace design that is most appropriate for the patient [26].

Figure 2. The 4 Schroth curve types compared to no scoliosis.



https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0168746

AIS has an overall prevalence of 0.47–5.2 % in the current literature [19]. When a patient's scoliosis is defined as a Cobb angle of at least 10°, epidemiological studies estimate that 1–3% of the at-risk population (children aged 10–16 years old) will have some degree of spinal curvature, although most curves will need no intervention [13]. Only 0.3%-0.5% of affected patients will have a curvature of over 20°, which is the minimum curve magnitude at which treatment is generally recommended [27].

Indications for Treatment Options

Table 1. Indications for treatment types for AIS.

Curve Degree	Risser Grade	Action
0-20º	0 or 1	Observe
20-40º	0 or 1	Brace
0-30º	2 or 3	Observe
30-40º	2 or 3	Brace
40-50º	0 to 3	Undecided
>50º	0 to 4	Surgery

Table 1 shows the treatment that is recommended for patients depending on the patient's Risser grade (skeletal maturity) and Curve degree (Cobb measurement) [28]. Typically, observation is recommended for immature patients with curves of less than 25°. Orthotic management, or bracing, is recommended for immature patients with progressing curves between 25° and 50°. Brace treatment is begun when the likelihood of progression of scoliosis is high. A patient with a mild curve near the completion of growth is unlikely to have further progression of their scoliosis and would probably not benefit from wearing a brace. A patient with a moderate curve ($>30^0$) and more growth left is at a much higher risk for progression and may benefit substantially from a brace. In general, for an adolescent with a curvature $30\text{-}45^0$ and growth still remaining, brace treatment is indicated and will stop progression in 50% of patients, improve curvature in 30% and curve progression will continue in spite of bracing in 20% [29]. Surgical correction of idiopathic scoliosis is considered for curves greater than 45° in adolescent patients [30].

Skeletal Maturity Measurement

It is most common for clinicians to measure skeletal maturity in patients with AIS using Risser grading. Risser sign is defined by the amount of calcification present in the iliac apophysis and measures progressive ossification[31]. Seen on a radiograph, a Risser grade 1 signifies up to 25% ossification of the iliac apophysis, and up to grade 4, which signifies 100% ossification. A Risser grade 5 means the iliac apophysis has fused to the iliac crest after 100% ossification. It is common for children to progress from Risser 1 to 5 in about 2 years [31]. Another assessment of skeletal maturity is the Sanders Digital Skeletal Maturity Staging System, which breaks down the fusion of the finger's epiphyseal growth plates into the following 8 stages: 1; Juvenile Slow Stage, 2; Preadolescent Slow Stage, 3; Adolescent Rapid Stage—Early, 4; Adolescent Rapid Stage—Late, 5; Adolescent Steady Progression Stage—Early, 6; Adolescent Steady Progression Stage—Late, 7; Early Mature Stage, and 8; Mature Stage [32]. Radiographs of the hands are needed in order to use this method [4, 32].

AIS Theories of Etiology

The true cause of AIS is still largely under debate, but it is thought to be attributed to genetic factors, nutrition, early exposure to toxins, and hormonal dysregulations. AIS represents a complex trait, meaning it is caused by both polygenetic inheritance working together with environmental factors [33].

The most studied of these possible etiology's is genetic predisposition. In general, it has been shown that specific gene mutations (like in Vang-like protein 1) are found in high levels in AIS patients but very rare in control groups and thus can predispose individuals to AIS in later life [34]. Genetic growth imbalances have also been linked to AIS, presenting mutations in collagen and in the extracellular matrix. Similarly, mutations on specific G-protein receptors that play a role in musculoskeletal development have also been attributed to AIS pathogenesis [34]. Table 2 represents the most commonly reported gene mutations associated with AIS.

Table 2. Most commonly reported genes associated with AIS

The most reported SNPs with statistically significant evidence in association with AIS by GWAS until 2019 [54].

Gene	SNP risk allele	Context	OR (95% CI)	*p*-Value
FOXA2, PAX1	rs6137473-G	Intergenic	1.30 [1.19–1.41]	3,00E-08
PAX1	rs169311-A	Intergenic	1.51(1.28–1.78)	1.25E-06
PAX1	rs6047663-G	Regulatory region	1.22 (1.12–1.34)	2,00E-15
TNIK	rs9810566-A	Intron	1.19 (1.08–1.32)	1,00E-11
MAGI1	rs7633294-G	Intron	1.20 (1.09–1.32)	2,00E-12
MEIS1	rs7593846-G	Intron	1.21 (1.10–1.32)	1,00E-13
BNC2	rs3904778-G	Intron	1.21 [1.14–1.28]	5,00E-08
BNC2	rs10756785-?	Intron	1.21 [1.14–1.28]	7,00E-10
LBX1	rs11190870-T	Intergenic	1.61 [1.50–1.73]	5,00E-39
LBX1 AS1	rs678741-G	Intron	1.44[1.37–1.52]	1,00E-36
BCL2	rs4940576-T	Intron	1.35 [1.22–1.48]	2,00E-09
AJAP1	rs241215-G	Intergenic	1.33 [1.19–1.47]	5,00E-07
PAX3/EPHA4	rs13398147-T	Intergenic	1.38 [1.23–1.54]	3,00E-08
GPR126	rs6570507-A	Intron	1.23 [1.16–1.3]	7,00E-13
SOX9, KCNJ2	rs12946942-T	Intergenic	2.21 [1.76–2.77]	6,00E-12
CDH13	rs4513093-A	Intron	1.23 [1.18–0.01]	2,00E-15

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6547389/

Twin studies have also shown that there are heritable factors to AIS, reporting slightly higher risks of having curves requiring treatment in patients with family history of scoliosis [35]. In monozygous twins, there was a high concordance of ~73% and in dizygous twins ~36%, providing strong evidence for a genetic etiology of AIS [36]. A higher incidence of AIS in monozygous twins could be due to genetic susceptibilities that are defined in twins, such as variability in the oestrogen receptor gene that has been shown to be associated with curve severity [37]. In a study done on 415 Chinese patients with AIS, it was shown that overall, the heritability for AIS was estimated to be 87.5%, which was comparable to that of body height [33].

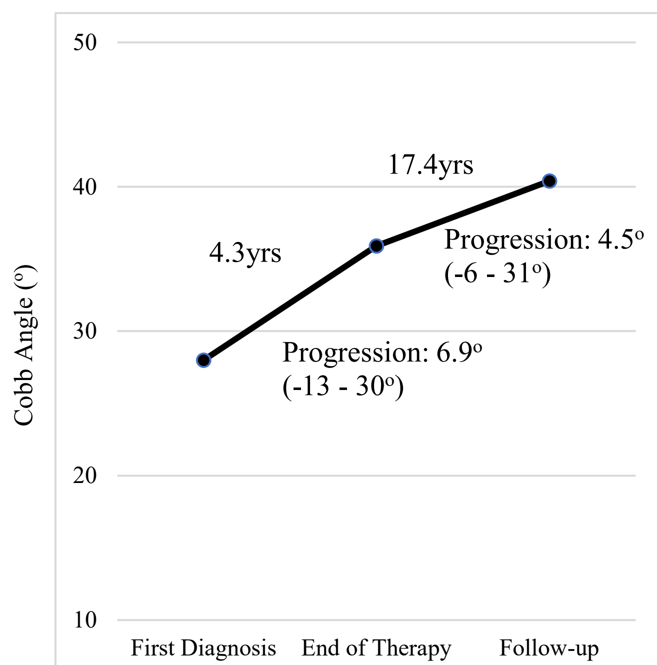
It has been reported that skeletal growth around peak height velocity (PHV) and an increase in growth hormones can also be attributed to AIS. Studies have noted in patients with AIS that they hit PHV at an earlier age and also had a significant increase in their PHV [37]. Caroline Goldberg explains that "…scoliosis is not a disease or group of diseases, but a symptom or sign of environmental stress significant enough to overwhelm the intrinsic stability of the morphological genome" [38]. Another theory proposed by Dr. Ian Stokes is the "vicious cycle" hypothesis and describes AIS curve progression being a result of asymmetrical loading of a skeletally immature spine causing asymmetrical growth, and hence, a progressive wedging deformity [38]. Similarly, the relative anterior spinal overgrowth (RASO) condition has been shown in patients with structural scoliosis, describing the initiating factor of scoliosis as the anterior elements of the spine being longer than the posterior elements [39]. Research has also been done to determine if hormonal factors are associated with AIS. A study done by Moreau et al. shows that melatonin signaling was disrupted in osteoblasts of all patients with AIS that were tested [40].

There has been a marked increase in the research being done on the relation between epigenetics and scoliosis, but nothing has been clear for AIS specifically. Research continues to focus on the main etiological theories for AIS, with the aim of eventually being able to determine the main causes, and thus, the most effective treatments.

Curve Severity and Related Outcomes

Curve severity affects both physical and psychological outcomes in patients with AIS. Increased curve severities in adolescence predict progression into adulthood [41]. Haefeli et al. studied curve progression since first diagnosis in 40 participants [41]. Participants had a mean age of 35.7 at their follow-up, and an average of 23.8 years between the first diagnosis and follow-up. Figure 3 shows curve progression between the first diagnosis and end of growth in 31 patients with AIS who had radiographs available [41].

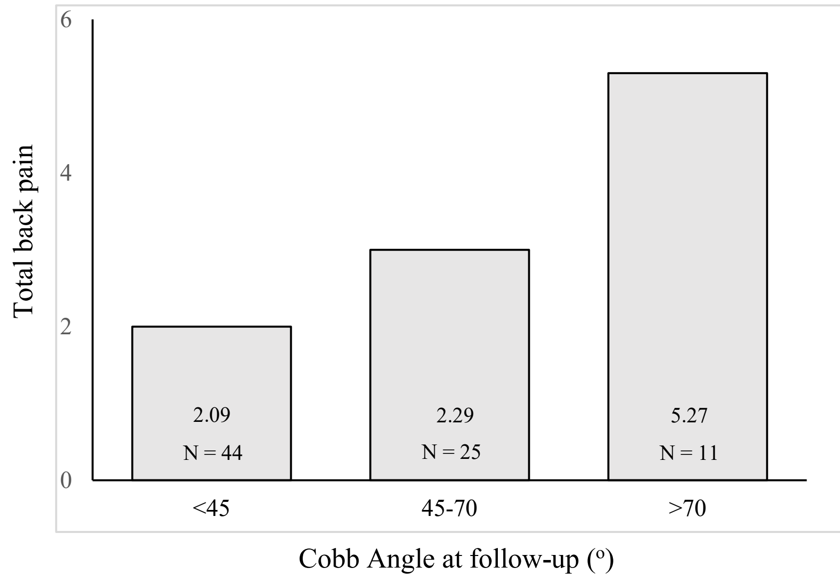
Figure 3. Cobb angle progression from diagnosis to end of growth.



Weinstein et al. showed that curves between 40^0 and 50^0 in adolescent patients continue to progress at a rate of about 1^0 per year into adulthood, and curves less than 30^0 rarely get worse [42]. Those with curves over 30^0 but less than 50^0 progress at about 0.5^0 per year [42]. In terms of physical functioning, curves with Cobb angles greater than 50^0 at skeletal maturity is a significant predictor of decreased pulmonary function. Comparably, 22% of 98 patients with AIS reported shortness of breath during everyday activities, compared to only 15% of controls [42]. Curve type also plays a role in pulmonary function, as patients with a combination of a thoracic apex and a large primary curve (>80^0) had significantly greater odds of shortness of breath than those with large primary lumbar curves (>50^0) [42]. Haefeli et al. similarly reported that 5 of 8 patients with AIS who had thoracic curves greater than 80^0 had restrictive pulmonary disease, and only patients with thoracic curves of more than 100° are at increased risk of death [41].

When assessing the curve type, Danielsson & Nachemson reported that pain, effect on daily life, and back function did not show any differences between patients with different curve types (single thoracic n=50, lumbar n=19, or double curves n=40) [43]. In contrast, the severity of the primary curve in patients with AIS at a 10 and 60-year follow-up was a significant predictor for total back pain when controlling for age (Figure 4) [41]. However, Ascani et al. reported that back pain frequency in patients with AIS is comparable to that of the general population and does not cause excessive disability in undertaking every-day activities [44]. This contrasts with the Weinstein paper, where it was shown that chronic back pain was more frequent and had a greater intensity and duration in patients with scoliosis compared to their peers [42]. Although these are conflicting results, both papers agreed that scoliosis does not cause excessive disability compared to the general population [13].

Figure 4. Total back pain associated with increased Cobb angle at follow-up [41]



Despite the above, it was also reported that a greater Cobb angle severity, when controlled for age, is associated with greater disability in managing every-day activities according to the ODI questionnaire [41]. Nonetheless, it has been reported that the risk of pain, functional impairment, and disability does increase with age in patients with AIS [45]. Weinstein et al. found that overall pain reported was slightly worse in patients with AIS compared to controls [42]. Table 3 shows this data.

Table 3. AIS reported pain level compared to matched controls.

Description of Pain	Score	Scoliosis	Control	*P* value
		Overall Pain		
None	0	21/92 (23%)	31/48 (65%)	<.001
Some	1-5	71/92 (77%)	17/48 (35%)	

Although the prevalence of back pain in untreated scoliosis likely exceeds that in the general population, it does not appear to cause excessive disability to the point where activities of daily living are regularly effected [42]. In general, it has been shown that an increase in curve severity is associated with increased pain reported by patients with AIS.

Health-Related Quality of Life

Patients with AIS perceive themselves to be less healthy than their peers and experience limitations in certain activities such as lifting, walking long distances, standing, and sitting for periods of time, traveling, and socializing outside the home [42]. Perhaps the biggest consequence of having scoliosis as an adolescent is the psychological impact. According to Payne et al., the presence of scoliosis is a risk factor for psychological disturbance during adolescence, as indicated by higher incidence of suicidal thoughts and alcohol consumption later in life compared with controls without scoliosis [46]. This study used the Adolescent Health Survey to report this information [46]. Tones et al. reported that adolescents with scoliosis are also more likely to be dissatisfied with their appearance and fear that their bodies are developing abnormally compared to adolescents without scoliosis [45]. Tones et al. analyzed responses over a variety of HRQOL surveys, including the SF-36, SRS-22, and SRS-24) [47]. In general, almost 30% of individuals with AIS in a study done by Haefeli et al. reported to have had psychological problems due to scoliosis at least once since first diagnosis [41].

Physical Health Limitations

Reduced lumbar spine range of motion was found to correlate with respectively higher pain intensity, larger extension of lumbar back pain, and larger extension of pain all over the body [48]. Weinstein et al. reported that 39% of patients with AIS and 31% of controls had shortness of breath while walking one city block [42]. Activities of daily living (ADL) do not seem to be significantly affected by a scoliosis diagnosis in adolescence, and further, it has been shown that there is no significant difference in the capacity to perform these activities [42].

Overall, patients diagnosed with AIS are more likely to face negative psychological consequences as well as physical limitations associated with curve severity [41, 42]. Although adolescents are more likely to have a negative experience accompanying their treatment, it has been shown that an increase in curve severity leads to an increase in overall back pain, demonstrating the importance of treatment at an early age in patients with AIS [41, 45]. In contrast, it has also been shown that regardless of treatment type, there is no significant effects on the HRQOL in AIS patients who are followed into adulthood [48].

Imaging Scoliosis

Adolescent's with idiopathic scoliosis can receive numerous x-rays throughout their treatment to establish the diagnosis and monitor curve progression. This exposes them to harmful radiation throughout their growing years. Particularly in young children, this increased exposure to radiation has been shown to increase the incidence of cancer [3]. New technology has been created to reduce the radiation exposure during an x-ray. Most notably, EOS imaging has shown to decrease the dose of radiation during an x-ray up to 50% compared to standard spine radiographs [15]. In a clinical setting, spinal alignment parameters are usually measured from a single frontal radiographic image obtained in an upright, standing posture. However, other spinal parameters like lordosis and kyphosis obtained from lateral images can be over or under-estimated due to the natural sway of the human body in standing [49]. Another notable source of variability is the impact of different arm positions on the sagittal alignment of the spine [8, 10, 12, 50, 51]. It is necessary to have the arms elevated during radiographs in order to expose the whole sagittal plane of the spine and avoid the bones of the arms overlapping with vertebral bodies. Sagittal views of the spine are necessary to measure parameters such as kyphosis and lordosis in scoliosis patients. It is therefore unknown which arm position during radiographic imaging will most accurately represent habitual standing postures in patients with AIS. It would also be beneficial to known which position will simultaneously allow exposing the hands in order to determine skeletal maturity. To date, there has been no uniform arm positioning that has been established as the standard of care, resulting in inconsistent arm positioning between health care centers [12].

Methods in Scoliosis Imaging

The literature found uses several non-radiographic imaging methods to determine the best arm position. Marks et al. analyzed coordinate changes in reflexive markers to measure sagittal alignment changes, whereas Pan et al. used the Epionics SPINE system, which includes two flexible strain-gauged strips placed on the back with a tri-axial accelerometer at the end of both [8, 49]. Most of the literature found uses a lateral radiograph image to compare arm positions [5, 10, 52]. A limitation to these studies is the small number of arm positions that are compared to avoid the repeated radiation exposure that would be accompanied with comparing more positions. There was no literature found that uses 3D ultrasound (3DUS) imaging to directly compare arm positions, further reinforcing the need to study the results and reliability of this imaging method in patients with and without scoliosis. A large benefit of using 3DUS to image patients is there is no exposure to harmful radiation, allowing for a number of positions to be compared. Spinal measurements using 3DUS imaging have been found to be comparable to that of radiograph measurements in those without scoliosis and patients with scoliosis [53]. Further, the literature found did not directly compare the results of different non-invasive imaging methods in healthy patients or patients with scoliosis.

Arm Positioning and Effect on Sagittal Alignment

Non-scoliotic

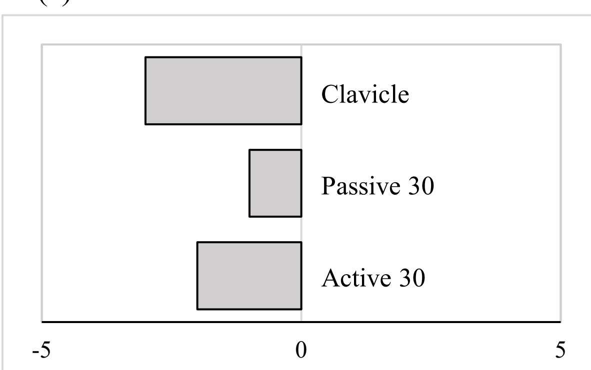
Pasha et al. measured 3D parameters of the spine and pelvis using EOS imaging in two different arm positions [12]. In position one, patients placed their knuckles on their collarbone while flexing their shoulders to 45 degrees (clavicle position), standing with feet shoulder-width apart. In position two, patients placed their hands and forearms on the wall in front of them with 90 degrees of shoulder and elbow flexion, keeping their distance an upper arm length from the wall (wall position), standing with feet shoulder-width apart. When comparing to the wall position, there was a significant increase in the mean T1–T12 thoracic kyphosis angle and the mean T4–T12 thoracic kyphosis angle when in the clavicle position [12]. There was a significantly smaller posterior pelvic rotation shown in the wall position, possibly due to the wall contributing to a patient's "self-correction" - a natural tendency to force the pelvis and shoulders to align parallel with the wall. This position is most notably affected by patients either leaning on the wall or pushing back from the wall.

Similarly, Pan et al. measured changes in lordosis in 20 non-scoliotic participants during eight different arm positions: arms relaxed, hands on clavicles, hands on cheeks, 90^{o} passive, arms crossed on chest, arms on back of the head, arms clasped, 90^{o} active [49]. These positions were chosen because the arms are brought in front of the spine, which has been shown to increase the flexion moment of the spine and thus, requiring increased back muscle forces to balance [54]. Using the Epionics SPINE device Pan et al. found that there was no significant difference in lordosis over the 8 positions [49]. Nevertheless, it was noted that during the 90^{o} passive position, there was a non-significant, but smaller lordosis angle compared to relaxed, chest, clavicles, backhead, cheeks, 90º active, and clasped. The change of sacral orientation was significantly less in 90º passive compared to the same arm positions ($p<0.05$) [51].

Comparably, Marks et al. measured kyphosis and lordosis using motion analysis markers placed on the skin in 22 non-scoliotic female participants across four arm positions: arms relaxed, active 30º, passive 30º, hands on clavicle [8]. Mean values for each test position were normalized to the optimal position of relaxed standing (control) by subtracting the control mean from each test position mean for each subject. There were no significant differences recorded between these positions for both kyphosis and lordosis measurements, shown in Figure 5. Nonetheless, each position did result in decreased kyphosis and increased lordosis, with 30º passive demonstrating the smallest decrease in kyphosis ($p>0.05$ vs other positions) as shown in Figure 5 (a) and (b). There was a significant decrease found in the sagittal vertical axis (SVA) relative to the mean value for the control ($p<0.05$) as shown in Figure 6 [8].

Figure 5. Mean differences from control (arms relaxed position (0 value)) in kyphosis (a) and lordosis (b) during 3 different arm positions [8]

(a)



(b)

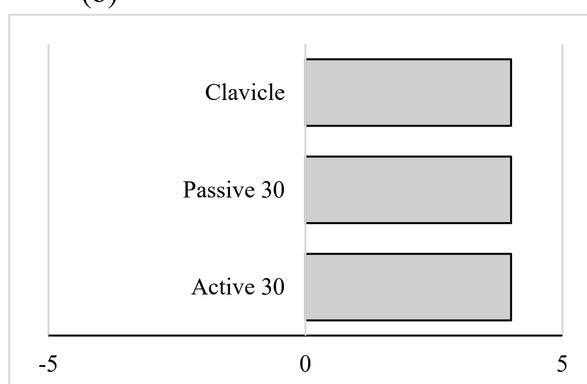
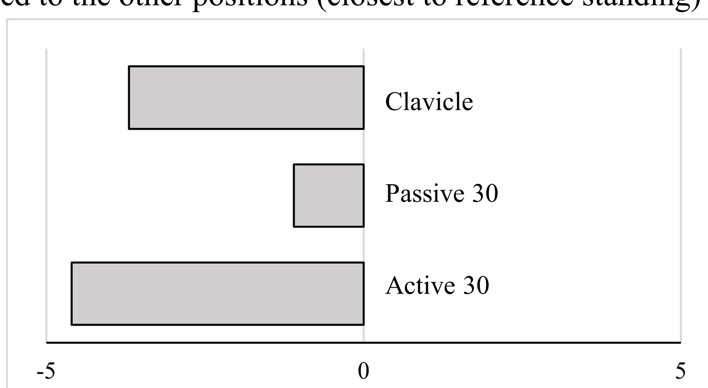


Figure 6. Mean differences in SVA from the control arms relaxed position (0 arm flexion value) during 3 different arm positions. Star: significant compared to the other positions (closest to reference standing) [8]



The study done by Marks et al. provides evidence that, of the three elevated arms positions compared, arms passively flexed at 30º provides the best standing position that more similarly reproduces a patients' relaxed habitual posture in non-scoliotic individuals [8]. Aota et al. also found a significant negative shift in SVA with the clavicle position relative to habitual standing postures, and as found by Marks et al, it was significantly less than shoulder-flexion positions [7]. Another study comparably using 3D surface topography concluded that a hands-on-clavicle position produces an unspecified significant increase in lordosis compared to standing hands-free [55].

Force plates have also been used to identify which arm positions represent the closest gravity line to habitual standing. In a study done by Sieh et al., it was measured that 9 different arm positions significantly anteriorly shifted the gravity line compared to the control (habitual standing) [56]. The only position that did not shift the gravity line significantly was the clavicle position, thus, making it the most representative of habitual standing when measuring the offset of the gravity line from the heel [7]. Although the literature is suggesting the fists-on-clavicle position to be the best option, Aota et al. did report that this position blocks important landmarks, as T2-T12 kyphosis angles could not be measured on radiograph images in 6 subjects [7]. This justifies the need to find an arm position that elevates the arms higher than the clavicle in order to expose the entire sagittal profile of the spine. These studies did not examine positions that exposed the hands while allowing lateral images that capture all vertebral bodies.

Arm Positioning and Effect on Sagittal Alignment

Patients with Scoliosis

Maçaneiro et al. measured kyphosis across two different arm positions in 20 adolescent scoliosis patients – arms actively flexed at 90º and hands resting on clavicles with arms at 45º [57]. There were no statistically significant differences in Cobb angles or kyphosis measurements shown between the position of the arms [57]. Lordosis was not measured in this study. Horton et al., similarly, measured no significant differences in kyphosis and lordosis measurements in scoliosis patients when passively flexing arms at 90º and 60º, as well as with hands resting on clavicles [52]. However, there was a significant positive shift in SVA measured during the 60º passive flexion compared to the clavicle position. While there was no significant difference comparing the clavicle and 90^{o} positions, there was a negative shift in SVA measured during 90^{o} passive flexion position compared to 60^{o} passive flexion. Again, it was concluded that the clavicle position should be used when imaging scoliosis patients [52]. This study did not compare to a resting habitual posture; however, they did look to determine the best visualization of the sagittal spine during a radiograph, concluding that hands on the clavicle also provides the most observations of the vertebrae as opposed to the other positions [52].

As shown in non-scoliotic participants, Faro et al. demonstrated that active shoulder-flexed arm positions produce a negative shift in the SVA compared to habitual standing [10]. In patients with AIS, the fists-on-clavicle arm position produced less SVA shift compared to active shoulder-flexion positions.

There was also a significant decrease in kyphosis through the thoracic spine in the clavicle position compared to a 45^{0} active shoulder-flexion position ($p < 0.05$) [10]. In contrast, when comparing two differing passive shoulder-flexion positions (arms at 30^{o}, arms at 90^{o}), Vedantam et al. showed no statistical significance between kyphosis, lordosis, and SVA measurements [11]. Horton et al. also found evidence to support a minimal change in kyphosis and lordosis comparing arms raised anteriorly 90^{o} and 60^{o}, and fingers to clavicle [52]. Vedantam et al., who only tested passive positions, recommended the best positioning would be arms at 30^{o} of passive shoulder flexion from the vertical for radiographic imaging of the spine [11].

Evidently, there are contrasting conclusions when it comes to the best positioning for scoliosis imaging. It appears as though majority of the literature available suggests the clavicle arm position is most suitable for viewing the sagittal spine, and there is evidence to support that this position will not cause a significant change in kyphosis, lordosis, or Cobb angles [10, 52]. There is also evidence concluding that passive arm flexion will not cause significant changes in spinal parameters, but these positions tend to block the side-profile of the image [11, 52]. Interestingly, there is also evidence to support that the clavicle position increased lordosis measurements compared to habitual standing in non-scoliotic participants [55]. There are no current studies that compare the effects of different arm positions between non-scoliotic and patients with scoliosis. This would be very important to understand since there is conflicting evidence between non-scoliotic and scoliosis spinal parameters and how these are affected by differing arm positions. It could be important to note that the mentioned studies with scoliosis participants typically had small sample sizes (the largest being n =50), possibly lowering the chance of detecting significant changes in measurements between positions. The current literature does not compare curve types in patients with AIS, reinforcing the need to examine if curve type (single or double) has an effect on spinal parameters.

Arm Positioning and Effect on Sagittal Alignment

Comparing Sexes

There is very little literature comparing sex differences in spinal parameters and the effects of arm positioning, however, Pan et al., measured that lordosis and sacral orientation (SVA) were greater in non-scoliotic females than in males in each of the 8 arm positions tested. That being said, both sexes also displayed the same level of change in lordosis with each arm position [49]. No significant differences were found between each of the positions tested, hence, it was concluded that no specific position would help improve the variability of back lordosis during still standing radiographs [49]. Wojciech et al. observed that differences in spinal parameters (kyphosis, lordosis, and SVA) between habitual standing posture and a hands-on-clavicle position were significant regardless of sex in non-scoliotic individuals [55]. It is clear that there needs to be more research done to examine the differences that arm positioning has on non-scoliotic males and females, and there is little to no research studying the impacts of sex on scoliosis patients.

Arm Positioning and Effect on Sagittal Alignment

Comparing Age Groups

Asano et al., measured a shift in C7, kyphosis, and lordosis in 24 non-scoliotic adolescent patients comparing natural standing to the clavicle position [50]. It was shown that all participants had a significant posterior shift in SVA during the clavicle position. There was also significant increases in lumbar lordosis and a decrease in cervical kyphosis in all participants compared to natural standing [50]. These results contrast to results in non-scoliotic adult participants, where there is typically no significant changes in kyphosis and lordosis measurements [8, 49]. Similar to the findings in studies with adult participants, Maçaneiro et al. noted no significant changes in any parameters over two arm-flexion positions in adolescent scoliosis participants [57]. Additionally, Yan et al. measured the clavicle position in 257 non-scoliotic adult participants, noting that no significant changes in sagittal parameters were found among the five age groups compared ($p>0.05$) [58]. The ages ranged from 22 to 74 years old, stratified into: group A, 41.2±13.0; group B, 38.5±11.8; group C, 42.2±12.0; group D, 43.3±13.1; groups E, 39.4±13.8 [58]. There is particularly limited and conflicting data comparing the effect that age can have on sagittal parameters in differing arm positions. There were no studies found that directly compared different age groups. Studying the effect of positioning in a sample representing patients visiting a specialized scoliosis clinic appears important.

What is Missing?

Overall, there is limited literature to describe the effects that arm positioning has on the sagittal profile. The research provided focuses more on non-scoliotic participant measurements as opposed to scoliosis participants. The literature that does describe the effects of arm position on sagittal parameters does not include a head-to-head comparison between non-scoliotic and scoliosis participants and how spinal curvature in scoliosis patients can alter the effects of arm positioning. More specifically, it is not known how different curve types (double vs. single curves) can also influence sagittal parameters during different arm positions. Faro et al. is the only study to describe how arm position alters sagittal parameters in surgically treated versus non-surgically treated patients [10]. It is also unknown how age impacts the sagittal profile, as the majority of the literature's inclusion criteria required adult participants (18+) or combined a number of age groups and did not compare the results between groups. Table 4 shows similar studies and their corresponding participants, demonstrating how only Faro et al. had measured adolescent idiopathic scoliosis patients by then [10, 56].

A common theme for most of the literature done on this topic is that there is a rather small sample size for all groups. This can increase the variability within the sample and can make it harder to detect significant differences in the results. A small sample size combined with a measurement device that is less precise (like visible body landmarks used by Marks et al.) can create results that are not necessarily representative of the population or miss important differences [8]. It is also important to note that several of the studies done do not use a comparison arm position that represents habitual posture, as shown in the 'Remarks' column in

Table 4 [56]. Table 4 also shows that the suggested arm position for radiography varies amongst different authors, leaving room for more informative research in this area [56].

The positions investigated that had not yet been compared to natural standing are: hands on chin, hands on eyebrows, arms abducted 90º, hands on blocks, and hands unsupported. Hands on chin and hands on eyebrows were chosen because it was hypothesized that the higher the arms are raised compared to the commonly used clavicle position, the easier it would be able to view vertebrae. Positions that raise the hands above the shoulder were chosen in order to expose the hands for assessing bone age.

It is worth noting that there was limited literature found that directly investigated the effects of arm positions that simultaneously allow for scoring of skeletal maturity. Arms abducted 90^{0}, hands on blocks, and hands unsupported will allow for this. Pasha et al. was the only study found to use a position that holds the arms above the head and expose the hands, but there was a significant difference found between the spinal and pelvic parameters when comparing to the more commonly used clavicle position [12]. This reinforces the need to include and study the effects of more arm positions that expose the hands. The positions included in our study did expose the hands and had not yet been compared to natural standing within the current literature. No current literature had directly analyzed the effects of arm positions on the angle of vertebral rotation (AVR), a spinal parameter that our study did analyze. Lastly, it was rare to find literature that measured all commonly used spinal parameters including SVA, thoracic kyphosis, T4/T5 kyphosis, lordosis, Cobb angle, and AVR. As well, no literature had included head-to-head comparisons of non-scoliotic participants to AIS single and AIS double curves.

Table 4. Authors and corresponding arm position recommendations [56].

Author	Subjects	Arm positions	Measurement	Measuring technique	Suggested position	Remarks
Marks, 2003[14]	15 healthy adults	1. Control 2. Arm flexion 3. Knee and arm flexion 4. Knee flexion	SVA	Reflective markers	Arm flexion	Only assess arm flexion
Faro, 2004[12]	50 Adolescent idiopathic scoliosis (AIS) patients	1. Clavicular 2. 45° active flexion	SVA	Lateral radiograph	Clavicular	Not asymptomatic subject No comparison with functional position
Horton, 2005[13]	25 scoliosis patients	1. Clavicular 2. 90° passive flexion 3. 60° passive flexion	Visualization	Lateral radiograph	Clavicular	Not asymptomatic subject No comparison with functional position
Aota, 2009[10]	14 young adult males	1. Control 2. Clavicular 3. 45° active flexion	SVA	Lateral radiograph	Clavicular	Significant posterior shift of the SVA in all positions
Marks, 2009[14]	22 healthy adults	1. Control 2. Clavicular 3. 30° active flexion 4. 30° passive flexion	SVA	Reflective markers	30° passive flexion	No comparison with functional position
Aota, 2011[11]	21 healthy young adults	1. Control 2. Clavicular 3. 45° active flexion 4. Arm across chest 5. Arm in front	SVA	Lateral radiograph	Arm in front	Visualization problem in arm in front position

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CHAPTER 3 – Systematic Review of Imaging Comparisons of Spinal Alignment among Standing Positions in Non-scoliotic Adolescents or Adolescents with Idiopathic Scoliosis

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ABSTRACT

Purpose Clinicians detect scoliosis worsening over time using frequent radiographs during growth. Arms must be elevated when capturing sagittal radiographs to visualize the vertebrae, and this may affect the sagittal angles. The aim was to systematically review the published evidence of the effect of arm positions used during radiography on spinal alignment parameters in non-scoliotic participants and those with AIS.

Methods Design was registered in PROSPERO (CRD42022347494). A search strategy was run in Medline, Embase, CINAHL, and Web of Science. Non-scoliotic participants ≥10 years old and participants with AIS between 10 and 18 years old, with Cobb angles >10° were included. Study quality was assessed using the Appraisal tool for Cross-Sectional Studies (AXIS). Meta-analysis was performed where possible.

Results Overall, 1332 abstracts and 33 full texts were screened. Data was extracted from 7 included studies. The most common positions were habitual standing, fists on clavicle, and active (arms raised unsupported). Kyphosis, lordosis, and sagittal vertical axis (SVA) were most measured. Meta-analysis showed significantly decreased kyphosis (SMD= 0.78, 95%CI= 0.48, 1.09) and increased lordosis (SMD= -1.21, 95%CI= -1.58,-0.85) when clavicle was compared to standing. Significant posterior shifts in SVA were shown in clavicle compared to standing (MD= 30.59mm, 95%CI= 23.91,37.27) and active compared to clavicle (MD= -2.01mm, 95%CI= -3.38,-0.64). Cobb angles and rotation were rarely studied (1 study).

Conclusion Meta-analysis evidence showed elevated arm positions modify sagittal measurements compared to standing. Most studies did not report on all relevant parameters, nor did studies report on the effect on differing curve types. It is unclear which position best represent habitual standing.

KEYWORDS

Arm, Patient Positioning, Radiography, Kyphosis, Lordosis, Review

INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is a 3D structural disorder of the spine with lateral curvature of over 10°, vertebral rotation, and sagittal changes that affects 2-3% of adolescents [13]. Patients with AIS receive numerous x-rays throughout their treatment to establish the diagnosis and monitor curve progression, which is defined as a five degree increase in Cobb angle compared to previous radiographs. This exposes them to harmful radiation throughout their growing years. Particularly in young children, increased exposure to radiation has been shown to increase the incidence of cancer [3]. Ronckers et al. followed 5513 females with scoliosis, finding they were exposed to an average of 22.9 radiographs per person during treatment and follow-up [59]. Similarly, a Milwaukee-based program following 13 females with AIS estimated that each patient had 22 films taken during a three-year course and showed increased risk for leukemia (3.4%), stomach/gastrointestinal (1.3%), lung (7.5%), and breast cancers (110%) [60]. A 2007 SOSORT Consensus Report stated that scoliosis experts agreed x-rays should be performed at the time of first evaluation and then every 6-12 months afterward to minimize total number of x-rays [2].

All radiographic measurements, when imaging patients with AIS, depend on being able to see the detail of key vertebral landmarks while ensuring that the arm position used during the radiograph does not affect the sagittal and frontal spinal parameters. Sagittal views are necessary to measure spinal parameters such as kyphosis and lordosis. The SRS Radiographic Measurement Manual states an ideal standing lateral radiograph should include vertebrae C7 to S1 and the ability to visualize C0–C1 and the hip joints is optimal [61]. Key landmarks to assess kyphosis and lordosis include vertebrae T1/T2, T4/T5, T10-T12, L1 and the sacrum. Another key sagittal parameter includes SVA, requiring the x-ray to show the anterior-posterior position of vertebrae C7 relative to the superior posterior corner of the sacrum [10]. Historically, only frontal radiographs were collected, but research has demonstrated that sagittal deformity is more strongly related to quality of life [62]. Recently, low-dose radiographic systems have become available that simultaneously acquire a frontal and a sagittal image that reconstruct the spine in 3D [54]. It is necessary to have the arms elevated when using such systems in order to expose the whole sagittal plane of the spine and avoid the arms from overlapping with vertebral bodies. However, raising the arms has been shown to affect sagittal angles [5–12]. Ideally, patient positioning during standing radiographs would reflect habitual posture parameters, or at minimum, be similar to the standing posture used to monitor frontal angles historically.

It would be beneficial to know which arm position used during imaging will simultaneously allow exposing the hands in order to determine skeletal maturity. Assessment of skeletal maturity can be done using the Sanders Skeletal Maturity Staging System. This system breaks down the fusion of the epiphyseal growth plates into 8 stages and can be used to determine how much growth a patient with AIS has left, and thus, estimate the scoliosis progression risk [32]. Risser staging has traditionally been the primary marker of skeletal maturity utilized in decision making for treatment of AIS because it is scored on routine frontal spine radiographs. This method requires determining ossification of the left iliac apophysis that is associated with the patient's state of spinal maturity [4]. Compared to Sanders assessment, Risser staging has been shown to result in suboptimal treatment in one in every four patients, with the vast majority being undertreated [4].

OBJECTIVES

The aim of this study was to review and synthesise the published evidence of the effect of arm positions used during radiography on spinal alignment parameters compared to habitual standing in non-scoliotic populations and populations with AIS. Spinal alignment parameters of interest include Cobb angle, whole thoracic kyphosis, T5-T12 kyphosis, lordosis, AVR twist, and any other spinopelvic parameters such as sagittal vertical axis (SVA). Sagittal angles are a primary parameter of interest. It was hypothesized that:

1. I will be able to identify an arm position that will allow exposing the hands for skeletal maturity assessment that does not significantly alter vertebral rotation, or any frontal or sagittal angles compared to habitual standing, and
2. The largest differences due to elevating the arms will be detected using sagittal angles (kyphosis and lordosis) compared to frontal or transverse measurements.

METHODS

Design and methods used for this systematic review were registered with the International Prospective Register of Systematic Reviews (PROSPERO CRD42022347494).

Reporting is compliant with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [63].

Search Strategy

The search employed sensitive topic-based strategies designed for each database from inception to June 29, 2022. Databases include Cumulated Index to Nursing and Allied Health Literature (CINAHL) (EBSCO), Embase (OVID), Medline (OVID), and Web of Science (All databases). The search syntax used in each database is reported in the Appendix of this document. The strategy includes terms and keywords identified by an expert on scoliosis, a master's student, and by librarian Liz Dennet from the Health Science library at the University of Alberta. The search for this review was designed by identifying terms related to the scoliosis population, imaging methods, measurements of interest, and patient positioning. To limit to the most relevant references, populations where scoliosis was a symptom of another disease were eliminated. Covidence was used to import all articles, and duplicates were eliminated automatically. Covidence is a web-based collaboration software platform that streamlines the production of systematic and other literature reviews [64].

Study selection criteria

Studies were included if they focused on non-scoliotic participants aged ≥ 10 years old and participants with AIS between the ages of 10 and 18 years old with Cobb angles > 10°. Studies comparing the effect of patient positioning and arm positioning for full spine imaging, limited to standing, were included. Cohort or cross-sectional study designs where positions were compared within a short time interval were included. Studies with participants diagnosed with spinal disorders other than AIS, injuries to the lower body, and studies with pregnant participants were excluded.

Selection Process

Two independent reviewers used Covidence to select relevant articles during a titles and abstract screening stage using the eligibility criteria outlined above. Reviewers were blinded to selections. For references meeting the criteria as identified by both reviewers, the two independent reviewers screened full text articles uploaded to Covidence. At both screening stages, if reviewers disagreed, they first had a consensus discussion, and if needed, a third reviewer made the final decision. Percent agreement was calculated between reviewers.

Data Extraction

Two reviewers independently extracted study information using a piloted Google spreadsheet. Reviewers first tried extraction on three papers and discussed results before continuing further. During extraction, if reviewers disagreed, they attempted to reach consensus via discussion, then consulted the opinion of a third reviewer if needed. The reviewers extracted the following study information (where available); sample descriptions including age and sex, diagnosis, curve type and severity, imaging methods, spinal measurements, descriptions of testing positions, and reported statistics comparing the positions.

Scoliosis measurement parameters including maximum curve angle, AVR, sagittal angles including kyphosis and lordosis, SVA, and any other relevant spino-pelvic parameters were extracted. Statistical results comparing positions were extracted. Kyphosis and lordosis angles were considered the primary outcomes.

Risk of Bias Assessment

The Appraisal tool for Cross-Sectional Studies (AXIS) was used to determine the quality of cross-sectional studies [65]. The AXIS quality appraisal was scored out of 12 for the 12 questions referring to methodological quality to avoid focusing on reporting quality (Table 9). "Positive" was selected when the answer to the question was clear and precise. An "unclear" result was given when the answer to the question was vague. A "negative" result was given if the study did not report on the question. Each study was given a final score out of 12, and a corresponding rating. Scores ranging from 1-3 were rated low, scores from 4-7 were moderate, and scores above and including 8 were rated high quality. AXIS has been shown reliable in comparison to an adapted Newcastle–Ottawa Scale (NOS) [66]. Both reviewers read the manual on AXIS grading, reviewed one article, compared results, and then appraised the rest of the papers. Both reviewers were trained in determining how to rate methodological questions sufficiently [67]. Both reviewers independently completed the appraisal for each selected article. Disagreements in quality scoring were resolved by consensus.

Data Synthesis

Summary tables were prepared: including levels of evidence summary statements based on quality assessment, study characteristics, extracted descriptive statistics, and outcome characteristics reported in and missing from current literature. Meta-analysis was performed for each measurement parameter if more than two studies reported on a similar spinal parameter and arm positions using RevMan 5.4.1 (The Cochrane Collaboration, version September 2020. Available at revman.cochrane.org). A random-effect meta-analysis of standardized mean differences was used for kyphosis and lordosis due to differences in measurement scales reported in the articles. In contrast, a random-effect meta-analysis of the mean differences was reported for SVA measurements due to consistent measurement scales used for this parameter. Point estimates and 95% confidence intervals (CI) were reported for each meta-analysis. Chi-square tests of heterogeneity were performed and I^2 was reported for each meta-analysis. I^2 results were interpreted as follows; 0-40% may not be considerable heterogeneity, 30%-60% may represent moderate heterogeneity, 50%-90% may represent substantial heterogeneity, and 75%-100% represents considerable heterogeneity [68].

Levels of evidence summary statements were formulated for other results. As adapted by Cornelius et al., the summary of results was graded using the levels of evidence considering the methodological quality and the consistency of the results across studies for each parameter and positions comparisons (Table 5) [69].

Table 5. Levels of evidence summary statements based on quality assessment and consistency of results among studies.

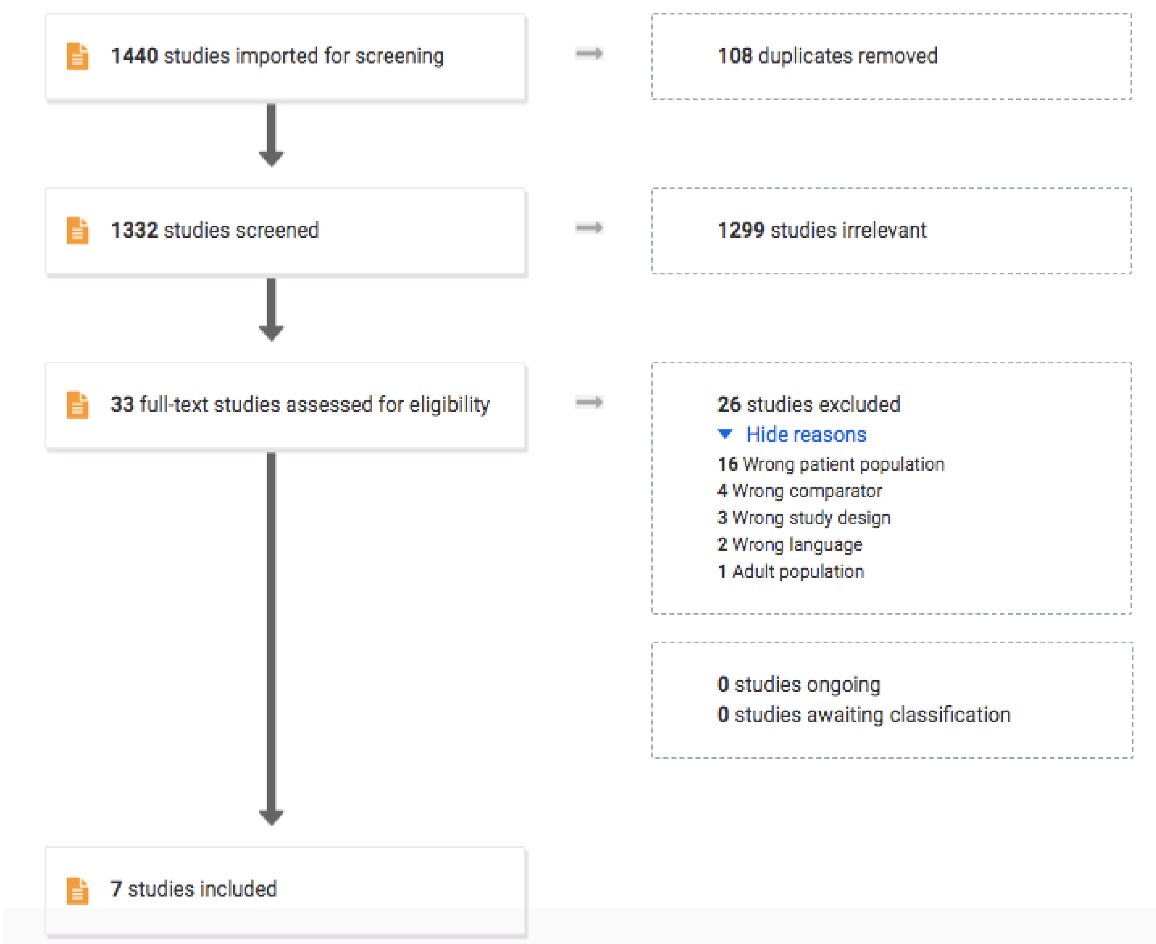
OPTION	
Strong	Consistent results (≥75%) from at least 2 high-quality studies
Moderate	1 high-quality study and consistent findings (≥75%) in 1 or more low-quality studies
Limited	Findings in 1 high-quality study cohort or consistent results (≥75%) among low-quality studies
Insufficient	Findings in 1 low-quality study cohort
No	No study identified
Conflicting	Inconsistent results irrespective of study quality

RESULTS

Study selection

A total of 1440 studies were identified across all databases (MEDLINE = 78, EMBASE = 338, CINAHL = 65, WEB OF SCIENCE = 851) (Figure 7). After 108 duplicates were excluded, 1332 abstracts and titles were screened by the two reviewers. After exclusion of 1299 irrelevant records, 33 full texts were screened by the two reviewers, and 26 studies were excluded. Seven papers were ultimately included for data extraction [8–10, 12, 50, 51, 55]. Percentage of agreement between the reviewers was 97.5% for title and abstract screening and 100% for full text screening.

Figure 7. PRISMA Study Selection Flow diagram.



Study description

Study characteristics including sample descriptions, disease characteristics, and methodology are shown in Table 7. Six arm positions were analyzed across included studies. These include: habitual standing, 30º or 45º active flexion, 30º passive flexion, fists to clavicle, and hands on wall. The most common positions reported in comparison studies were habitual standing (5 studies [8, 50, 51, 55, 70]), fists on clavicle (5 studies [8, 10, 50, 51, 55]), and active positions where the arms are raised and unsupported (3 studies [8, 10, 70]) (Table 7). The most commonly measured spinal alignment parameters were kyphosis (5 studies [8, 10, 12, 50, 51]), lordosis (5 studies [8, 10, 12, 50, 51]), and SVA (4 studies [8, 10, 12, 70]) (Table 7). Descriptive and comparative statistics for each of the imaging spine alignment outcomes extracted for the different positions are presented in Table 8.

Other spino-pelvic parameters were also assessed. Two studies assessed pelvic incidence, sacral slope, and pelvic tilt [10, 12] comparing active 45º or hands on wall to the clavicle position, respectively (Table 6). Further, Pasha et al. evaluated frontal balance, lateral pelvic tilt (LPT) and, and anterior pelvic plane (APP) inclination between hands on wall and the clavicle position [12]. Pasha et al. and Faro et al. both detected a significant sacral slope degree increase comparing the hands on wall and active 45º, respectively, to the clavicle position (p<0.05) [10, 12] Wojciech et al. found no systematic differences for trunk vertical inclination angle in the sagittal plane between standing and the clavicle position [55].

Table 6. Extracted descriptive statistics for imaging outcome and comparison statistics among the positions compared.

	Parameter		
Study	**Sacral Slope**	**Pelvic Tilt**	**Pelvic Incidence**
Pasha, 2016 [12]	WALL 44.1º ± 12.4 CLAVICLE 49.9º ± 15.6 Paired t-test: WALL < CLAVICLE p<0.05	WALL 6.8º ± 8.8 CLAVICLE 9.5º ± 11.2 Paired t-test: p>0.05	WALL 51.0º ± 14.8 CLAVICLE 50.6º ± 14.3 Paired t-test: p>0.05
Faro, 2004 [10]	ACTIVE 45° 41°±8 CLAVICLE 44°±7 ANOVA; 3±6, p=0.020	ACTIVE 45°: 8°±8 CLAVICLE 6°±8 ANOVA; -2±5, p=0.135	ACTIVE 45° 49°±14 vs CLAVICLE 50°± 12 ANOVA; 1±4, p=0.251

Table 7. Study Characteristics.

Study	Population				Disease Characteristics		Methodology	
	Sample size = N	Age (yrs); Mean ± SD (Min-Max Range)	Sex; Count, %	Count, % of Cohort within Dx Category	Curve Severity (º) Mean ± SD (Min-Max Range) Count, % Within Categories	Curve Types; Category, Count (%) for each type	Imaging Method Used	Arm position(s) used and description
Faro, 2004 [10]	50	14.7 ± 2.3	42 F, 84%	50, 100% AIS	NA	NA	Lateral spine radiograph	45° FLEXED: arms forward flexed at shoulders to ≈45° with elbows fully extended CLAVICLE: fists on ipsilateral clavicles with elbows fully flexed
Marks, 2009 [9]	22	13 ± 2 (12-20)	22 F, 100%	22, 100% non-scoliotic	Non-scoliotic	NA	Reflective markers, 8-camera infrared motion capture system	CONTROL: arms resting on either side 30º ACTIVE: standing with active shoulder flexion to 30° and elbows extended 30º PASSIVE: standing with passive shoulder flexion to 30° and elbows slightly flexed using "ski pole" type hand supports with rigid, stable bases placed in front and to the side CLAVICLE: standing with the elbows fully flexed and each fist placed over the ipsilateral clavicle
Marks, 2003 [8]	15	12.0 ± 1.9 10-14	15 F, 100%	15, 100% non-scoliotic	NA	NA	Reflective markers, 36-inch radiographs	RLX: Standing relaxed with arms at side; habitual standing posture SF: Standing relaxed with 45°

								active shoulder flexion and elbows extended
Asano, 2015 [50]	24	Mean 11.9	16 F, 67%	24, 100% school children screened for scoliosis	NA	NA	3D projection scanning system (SLS-1 David Vision)	NP: Natural dropped-arm CP: Fists-on-clavicle
Wojciech, 2013 [55]	694	10-18	275 F, 39.6%	NA	Non-scoliotic	NA	3D surface topography (3D Orthoscreen)	Hands hanging freely Fingers on clavicles
Abe, 2016 [51]	42	Mean 12.6	34 F, 81%	42, 100% school children screened for scoliosis	NA	NA	3D projection scanning system (SLS-1 David Vision)	NP: Natural dropped-arm CP: fists-on-clavicle
Pasha, 2016 [12]	37	10-18	NA	37, 100% AIS	Thoracic: 46° (0°-110°) Lumbar 30° (0°-90°)	95% of patients: Lenke 1 (A,B) or Lenke 3 (A, B, C,), one left-sided thoracolumbar curve, one Lenke 5C-type curve	EOS bi-planar low dose X-ray	CLAVICLE: knuckles on the ipsilateral clavicles while flexing the shoulders 45° HANDS ON WALL: hands and forearms on the wall in front with a 90° shoulder and elbow flexion, keeping their distance arm length from the front wall

Table 8. Extracted descriptive statistics for each imaging outcome and comparison statistics among the positions compared in each study when available.

Study	**Whole Thoracic Kyphosis Angle (º)** Mean ± SD (Min-Max), Statistical Differences Reported	**T4/T5 – T11/T12 Kyphosis Angle (º)** Mean ± SD (Min-Max), Statistical Differences Reported	**T10-L2 Kyphosis Angle (º)** Mean ± SD (Min-Max), Statistical Differences Reported	**Lordosis Angle (º)** Mean ± SD (Min-Max), Statistical Differences Reported	**Sagittal Vertical Axis (mm)** Mean ± SD (Min-Max), Statistical Differences Reported (- = posterior shift)	**Curve Severity (º)** Mean ± SD (Min-Max), Statistical Differences Reported	**AVR (º);** Mean ± SD (Min-Max), Statistical Differences Reported
Faro, 2004 [7]	ACTIVE 45º 32±12 CLAVICLE 28±14 ANOVA; CLAVICLE - ACTIVE 45º -5±9, *p*=0.014	ACTIVE 45º 24±12 CLAVICLE 20±13 ANOVA; -4±8, *p*=0.013	ACTIVE 45º 3±7 CLAVICLE 1±6 ANOVA; 2±7, *p*=0.269	ACTIVE 45º -55±28 CLAVICLE: -53±27 ANOVA; 3±7, *p*=0.064	ACTIVE 45º -50±24 CLAVICLE -18±23 ANOVA; 32±26, *p*<.001	NA	NA
Marks, 2009 [8]	Normalized mean differences vs. HABITUAL: ACTIVE 30º -2°±-7° CLAVICLE -3°±-8° PASSIVE 30º -1°±-6° ANOVA, Tukey: ACTIVE 30, CLAVICLE, PASSIVE 30 no different from HABITUAL *p*>0.05	NA	NA	Normalized mean differences vs. HABITUAL: ACTIVE 30º 4°±7° CLAVICLE 4°±6° PASSIVE 30º 4 ±5° ANOVA, Tukey ACTIVE 30º, CLAVICLE, PASSIVE 30º no different from HABITUAL, *p*>0.05	Normalized mean differences vs. HABITUAL: ACTIVE 30º -46±13 CLAVICLE -37±19 PASSIVE 30º -11±8 ANOVA, Tukey ACTIVE 30º, CLAVICLE < PASSIVE 30º < HABITUAL, *p*<0.05	NA	NA

Marks, 2003 [9]	NA	NA	NA	NA	STANDING 9±20 SF -46±32 ANOVA, Bonferroni STANDING> SF, $p<0.01$	NA	NA
Asano, 2015 [28]	HABITUAL 43.0° CLAVICLE 39.9° Normalized mean difference vs. HABITUAL CLAVICLE: -3.1±5.4° HABITUAL >CLAVICLE, $p<0.05$	NA	NA	HABITUAL 37.8° CLAVICLE 40.4° Normalized mean differences vs. HABITUAL CLAVICLE: 2.7± 3.4° HABITUAL <CLAVICLE, $p<0.05$	Normalized mean differences vs. HABITUAL: CLAVICLE 24.7±15, $p<0.05$ 38% with posterior shift >30mm from HABITUAL to CLAVICLE	NA	NA
Abe, 2016 [26]	HABITUAL 40° CLAVICLE 36.7° Normalized mean differences vs. HABITUAL CLAVICLE: -3.1±5.0 HABITUAL>CLAVICLE, $p<0.05$	NA	NA	HABITUAL 35.9° CLAVICLE 39.9° Normalized mean differences vs. HABITUAL CLAVICLE 3.8±3.7° CLAVICLE>HABITUAL $p<0.05$	Mean change (HABITUAL to CLAVICLE) 31.2±20mm, $p<0.05$ 54% showed posterior shift >30mm from HABITUAL to CLAVICLE	NA	NA

Wojciech, 2013 [27]	NA	NA	NA	Values not reported Systematic differences between standing with hands hanging freely < fingers on the clavicles	NA	NA	NA
Pasha, 2016 [16]	CLAVICLE: 33.6±12.5 WALL: 29.5±10.3 Paired t-test: CLAVICLE > WALL, $p<0.05$	CLAVICLE 22.6±10.6 WALL 19.8±10.4 Paired t-test: CLAVICLE > WALL, $p<0.05$	NA	L1-L5 WALL: 46.1°±13.9 Clavicle: 45.5°±13.1 L1-S1 WALL: 56.3°±13.7 CLAVICLE: 57.7°±13.1 Cervical Lordosis WALL: 5.9º±25.4 CLAVICLE: 7.6°±24.9 All paired t-tests: $p>0.05$	CLAVICLE 3±17 WALL -16±29 Paired t-test: WALL more posterior than CLAVICLE, $p<0.05$	Proximal thoracic: WALL 23.5°±12.6 CLAVICLE 27.7°±7.8 Main thoracic: WALL 50.3°±17.5 CLAVICLE 51.3°±17.2 Lumbar: WALL 43.9°±16.4 CLAVICLE 41.3°±17.7 All paired t-tests: $p>0.05$	AVR Thoracic: CLAVICLE -12±9.8 WALL -10.8±16.5 Lumbar: CLAVICLE 13.7±8.8 WALL 14.6±9.9 All paired t-tests: $p>0.05$

Abbreviations: NA = Not applicable, SF= Standing with 45° shoulder flexion, AVR= Axial vertebral rotation.

Quality appraisal

Of the seven studies, two were rated as high methodological quality, three as moderate, and two as low quality (Table 9). Our AXIS results commonly flagged questions regarding response rate, addressing biases, and the lack of descriptions justifying sample size. Alternatively, AXIS positively scored questions justifying results and conclusions, as well as appropriate study design choices.

Table 9. Axis quality assessment.

	Pasha, 2016[12]	**Abe, 2015**[51]	**Wojciech, 2013**[55]	**Asano, 2015**[50]	**Marks, 2003**[70]	**Marks, 2009**[8]	**Faro, 2004**[10]
Appropriate study design?	Positive	Positive	Positive	Positive	Positive	Positive	Negative
Justified sample size?	Positive	Negative	Negative	Negative	Negative	Negative	Negative
Sample taken from appropriate population?	Positive	Positive	Unclear	Unclear	Positive	Unclear	Positive
Appropriate selection process?	Positive	Positive	Unclear	Unclear	Positive	Unclear	Positive
Appropriate variables and risk factors measured?	Positive	Positive	Negative	Negative	Positive	Positive	Positive
Variables and risk factor measured correctly?	Positive	Unclear	Unclear	Negative	Positive	Unclear	Positive
Methods sufficiently described?	Positive	Unclear	Positive	Negative	Positive	Positive	Positive
Appropriate time between taking images?	Unclear	Positive	Unclear	Positive	Positive	Positive	Negative
Did response rate raise concerns about bias?	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
Results presented for all analyses described?	Positive	Positive	Unclear	Negative	Positive	Positive	Positive
Authors' conclusions justified by results?	Positive	Positive	Positive	Positive	Positive	Positive	Positive
Did funding or conflict affect authors' interpretation?	Positive	Positive	Unclear	Unclear	Positive	Positive	Positive
Axis Score /12	9	7	3	3	9	6	7
Rating	High	Moderate	Low	Low	High	Moderate	Moderate

(green)	Positive
(yellow)	Unclear
(red)	Negative

Meta-analysis estimates

Kyphosis

- There is limited evidence from 2 moderate[8, 51] and 1 low quality studies[50] of a medium effect size of 0.78 [95% CI 0.48,1.09, $p < 0.01$] where kyphosis is smaller in the clavicle position when compared to habitual standing (Figure 8a). This analysis had low heterogeneity ($I^2 = 0\%$).
- Similarly, there is moderate evidence from 1 high[12] and 2 moderate quality studies[8, 10] of a non-significant and negligible effect size of 0.03 [95% CI -0.38,0.45, $p = 0.88$] for difference in kyphosis between the clavicle compared to the active position (Figure 8b). This analysis has substantial heterogeneity ($I^2 = 56\%$).

Lordosis

- There is limited evidence from 2 moderate[8, 51] and 1 low quality study[50] of a large effect size of -1.21 [95% CI -1.58,-0.85, $p < 0.01$] where lordosis is larger in the clavicle position compared to habitual standing (Figure 8c). This analysis has low heterogeneity ($I^2 = 20\%$).
- There is moderate evidence from 1 high[12] and 2 moderate quality studies[8, 10] of a non-significant and negligible effect size of -0.06 [95% CI -0.32,0.21, $p = 0.68$] about the difference in lordosis between the clavicle compared to the active positions (Figure 8d). This analysis has low heterogeneity ($I^2 = 0\%$).

SVA

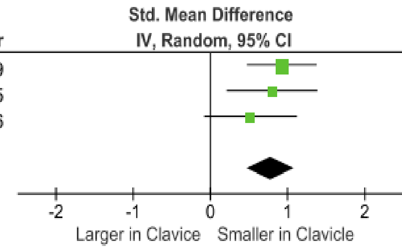
- There is limited evidence from 2 moderate[8, 51] and 1 low quality study[50] of a large mean difference of 30.59 mm [95% CI 23.91, 37.27, $p < 0.01$] where the SVA is shifted more posteriorly in the clavicle position compared to habitual standing (Figure 8e). This analysis however presented substantial heterogeneity ($I^2 = 67\%$).
- There is also moderate evidence from 1 high[12] and 2 moderate quality studies[8, 10] of a significant but small mean difference of -2.01mm [95% CI -3.38,-0.64, $p = 0.004$] where SVA is shifted more posteriorly in active positions compared to the clavicle position (Figure 8f). This analysis has substantial heterogeneity ($I^2 = 83\%$).

Figure 8a-f. Meta-analysis forest plots for comparisons of pairs of position of interest.

a. Standardized mean difference in kyphosis between habitual standing and clavicle

	Habitual Standing			Clavicle				Std. Mean Difference	
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI	Year
Marks, 2009	40	0.1	42	36.7	5	42	46.6%	0.92 [0.47, 1.38]	2009
Asano, 2015	43	0.1	24	39.9	5.4	24	27.2%	0.80 [0.21, 1.39]	2015
Abe, 2016	0	0.1	22	-3	8	22	26.2%	0.52 [-0.08, 1.12]	2016
Total (95% CI)			**88**			**88**	**100.0%**	**0.78 [0.48, 1.09]**	

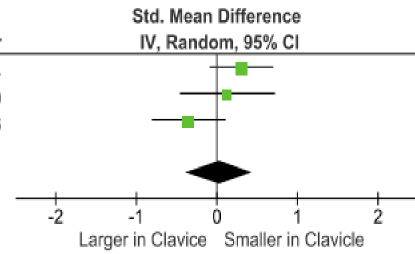
Heterogeneity: Tau² = 0.00; Chi² = 1.11, df = 2 (P = 0.57); I² = 0%
Test for overall effect: Z = 4.99 (P < 0.00001)



b. Standardized mean difference in kyphosis between active positions and clavicle

	Active			Clavicle				Std. Mean Difference	
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI	Year
Faro, 2004	32	12	50	28	14	50	38.7%	0.30 [-0.09, 0.70]	2004
Marks, 2009	-2	7	22	-3	8	22	26.9%	0.13 [-0.46, 0.72]	2009
Pasha, 2016	29.5	10.3	37	33.55	12.5	37	34.4%	-0.35 [-0.81, 0.11]	2016
Total (95% CI)			**109**			**109**	**100.0%**	**0.03 [-0.38, 0.45]**	

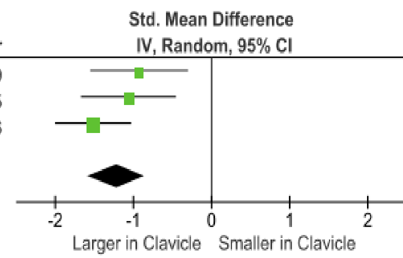
Heterogeneity: Tau² = 0.08; Chi² = 4.58, df = 2 (P = 0.10); I² = 56%
Test for overall effect: Z = 0.15 (P = 0.88)



c. Standardized mean difference in lordosis between habitual standing and clavicle

	Habitual Standing			Clavicle				Std. Mean Difference	
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI	Year
Marks, 2009	0	0.1	22	4	6	22	28.4%	-0.93 [-1.55, -0.30]	2009
Asano, 2015	37.8	0.1	24	40.4	3.4	24	29.7%	-1.06 [-1.67, -0.46]	2015
Abe, 2016	35.9	0.1	42	39.9	3.7	42	41.9%	-1.51 [-2.00, -1.03]	2016
Total (95% CI)			**88**			**88**	**100.0%**	**-1.21 [-1.58, -0.85]**	

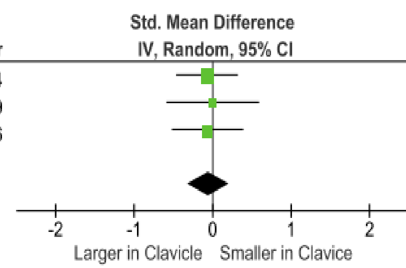
Heterogeneity: Tau² = 0.02; Chi² = 2.50, df = 2 (P = 0.29); I² = 20%
Test for overall effect: Z = 6.49 (P < 0.00001)



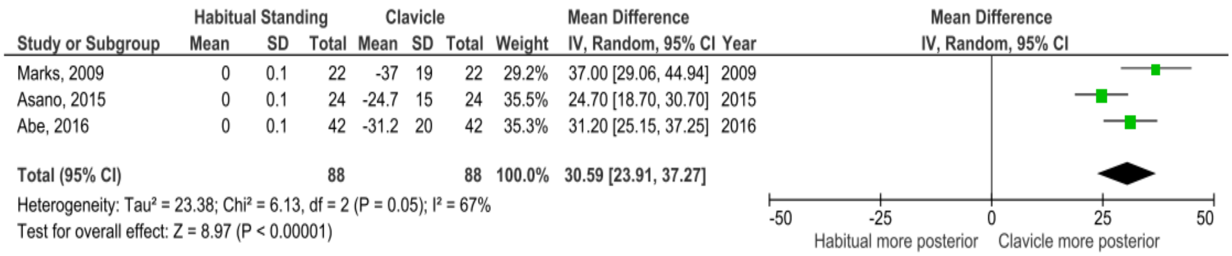
d. Standardized mean difference in lordosis between active positions and clavicle

	Active			Clavicle				Std. Mean Difference	
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI	Year
Faro, 2004	-55	28	50	-53	27	50	45.9%	-0.07 [-0.46, 0.32]	2004
Marks, 2009	4	7	22	4	6	22	20.2%	0.00 [-0.59, 0.59]	2009
Pasha, 2016	5.9	25.4	37	7.6	24.9	37	33.9%	-0.07 [-0.52, 0.39]	2016
Total (95% CI)			**109**			**109**	**100.0%**	**-0.06 [-0.32, 0.21]**	

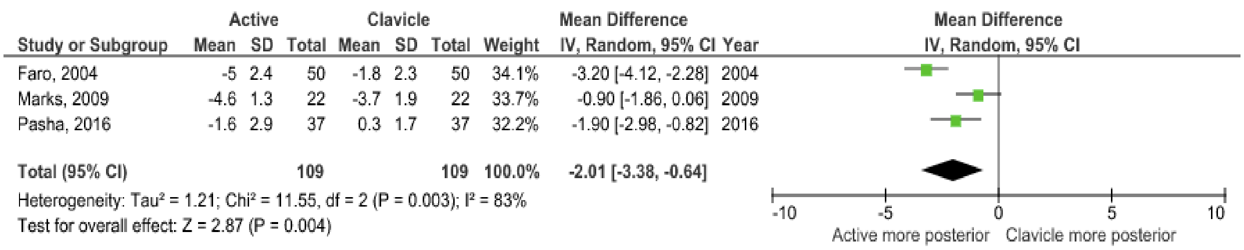
Heterogeneity: Tau² = 0.00; Chi² = 0.04, df = 2 (P = 0.98); I² = 0%
Test for overall effect: Z = 0.41 (P = 0.68)



e. Mean difference in SVA (mm) between the habitual standing and clavicle



f. Mean difference in SVA (mm) between active positions and clavicle



Level of evidence summary statements

A total of 24 strength of evidence summary statements were formulated based on the number and the quality of studies to include the evidence from studies contributing results which could not be meta-analysed with those in the meta-analysis that examined each spinal alignment outcome between standing positions (Table 10). No summary statement offered strong evidence, 14 offered limited strength and 7 moderate strength of evidence. Sixteen statements demonstrated evidence of no differences, two statements demonstrated conflicting evidence, and one insufficient evidence statement between compared positions.

Table 10. Strength of Evidence Summary Statements Based on Combining Studies Contributing Results which could not be Meta-analysed with those in the Meta-analysis and Based on their Quality Assessment Comparing Specific Outcomes between Imaging Positions.

Strength of Evidence	**# of Studies of specific quality and reported effects**	**Effect**	**Outcome Measure**	**Positions Compared**
Conflicting	1 high [12], 1 moderate quality study [10] with sig diff. & 1 moderate quality study with no sig. diff. [13]	Decreases Or no difference	Whole thoracic kyphosis	Passive 30º, Active 45º, Active 30º, Hands on wall vs. Clavicle

Conflicting	1 low [50], 1 moderate quality study [51] with sig. diff. & 1 moderate quality studies with no sig. diff. [8]	Decreases Or no differences	Whole thoracic kyphosis	Clavicle vs. Habitual
Limited	1 moderate with no sig. diff. [8]	No difference	Whole thoracic kyphosis	Passive 30º vs. Active 30º
Limited	1 moderate with no sig. diff. [8]	No difference	Whole thoracic kyphosis	Passive 30º, Active 30º vs. Habitual
Limited	1 moderate with no sig. diff. [7]	No difference	T10-L2 kyphosis	Active 45º vs. Clavicle
Moderate	1 high quality [12] and 1 moderate quality study with sig. diff.[10]	Decreases	T4/T5 kyphosis	Hands on wall, Active 45º vs. Clavicle
Limited	1 moderate with no sig. diff. [8]	No difference	Lordosis	Active 30º, Passive 30º vs. Habitual
Limited	2 low [50, 55], 1 moderate quality study [51] with sig. diff. & 1 moderate quality study with no sig. diff. [8]	Increases	Lordosis	Clavicle vs. Habitual
Moderate	1 high [12], 2 moderate quality studies with no sig. diff. [8, 10]	No difference	Lordosis	Active 45º, Active 30º, Hands on wall vs. Clavicle
Limited	1 moderate quality study with no sig. diff. [8]	No difference	Lordosis	Active 30º vs. Passive 30º
Moderate	1 high [9], 2 moderate [8, 51] and 1 low quality study [50]with sig. diff.	Posterior shift	SVA	Active 45º, Active 30º, Passive 30º, Clavicle vs. Habitual
Moderate	1 high [12], 1 moderate quality study with sig diff. [10] and 1 moderate with no sig. diff. [8]	Posterior shift	SVA	Active 45º, Active 30º, Hands on wall vs. Clavicle
Limited	1 moderate quality study with sig. diff. [8]	Posterior shift	SVA	Active 30º vs. Passive 30º

Insufficient	1 low quality study with no sig. diff. [55]	No differences	Sagittal trunk vertical inclination angle	Clavicle vs. Habitual
Limited	1 high quality study with no sig. diff. [16]	No differences	Curve Angle	Hands on wall vs. Clavicle
Limited	1 high quality study with no sig. diff.[12]	No differences	Thoracic AVR & AVT	Hands on wall vs. Clavicle
Limited	1 high quality study with no sig. diff.[12]	No differences	Lumbar AVR & AVT	Hands on wall vs. Clavicle
Moderate	1 high [12], 1 moderate quality study [10] with no sig. diff.	No differences	(Sagittal) Pelvic incidence angle	Active 45º, Hands on wall, Clavicle
Moderate	1 high [12], 1 moderate quality study [10] with sig. diff.	Decreased	(Sagittal) Sacral slope angle	Active 45º, Hands on wall vs. Clavicle
Moderate	1 high quality study with sig. diff. [12] and 1 moderate quality study with no sig. diff. [10]	No difference	(Sagittal) Pelvic Tilt angle	Hands on wall, Active 45º vs. Clavicle
Limited	1 high quality study with sig. diff. [12]	Decreased	(Sagittal) T1 tilt angle	Hands on wall vs. Clavicle
Limited	1 high quality study with no sig. diff.[12]	No differences	(Sagittal) L4 tilt angle	Hands on wall vs. Clavicle
Limited	1 high quality study with no sig. diff.[12]	No differences	Spinal height	Hands on wall vs. Clavicle
Limited	1 high quality study with no sig. diff. [12]	No differences	Lateral pelvic tilt angle	Hands on wall vs. Clavicle

Overall, for comparisons to habitual standing, one statement showed no significant differences vs habitual standing in whole thoracic kyphosis in Passive 30º and Active 30º. One statement each showed significant increases in lordosis in the clavicle position and significant posterior shifts in SVA in Active 45º or 30º, Passive 30º and Clavicle compared to habitual standing. Other summary statements for comparisons to habitual standing were either conflicting (Kyphosis vs Clavicle) or showed no difference (kyphosis and lordosis vs Passive and Active 30º).

Summary statements about comparisons of elevated arms positions to the clavicle positions found: decreased T4/T5 kyphosis with Hands on wall and Active 45º; posterior shift of SVA with Active 30º or 45º and Hands on wall; decreased sacral slope in Active 45º and Hands on wall; and decreased Sagittal T1 tilt angle in Hands on wall. Other summary statements including comparisons among arms-elevated positions and Clavicle were either conflicting (whole kyphosis vs Passive 30º, Active 30º or 45º and Hands on wall) or showed no difference (lordosis for Active 30º or 45º and Hands on wall; lumbar and thoracic AVR or axial vertebral translation (AVT) in Hands on wall; pelvic incidence angle in Active 45º and Hands on wall; in four other spino-pelvic parameters in Hands on wall and one other spino-pelvic parameter in Active 45º).

Summary statements comparing Active 30º to Passive 30º found no differences in kyphosis and lordosis, but a posterior SVA shift in Active compared to Passive 30º.

For eight of the parameters of interest stated a priori, summary statements were formulated to quickly identify positions tested to date and help researchers determine which positions have not yet been studied (no evidence) (Table 11). Positions that have not yet been reported depending on the alignment parameters are hands actively raised above the shoulders, hands on wall or blocks, hands to chin, hands to cheeks, and hands to eyebrows. Among hand raised positions, which could allow assessing skeletal maturity, only hands on wall has been previously studied [12]. Studies seldom reported on all spinal parameters identified as of interest a priori, most notably, frontal (maximum curve angle) and transverse angles have been rarely studied (AVR twist) (Table 11). Only one study to date assessed the effects on curve angle, AVT, and AVR [12].

Table 11. Outcome Characteristics and Position Comparisons of Interest NOT yet reported in Literature.

Strength of Evidence	# of Studies of specific quality and reported effects	Outcome Measure	Positions Compared
No evidence	No studies	T4/T5 kyphosis	Positions other than Habitual, Clavicle, Passive 30°, hands on wall, Active 45°
No evidence	No studies	Whole kyphosis	Positions other than Habitual, Clavicle, Passive 30°, hands on wall, Active 30° or 45°
No evidence	No studies	T10-L2 kyphosis	Positions other than Habitual, Passive 30°, Active 45°
No evidence	No studies	Lordosis or SVA	Positions other than Habitual, Clavicle, Passive 30°, Hands on wall, Active 30 or 45°
No evidence	No studies	AVR or AVT	Positions other than Clavicle, Hands on wall
No evidence	No studies	Pelvic tilt, Pelvic Incidence, or Sacral slope	Positions other than Clavicle, Hands on wall, Active 45°
No evidence	No studies	T1 tilt, L4 tilt, Spinal height, Lateral pelvic tilt	Positions other than Clavicle, Hands on wall
No evidence	No studies	Cobb angle	Positions other than Clavicle, Hands on wall

Abbreviations: SVA = Sagittal Vertical Axis, AVR = Axial Vertebral Rotation, AVT = Axial Vertebral Translation

DISCUSSION

The results of our systematic review found limited evidence on arm positions in adolescents that compared spinal parameters to habitual standing. Of the few positions that are discussed in the existing literature, our meta-analysis shows there are also mixed results when using these positions. The spinal parameters most commonly discussed are kyphosis, lordosis, and SVA – all sagittal parameters. Finding the effect of positioning on sagittal parameters was prioritized, but little to no research has been published on the effect of arm positions on frontal or transverse plane parameters like Cobb angle, AVT, and AVR or AVR twist, respectively. Our meta-analysis results show that the most commonly used arm position during radiography clinically, the clavicle position, significantly decreases kyphosis and increases lordosis compared to habitual standing. Consequently, this position also significantly shifts SVA posteriorly. Our meta-analysis results show that the most commonly used arm position during radiography clinically, the clavicle position, significantly decreases kyphosis and increases lordosis compared to habitual standing. Consequently, this position also significantly shifts SVA posteriorly. Our meta-analysis results show that active arm positions, when compared to the clavicle position, show non-significant decreases in kyphosis and increases in lordosis (Figure 8b,d). Further, active positions significantly shift SVA posteriorly when compared to the clavicle position (Figure 8f). There are a number of positions that have not been tested in the literature that would allow for the hands to be exposed for the scoring of skeletal maturity. Pasha et al. reported results for the hands-on wall position and is the lone study comparing a position that could expose the hands but did not compare spinal alignment parameters in this position to habitual standing [12].

It is important to ensure that arm positioning during radiography is not having significant effects on spinal alignment parameters for a number of reasons. If conclusions about treatment for patients with AIS is made based upon radiograph measurements that are not accurately reflecting habitual standing or the position adopted during prior radiographs, this could result in incorrect treatment options recommendation in the clinic. Accurate parameters are needed to construct custom braces and plan surgeries for AIS. If these are inaccurate based on changing arm positioning, brace construction may be inappropriate and cause this treatment to be uncomfortable and unsuccessful. If patients with AIS are nearing indications of surgery, which is defined by the SRS as a curve degree of over 45º-50º and/or those who are at high risk of continued worsening, precise radiograph results are imperative to determine if surgery will be recommended [71]. Similarly, if patients are consistently changing arm positions over the course of treatment, it may be hard to determine curve degree over time and adequately detect progression. For these reasons, it is critical to guarantee the arm position used during radiography is consistent and a reflection of habitual standing parameters.

A 2017 literature review compared arm positions during radiography [72]. The review included 22 studies using radiograph measurements and 16 studies that used photogrammetry measurements. All populations including adults, adolescents, scoliotic, and non-scoliotic participants were included. Our review differs most notably from this review because *only* the adolescent populations were included within the search. Our reviews retrieved only one study in common and, we did not miss any relevant articles that were retrieved by Okazaki and Porto [72]. This 2017 literature review included the comparison of radiography and photogrammetry imaging methods and was only interested in extracting thoracic kyphosis and lordosis measurements. Like our review, it was concluded there is a lack of standardized patient positioning during imaging. Okazaki and Porto suggested that, due to the lack of studies with comparisons among different arm positioning, radiographs be performed with arms flexed and fists resting on the clavicles, ensuring changes in the sagittal vertical axis and pelvic parameters do not occur [72]. Although a conclusive statement was made, it remains unclear how to ensure that any changes are not occurring in the SVA and/or other pelvic parameters during imaging in the clavicle position. Our review results concur with Faro et al, who stated that although the fingers on clavicle position is commonly used in clinics and in the literature [10], this position is not a reflection of habitual standing due to significant decreases in kyphosis, increases in lordosis, and shifts in SVA reported in adolescents.

The literature found in this review did not use consistent imaging methods. Only three studies used radiographs to detect differences in spinal parameters [9, 10, 12]. The remaining studies used varying surface topography methods [50, 51, 55] or reflective markers [8]. Across the studies we reviewed, only one justified the sample size [12]. Among studies that did not justify sample, the size ranged from 15 to 695 participants. Small samples (<30 participants) may be insufficient to detect clinically important differences between positions. The choice and description of methods used for measuring the different spinal parameters were found to be inconsistent across the literature. Due to methodological inconsistencies across the studies reviewed, and according to AXIS scoring, only two studies were deemed high quality, three were deemed moderate, and two were deemed low quality studies. It is recommended for future research to use consistent imaging methods and spinal parameter measuring techniques when comparing arm positions to habitual standing. The SRS Radiographic Measurement Manual and the SRS-Schwab Adult Spinal Deformity Classification offer clear instructions obtaining relevant measurements and it is recommended that these measurements be used in future studies [61, 73]. Sample size estimation strategies should be presented, and studies planned with adequate power to detect clinically important differences in the relevant parameters used in comparing positions.

The summary statements of our review show there are non-significant effects on lordosis among the commonly used arms elevated positions (clavicle, active, and passive positions). However, our statement comparing the clavicle position to habitual standing agrees with our meta-analysis, by showing a significant increase in lordosis measurements in the clavicle position compared to habitual standing. This suggests that most arm-elevated positions may change the spinal sagittal alignment compared to habitual standing. One study in our review also showed a significant decrease in kyphosis during the hands-on wall position compared to the clavicle position, but our meta-analysis did not show any significant differences in kyphosis measurements when comparing similar active positions [12]. Our summary statements show a conflicted strength of evidence with two studies [50, 51] showing significant decreases and one finding no difference in whole thoracic kyphosis when comparing the clavicle position to habitual standing [8]. Our meta-analysis, however, shows significant decreases in kyphosis across the literature when combining the evidence comparing these positions. Most of the literature shows significant posterior shifts in SVA in all positions with elevated arms measured compared to habitual standing [8, 10, 70] (Table 10). When the arms are held in active positions, there appears to be more important posterior shifts in the sagittal profile, and thus, such positions do not represent habitual standing. Similarly, the literature shows that the clavicle position, when compared to active positions and when the hands are held on the wall, are also not interchangeable [10, 12]. Only one study directly compared active and passive positions, showing that while there are no significant effects on kyphosis and lordosis, active arm elevation led to a significantly larger posterior shift in SVA [8]. The majority of the literature found on this topic did not compare enough positions and does not report on all relevant spinal parameters

(Table 11). Only one paper addresses sex differences without reporting data, stating differences between the clavicle position and standing were significant regardless of sex [55]. A significant gap in knowledge remains.

Our review was specific to adolescent populations, limited to arm positions while standing. By eliminating adult populations and sitting or lying positions, this limited results in our search. This being said, only adolescents were included because they are the population effected by AIS for which treatment decisions should be made based on regular radiograph comparisons during growth. Studies could have been missed in our search due to excluding languages other than English. Including more databases could have resulted in finding more research. Articles and abstracts were screened by two independent and blinded reviewers. Both reviewers were novice but reached good levels of agreement. Our meta-analysis results may be affected by the use of differing measurement methodologies between studies. Notably, the standardized mean difference was reported for kyphosis and lordosis analysis due to a difference in the reporting of these parameters between the studies. Our chosen quality appraisal tool, AXIS and scoring strategy, focuses mainly on the methodological quality of the chosen methods and analysis and is less focused on the quality of reporting [65]. We were then able to accurately determine the methodological quality of the studies reported.

Our review shows sagittal spinal parameters, most notably posterior shifts in SVA, are more prone to change when raising the arms in comparison to habitual standing measurements. Similarly, there are reported differences among positions that raise the arms and therefore prevent these positions from being used interchangeably. Therefore, spinal parameters in radiographs using these positions do not accurately reflect habitual standing. No position exposing the hands during imaging have been compared to habitual standing, and only the hands on wall position has been compared to other arm positions. Limited literature in this topic that is specific to AIS reinforces the need for more research and it remains unclear which arm position best represents habitual standing during radiography in patients with AIS.

CHAPTER 4 – The Test-retest Reliability of Frontal, Sagittal, and Transverse Spinal Measurements during Three Standing Arm Positions in Adolescents with Idiopathic Scoliosis Measured Using Ultrasound Imaging

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ABSTRACT

Purpose Clinicians monitor scoliosis progression using radiographs during growth. We compared standing imaging positions because the arms must be elevated to visualize all vertebrae, possibly affecting sagittal spinal parameters. 3D Ultrasound (3DUS) is a safe method to assess arm positions without any radiation exposure, but its test-retest reliability has not been established for common standing radiograph positions. The aim was to determine the test-retest reliability of frontal, sagittal, and transverse measurements obtained from three positions using 3DUS imaging.

Methods Females with AIS were recruited from a scoliosis clinic in Edmonton, Alberta. Participants underwent US scans in three positions: habitual standing, fingers to clavicle, and hands on wall. Participants were re-scanned in the same three positions 20-minutes following the first scans. Custom software was utilized to obtain measurements. Test-retest reliability ($ICC_{3,1}$) with standard error of measurement (SEM) was assessed by one evaluator who was blinded to the test measurement when completing retest.

Results Forty-two participants with AIS had an age, height, and weight of 15±2 years, 164±10 cm, and 54±11 kg, respectively. Curve angle in standing was 23±11°. Maximum curve angle, T4/T5 kyphosis, and AVR twist in habitual standing satisfied criteria for individual use (ICC>0.90). AVR twist in fingers to clavicle satisfied criteria for individual use, and all measurements for hands on wall satisfied the criteria for individual use (ICC>0.90). All other parameters satisfied the criteria for research use (ICC>0.70). The range of SEM for curve angle, whole kyphosis, T4/T5 kyphosis, lordosis, and AVR twist were 3.0-4.8°, 4.0-5.1°, 3.6-5.3°, 3.9-5.6°, and 1.6-2.2°, respectively.

Conclusion 3DUS produces reliable frontal, sagittal, and transverse spinal measurements for research use in three standing positions. Additionally, the hands on wall position produces reliable measurements for clinical practice.

KEYWORDS: Scoliosis, Reproducibility of Results, Standing Position, Arm

INTRODUCTION

Scoliosis is diagnosed and monitored with radiographs that can include a standing x-ray of the entire spine looking from the back as well as sometimes from the side [2]. The potential for progression is assessed taking into consideration frontal, sagittal, and transverse radiographic parameters [74]. Historically, scoliosis imaging was obtained from a single, frontal radiographic image obtained in an upright, standing posture, but it has been shown that sagittal alignment issues are more strongly related to quality-of-life [14, 49, 62]. New low-dose radiographic systems take simultaneous frontal and sagittal images, where it is necessary to have the arms elevated to expose the whole sagittal plane of the spine and avoid the bones of the arms overlapping with vertebral bodies [52].

There are multiple measurements extracted from frontal and lateral radiographs to monitor scoliosis. Significant progression of a scoliotic curve is defined as a change in the frontal Cobb angle of five or more degrees [14]. Axial vertebral rotation (AVR) angles are defined as the degree of rotation of each vertebra [61]. AVR is one of the important parameters to evaluate the severity and predict the progression of scoliosis [75]. AVR Twist is measured as the difference between the average of the three most-rotated lamina to the left, and the three most-rotated lamina to the right. Sagittal views of the spine are necessary to measure parameters such as kyphosis and lordosis. However, sagittal parameters like lordosis and kyphosis can be over or under-estimated due to the natural sway of the human body [49] and with varying arm elevation positions [1].

Spinal alignment can be quantified repetitively using non-invasive 3D ultrasound (3DUS) imaging to propose the most accurate arm elevated position to standardize radiograph acquisitions. Using 3DUS offers a safer, risk-free, method for comparing many positions in a short time compared to x-rays [75–79]. Intra-rater reliability for curve angles obtained using 3DUS has been very good ($ICC_{(2,1)}$=0.86-0.96) with a low standard error of measurement (1.3 to 2.5°)[80, 81]. Curve angles measured on US images are valid representations of radiographs with an inter-method error of only 3.3° [81]. US kyphosis and lordosis measurements have also been found reliable [82]. There is a need to document the test-retest reliability of 3DUS measurements in common positions used during radiography in addition to habitual standing.

OBJECTIVE

This study aimed to determine the test-retest reliability of maximum Cobb angle, AVR twist, kyphosis, and lordosis measurements from 3DUS images obtained from participants with AIS taken in three different standing positions. The minimum accepted level of reliability for individual and group comparison in research are 0.90 and 0.70, respectively [83]. I hypothesized that the test-retest reliability of the 3DUS measurements investigated to reach an adequate reliability coefficient estimate for research and individual inferences.

METHODS

Study Design

This was a within-session test-retest study comparing the reliability of measurements obtained from 3DUS images.

Participants

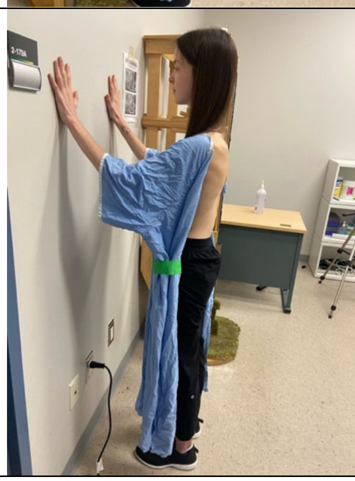
Females and males with AIS treated non-operatively were consecutively recruited from a specialized scoliosis clinic in Edmonton, Canada, as well as mail-out letters. Inclusion criteria included: able to stand unassisted for over five minutes, aged 10 to 18 years old, treated non-operatively, and with curve angles >10°. All patients having had spine or torso surgery, trauma, lower extremity conditions affecting posture, upper extremity conditions limiting movements or wounds affecting the back were excluded. All participants 18 years of age provided a signed informed consent. Participants under the age of 18 provided assent and a signed parental consent was obtained. This project was approved by the Health and Research Ethics Board at the University of Alberta (PRO00111881).

Procedure

During a 1-hour long single assessment, participants wore a gown exposing the back. Height and weight were recorded. Levels C7 and S1 were identified and marked on the back. This study was conducted as part of a larger project in which all participants were first scanned twice using 3DUS in each of 10 standing positions in the following order: 1) habitual with arms down, 2) arms supported on bar anteriorly at 60° of shoulder flexion *(local EOS positioning)*, 3) fingers to clavicle, 4) fingers to chin, 5) fingers to zygomatic, 6) fingers to eyebrows, 7) shoulders abducted 90º hands open with thumb on shoulder, 8) hands on wall, 9) hands on block, and 10) hands unsupported. The last 4 positions listed would allow for the assessment of skeletal maturity. Following the acquisition of all 10 positions, position 1) habitual with arms down, 3) fingers to clavicle, and 8) hands on wall, were each re-scanned twice for the present test-retest study. Patients were completely reset from positioning following the test scan before the retest scan. The 3DUS equipment was re-oriented before acquiring the retest, but not completely restarted. These three positions were chosen based on current literature measuring the fingers to clavicle position most commonly, and the hands on wall position was hypothesized to be the position that represents habitual standing as well as exposes the hands. Habitual standing was chosen to retest as it is our control position. It was decided that not all standing positions were to be retested, rather, a position with arms resting, slightly raised, and fully elevated (exposing the hands) were chosen. A description of the standardized instructions for these three positions is in Table 12.

Table 12. Description of Three Standing Positions Used for Ultrasound Scans.

Position	Picture	Description
Habitual Standing		Individual stands habitually on a platform in a custom wooden frame. The frame contains probes that extend horizontally in alignment with the participant's ASIS and coracoid processes to offer stability and feedback on position. Their feet are placed inside two separate holes in the frame. The participant is encouraged to stand in a natural position with relaxed shoulders, hands dangling at their side, and looking straight forward. The evaluator confirms that the participant is not deviating anterior or posteriorly.

Fingers to Clavicle		Individual stands habitually, looking straight forward with toes shoulder-width apart touching the edge of the frame. Ensuring their shoulders are relaxed, the participant places their proximal knuckles lightly on their clavicles.
Hands on Wall		Individual stands habitually, looking straight forward with toes shoulder-width apart. The participant's feet are aligned one tile square away from the wall. Ensuring their shoulders are relaxed, the participant places their hands on the wall. The evaluator ensures the participant's wrists are above shoulder height and that their fingers are visible from behind.

3DUS Image Acquisition

The evaluator instructed participants to adopt each position by demonstrating and stating the standard instructions in Table 1. A Sonix Q+ system was used with a C5-2/60 convex curvilinear transducer. The acquisition parameters were standardized as follows: scan frequency 2.5MHz, gain 20%, reject 20, map 12, intensity 70db, framerate 32 frames per second, clarity high, power 0, and time gain compensation used oblique two linear. Depth (6-9cm to ensure visibility of the lamina) and focus (at the depth level of laminae) were set according to the participant's size. After identifying the position of C7 and S1, the whole spine scan was acquired by sliding the curvilinear US probe down along the spinous process line from C7 to S1. The acquired scan data was exported to create a 3D image file for off-line analysis using custom Matlab software (MIAS v10.3.26). The 3D volume images were obtained after the acquisition of the 2D ultrasound images registered in space by using the recorded position and orientation of the probe at the time of acquiring each image to position each pixel within the 3D volume. The

MIAS program was used to rearrange the location of each pixel in the acquired images into regular 3D spacing and using an interpolation method using neighboring pixels to distribute the signal intensities throughout the 3D volume.

Ultrasound Image Analysis

Frontal Parameters

Our custom software, MIAS, was used for all image analysis and extraction of measurements. First, the center of the lamina (COL) on the right and left side of each vertebra was manually digitized on the coronal plane image. The curve angle was found by determining the angle between the most tilted laminas above and below the apex for each curve as shown in Figure 9A. A transverse view of the lamina aided in identification by displaying the depth of the reflective surface of the lamina for verification as shown in Figure 9B. The level of the upper-end, apex, and lower-end vertebrae for all upper thoracic, thoracic, and lumbar curves was also extracted. Intra-rater reliability for curve angles obtained using 3DUS has been very good ($ICC_{(2,1)}$=0.86-0.96) with a low standard error of measurement (1.3 to 2.5^{o})[80, 81]. Curve angles measured on US images are valid representations of radiographs with an inter-method error of only 3.3^{o} [81].

Sagittal Parameters

The mid-points of the lamina of T1-T2 and T11-T12 were digitized and connected by lines in the sagittal view to form a whole thoracic kyphosis angle. The mid-points of the lamina of T4-T5 and T11-T12 were digitized and connected by lines in the sagittal plane to form a T4/T5 – T11/T12 kyphosis angle (Figure 10A, B). Similarly, the mid-points of the lamina of L1-L2 and L4-L5 were connected by lines in the sagittal view to form a lordosis angle. On images without a T1 level completely visualized or substantial motion artifacts were evident, the T2-T3 pair was used to calculate the whole kyphosis curve angle. The number of instances where the T2-T3 pair was used varied: habitual standing test/retest (10/11), fingers to clavicles test/retest (15/8), and hands on wall test/retest (8/10). All L4-L5 lamina pairs were visible and used to calculate lordosis curve angles. US kyphosis and lordosis measurements have also been found reliable [82].

Transverse Parameters

AVR was automatically determined between the line going through the COLs and a horizontal reference, as shown in Figure 9B. Extraction of AVR included reading the measurement for the rotation of the vertebra directly above, at, and below the apex for all upper thoracic, thoracic, and lumbar curves. The AVR of S1 was also recorded. The AVR Twist was measured by determining the difference between the average of the 3 most-rotated lamina to the left, and of the 3 most-rotated lamina to the right. High intra-rater reliability ($ICC_{(2,1)}$>0.98, Mean absolute differences <1.2°) and accuracy (mean absolute difference vs gold standard <1.7°) was demonstrated for AVR in a cadaveric study [75]. High intra-rater reliability has also been observed in-vivo for AVR ($ICC_{(2,1)}$ >0.95, mean absolute difference <0.7±0.7°) [77].

Figure 9. Laminae, spinous process column, skin, subcutaneous fat and transverse processes in an ultrasound image: (A) coronal plane and (B) transverse plane. (L) = Left, (R) = Right

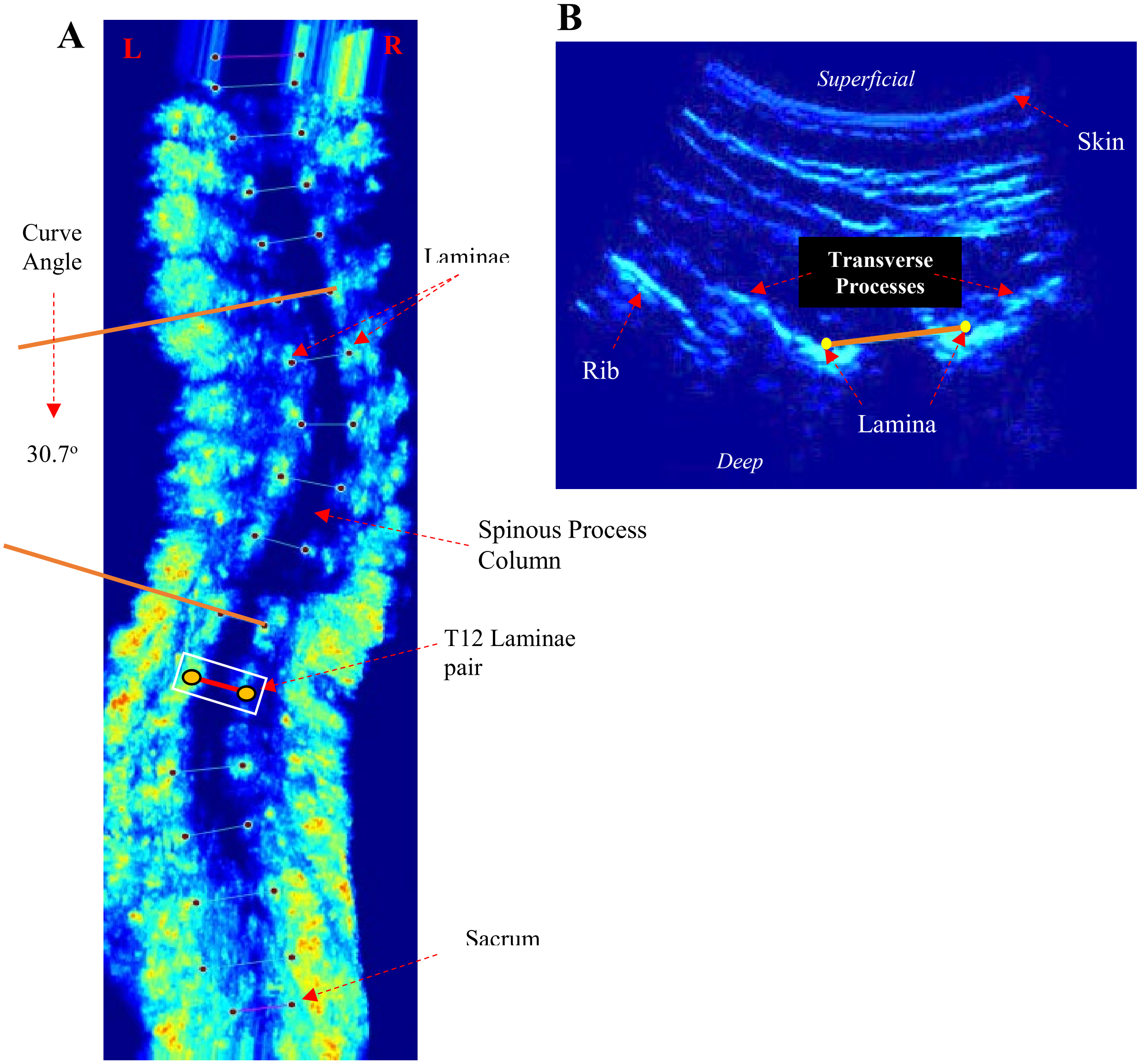
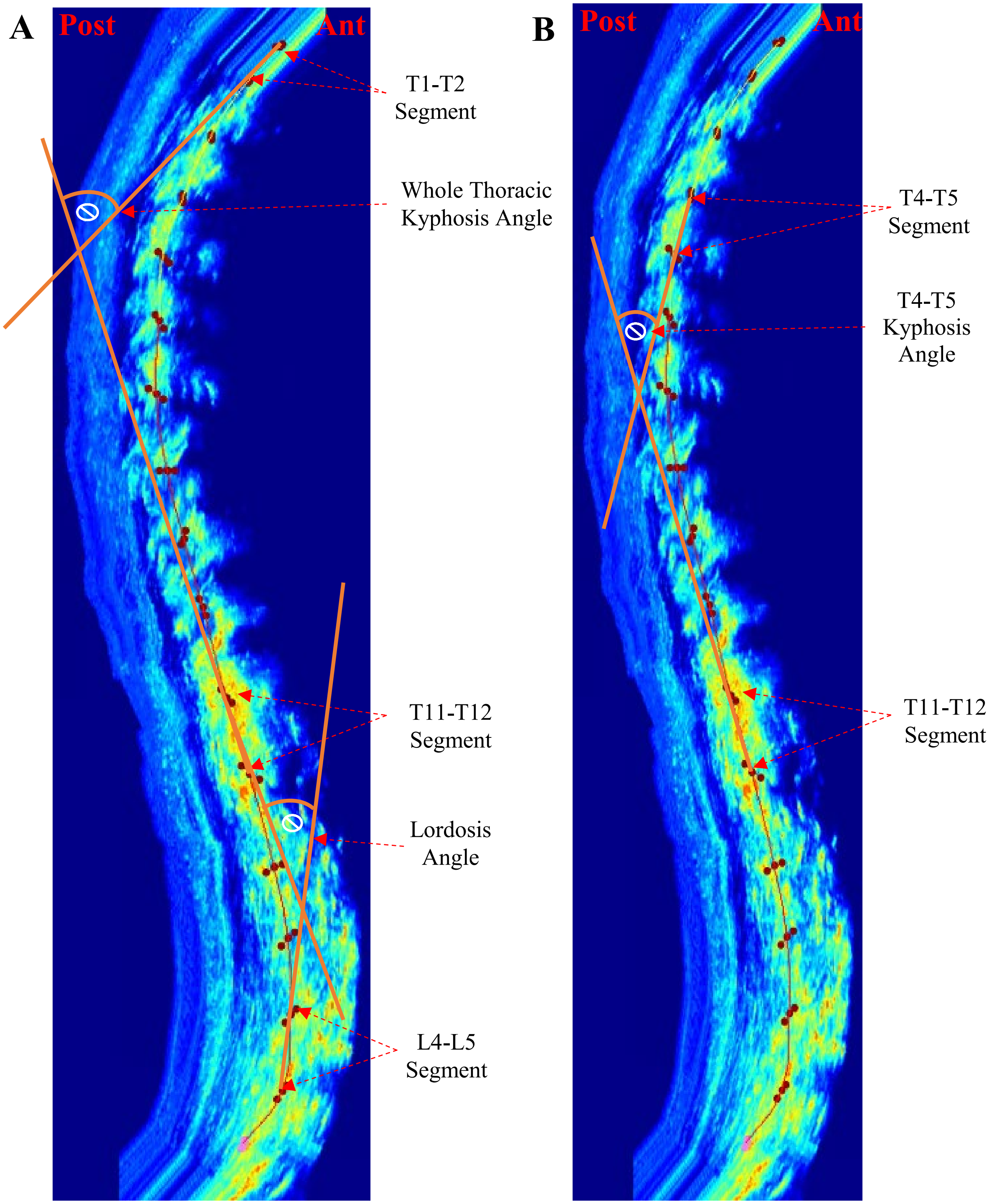


Figure 10. Sagittal curvature measurements and vertebral segments (A) whole thoracic kyphosis and lordosis angles (B) T4-T5 kyphosis angle. Ant = Anterior, Post = Posterior.



Statistical Analysis

Means and standard deviations (SD) of continuous descriptive variables as well as frequencies of categorical descriptive variables were recorded. Means and SD of test and retest values for the parameters of interest were reported. We report the intraclass correlation coefficient ($ICC_{3,1}$) with a 95% CI for test-retest reliability. We calculated the standard error of measurement (SEM) by taking the square root of the mean square residual from the ANOVA table produced during the $ICC_{3,1}$ calculation [84]. $ICC_{3,1}$ <0.9 were deemed accepted level of reliability for inferences about individual cases and >0.07 as acceptable for group comparisons in research [85]. For each reliability analysis, we reviewed a scatter plot of the test against re-test values to determine possible outliers.

Sample Size

A sample size of 43 subjects with 2 observations per subject achieves >80% power to detect an $ICC_{3,1}$ of 0.85 under the alternative hypothesis when the intraclass correlation under the null hypothesis is 0.7 (adequate for research use) using an F-test with a significance level of 0.05. This sample achieves >80% power to detect an $ICC_{3,1}$ >0.96 under the alternative hypothesis when the intraclass correlation under the null hypothesis is 0.9 (adequate for individual inference use) using an F-test with a significance level of <0.05 [86].

RESULTS

Participant Description

Thirty-four females and 10 males with AIS were included with a mean age, height, and weight of 15±2 years, 164±10 cm, and 54±11 kg, respectively. One male was excluded due to presenting with hyper-kyphosis (>65°) and maximum curve of <10°. Twenty-one patients presented with a single-curve pattern and 22 patients presented with a double-curve pattern. The mean maximum curve angle in standing for all curve types was 22±11°. For all curve types in habitual standing, the mean maximum AVR twist angle was 15±8°, whole thoracic kyphosis was 43±12°, T4-T5 kyphosis was 30±11° and lordosis angle was 28±14°.

Test-Retest Reliability Analysis

Test and retest means and SD for positions are reported in Table 13. The mean maximum curve angles for our participants among all positions falls within mild scoliosis ranges (<25º) [13]. Mean whole thoracic kyphosis was slightly higher than normal ranges as stated by the SRS Radiographic Measurement Manual (10-40º), and mean lordosis angles presented slightly smaller than normal ranges (40-60º or ~30º more than the kyphosis angle) [61]. Mean AVR twist angles are understandably much higher than normal ranges, due to the rotation of the spine characterising patients with AIS.

Maximum Curve Angle

Both habitual standing and hands on wall had a test-retest $ICC_{3,1}$ above the threshold of 0.90 (Table 14). Fingers to clavicle presented an $ICC_{3,1}$ of 0.82, satisfying the criteria for research use. SEM for habitual standing, fingers to clavicle, and hands on wall are presented in Table 14 and did not exceed 5º.

Sagittal Parameters (Whole Thoracic and T4/T5 Kyphosis, Lordosis)

For whole thoracic kyphosis and lordosis, hands on wall was the only position with an $ICC_{3,1}$ above the threshold of 0.90 (Table 14). Habitual standing and fingers to clavicle presented $ICC_{3,1}$ of ≥0.87, satisfying the criteria for research use. Both habitual standing and hands on wall T4/T5 kyphosis measurements had ICCs satisfying the threshold for individual use. Further, fingers to clavicle satisfied the threshold for research use with an $ICC_{3,1}$ of 0.83. SEM for parameters and corresponding positions are presented in Table 14 and were ≤5.6º.

AVR Twist

All three positions satisfied the criteria for individual use with $ICC_{3,1}$ ≥0.91. Habitual standing AVR twist was the highest $ICC_{3,1}$ recorded among all parameters and positions at 0.96. AVR measurements presented the smallest range of SEM values (≤2.2º) (Table 14).

Table 13. Test and Retest Means and Standard Deviation for Maximum Curve Angle, Whole Thoracic Kyphosis, T4/T5 Kyphosis, Lordosis, and AVR Twist in Images Obtained in Three Standing Arm Positions.

	Maximum Curve Angle		**Whole Thoracic Kyphosis**		**T4/T5 – T11/T12 Kyphosis**		**Lordosis**		**AVR Twist**	
	Test Means ± SD (degree)	**Retest Means ± SD (degree)**	**Test Means ± SD (degree)**	**Retest Means ± SD (degree)**	**Test Means ± SD (degree)**	**Retest Means ± SD (degree)**	**Test Means ± SD (degree)**	**Retest Means ± SD (degree)**	**Test Means ± SD (degree)**	**Retest Means ± SD (degree)**
Habitual Standing	23±11	21±11	43±12	43±12	30±11	28±13	28±14	29±15	15±8	16±8
Fingers to Clavicle	19±11	19±12	42±14	42±14	28±13	26±12	30±16	28±14	15±7	15±8
Hands on Wall	18±13	19±11	38±24	39±13	26±13	27±13	29±16	29±14	16±8	15±8

AVR, Axial Vertebral Rotation; SD, Standard Deviation

Table 14. Intraclass Correlation Coefficients of Test-retest Reliability and Standard Error of Measurement for Maximum Curve Angle, Whole Thoracic Kyphosis, T4/T5 Kyphosis, Lordosis, and AVR Twist in Images Obtained in Three Standing Arm Positions.

	Maximum Curve Angle		**Whole Thoracic Kyphosis**		**T4/T5 – T11/T12 Kyphosis**		**Lordosis**		**AVR Twist**	
	$ICC_{3,1}$ (95% CI)	**SEM (degree)**	**$ICC_{3,1}$ (95% CI)**	**SEM (degree)**	**$ICC_{3,1}$ (95% CI)**	**SEM (degree)**	**$ICC_{3,1}$ (95% CI)**	**SEM (degree)**	**$ICC_{3,1}$ (95% CI)**	**SEM (degree)**
Habitual Standing	0.92 (0.87-0.96)	3.0	0.88 (0.79-0.93)	4.2	0.90 (0.83-0.95)	3.7	0.88 (0.78-0.93)	5.1	0.96 (0.92-0.98)	1.6
Fingers to Clavicle	0.82 (0.70-0.90)	4.8	0.88 (078-0.93)	5.1	0.83 (0.70-0.90)	5.3	0.87 (0.77-0.93)	5.6	0.91 (0.84-0.95)	2.2
Hands on Wall	0.92 (0.84-0.96)	3.5	0.91 (0.84-0.96)	4.0	0.92 (0.85-0.96)	3.6	0.93 (0.87-0.97)	3.9	0.94 (0.88-0.97)	2.0

AVR, Axial Vertebral Rotation; CI, Confidence Interval; ICC, Intraclass Correlation Coefficient; SEM, Standard Error of Measurement

DISCUSSION

This study showed that frontal and sagittal 3DUS imaging measurements have adequate test-retest reliability for use in research and for individual use in some positions. Further, for all positions, transverse spinal parameters demonstrated adequate test-retest reliability for use with individual patients with AIS. Most notably, the fingers to clavicle position produced the lowest overall ICCs for all parameters of interest, as well as the largest range of SEM among the positions tested. Although our ICCs did not reach the threshold for individual use for some positions when using frontal or sagittal parameters, the SEM estimates remained smaller than the clinically accepted error range [87]. Maximum curve angle SEM range was lower than the clinically accepted five-degree threshold, as well as the 8-degree threshold for kyphosis and lordosis [79, 87, 88].

The fingers to clavicle position is one of the most common positions used clinically [1]. Although all measurements in this position met the threshold for research use, ideally, this position would produce clinically acceptable results for use with individual, being able to use 3DUS as a safe alternative to radiograph imaging. There are solutions to increase the reliability of measurements in such positions in the future. 3DUS commonly produces artifacts during imaging that affect image analysis if the patient remains unstable. Our study used a wooden probe to remind patients where they are to be standing, but this was only used when patients were deemed unstable or distracted during imaging. More consistent external feedback from technicians, as well as consistently using probes for standardized and still patient imaging could increase the quality of 3DUS image acquisition. Similarly, adequate experience of the technician using 3DUS may be an important factor in the quality of images collected. It was noted that the imaging results of an experienced US technician were less effected by motion artifacts and better visualization of the vertebrae when compared to novice scanners. Lastly, the evaluator in this study was given a checklist of landmarks to identify during image analysis to remain consistent over time. Clearly defined rules for analysis largely benefit accuracy of measurements, but for parameters using the T1-T2 lamina, these landmarks are not always clearly seen on the 3DUS image. Most commonly, T1 was not always consistently captured clearly in the image, forcing the rater to use T2-T3 as the upper-end landmarks for this parameter. Consistently ensuring all vertebrae are captured in the image is key for the reliability of all spinal measurements, but most notably, sagittal parameters. Large standard deviations among our test and retest means for all positions show high variability within our sample and, therefore, increasing the generalizability of our findings (Table 13). Lastly, the incoming use of artificial intelligence could allow quickly extracting and averaging results from multiple image acquisitions thereby increasing the reliability [89].

Research assessing the reliability of 3DUS imaging measurements on patients with AIS is limited, but studies have shown high intra- and inter-rater reliability, and high accuracy with low average mean absolute difference for lateral curvature and AVR measurements compared to corresponding radiographic measurements [75, 77, 81, 90, 91]. Similar to this study, the current literature reports good test-retest reliability of AVR measurements in patients with AIS, indicating this may be the most reliable parameter when measured using 3DUS [77, 92]. Current literature seldom reports on the reliability of common patient positioning used for radiographs. Positions not yet reported on are shown in Table 11. One study has shown high intra- and inter-rater reliability of coronal balance and apical vertebral translation measurements acquired from 3DUS imaging in patients with AIS across 10 standing positions with $ICC_{2,1}$ thresholds above the clinically accepted 0.90 [93]. Likewise, the literature does not report on the effect of different curve types on 3DUS measurement reliability. Further research is needed with a larger sample size and including different curve type groups. Additionally, it may be beneficial to investigate whether or not our findings can be generalizable to all patients with AIS by including a larger male sample.

This study provided adequate power overall to test against relevant statistically and clinically significant thresholds. Additionally, the evaluator in this study was given standardized procedures for 3DUS image acquisition and digitizing, creating precise and reliable images for data analysis. The evaluator was similarly blinded to the measurements of the test images when completing retest image analysis, allowing us to draw conclusions about truthful test-retest reliability. Although the sample size provided us with sufficient power to draw significant conclusions, it would be beneficial to test differences between curve type and possible sex differences when using 3DUS imaging. Most of the 3DUS images we acquired were stable with scarce artifacts effecting data analysis, but more consistent use of our stabilizing chest probe could have limited artifacts that were seen to effect some images. It may be important for future research testing the reliability of 3DUS measurements to use consistent stabilizing techniques as well as stratify the sample into groups to determine possible effects of curve type and sex differences.

3DUS measurements provides adequate test-retest reliability from a radiation-free alternative to radiographic imaging for research use. Although this research adds to the increasing level of evidence around the validation of 3DUS in clinical practice, some frontal and sagittal measurements from the 3DUS imaging method needs subtle improvement depending on the acquisition position, with the suggestions mentioned formerly, if it is to be used clinically in patients with AIS. Nevertheless, our findings show that AVR measurements obtained from 3DUS in three common standing positions can reliably be used in clinical practice for patients with AIS.

CHAPTER 5 – The Effect of Arm Positions Used During Radiography on Spinal Alignment Parameters Assessed by 3D Ultrasound Imaging in Adolescents with Idiopathic Scoliosis

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ABSTRACT

Purpose Clinicians monitor scoliosis progression using multiple radiographs during growth. During imaging, the arms must be elevated to visualize all vertebrae, possibly affecting sagittal spinal parameters. This study aimed to determine the arm position that best represents habitual standing (as well as allowing hand-based skeletal maturity assessment) used during simultaneous frontal and lateral radiographs measured using frontal, sagittal, and transverse angles.
Methods Non-scoliotic females and females and males with Adolescent Idiopathic Scoliosis (AIS) were recruited consecutively. Using 3D Ultrasound imaging (3DUS), patients were scanned in 10 arm positions; habitual standing, arms supported anteriorly at 60º flexion, fingers to clavicle, chin, zygomatic, and eyebrows, arms abducted 90º, hands on wall, on blocks, and hands unsupported. Axial vertebral rotation (AVR) differences, frontal, and sagittal curve angles were measure using custom software. Repeated measures ANOVAs with Sidak post-hoc tests compared positions.
Results Ninety females with and without AIS with mean age, height, and weight of 17±4years, 162±6cm, and 55±10kg, and ten males with AIS with mean age height, and weight of 16±3 years, 174±11 cm, and 63±13 kg, respectively, were included. Female AIS single-curve showed larger curves in standing in all positions excluding hands on blocks ($p>0.05$). Sagittal parameters showed decreases in kyphosis in arms abducted 90º and increases in lordosis in fingers to cheeks/eyebrows ($p>0.05$). AVR twist was not significantly affected by change in position. Male AIS showed comparable results to females, but no significant differences detected.
Conclusion There is not one position that represents habitual standing for all groups. When arms are raised, decreases in max curve angle were shown in single-curve patients, and similarly, decreases in kyphosis and increases in lordosis for all groups. Most accurate positioning for all parameters is demonstrated in fingers to clavicle/chin position.

KEYWORDS
Scoliosis, Patient Positioning, Spine, Parameter, Ultrasonography

INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is a 3D structural spine disorder with a lateral curvature of over 10°, vertebral rotation, and sagittal changes that affects 2-3% of adolescents [13]. Patients with AIS receive numerous x-rays over time to establish the diagnosis and monitor curve progression. Progression of a scoliosis curve is defined as a change in the Cobb angle of five or more degrees [14]. Generally, observation is recommended for skeletally immature patients with less severe curves, whereas conservative treatments like bracing are recommended to patients with larger curves who are skeletally immature.

Frequent x-rays expose patients with AIS to harmful radiation throughout their growing years. Particularly in young children, this has been shown to increase the incidence of cancer [3]. EOS stereo-radiographic imaging decreases the dose of radiation up to 50% compared to standard spine radiographs [15]. However, the arms must be elevated when using stereo-radiographic imaging, and this can affect spinal parameters [5–12]. It is unclear which arm positions lead to sagittal measurements that are most representative of the habitual posture and whether such positions could simultaneously allow for the scoring of digital skeletal maturity. Assessment of skeletal maturity can be done using the Sanders digital Skeletal Maturity Staging System, which breaks down the fusion of the epiphyseal growth plates into 8 stages [32]. This system can be used to determine how much growth a patient with AIS has left, and thus, to infer scoliosis progression risk [32]. In general, in a patient with AIS with a Sanders' digital maturity stage (DMS) of 1-2, the risk of failure ranged from 73% (Cobb 20°) to 93% (Cobb 39°). Bracing reduced the risk to 50% and 84%, respectively. Risk was lower in DMS 3 patients, and the lowest risk of failure was noted at DMS 4 [4]. Lau et al have shown it is possible to assess digital skeletal maturity and spinal curve severity on the same images by elevating the hands above the shoulder [95]. However, it is important to ensure that arm positioning during radiography is not having significant effects on spinal alignment parameters as this could result in suboptimal management plans.

A meta-analysis was recently completed about the effect of patient positioning for scoliosis imaging showing that the most commonly used arm position for radiography, where the hands rest on the clavicle significantly decreases kyphosis, increases lordosis angles and significantly shifts the sagittal vertical axis (SVA) posteriorly [1]. Active and passive arm positions, where the arms are raised without and with support, respectively, showed non-significant decreases in kyphosis and increases in lordosis when compared to fingers to clavicle. However, similar to the clavicle position, both active and passive positions significantly shift SVA posteriorly [1]. This review also showed that sagittal spinal parameters, most notably SVA, are more prone to change when raising the arms in comparison to habitual standing measurements. Therefore, many imaging positions do not reflect habitual standing spinal parameters and may not be interchangeable. Further, many of the positions used clinically have not yet been compared and it remains unclear which arm position best represents habitual standing.

Spinal alignment can be quantified repetitively using non-invasive 3DUS imaging to propose the most accurate arm position for radiography. Using 3DUS offers a radiation-free, and reliable method for comparing many positions in a short time [75–79].

OBJECTIVES

This 3DUS study aimed to determine which arm positions that can be used to acquire simultaneous frontal and lateral radiographs best represent habitual standing posture. Parameters of interest included maximum Cobb angle, whole thoracic kyphosis, T5-T12 kyphosis, lordosis, and AVR twist. Sagittal angles were primary parameters. A secondary goal was to determine if any of the positions which would allow exposing the hands for skeletal maturity assessment while keeping arms elevated were adequate representation of the habitual standing. Finding such a position may help eliminate needing an additional x-ray to assess maturity.

I hypothesized that, by comparing 10 different standing positions using non-invasive 3DUS imaging technology;

1. I would be able to find an arm position that will allow exposing the hands for skeletal maturity assessment that does not significantly alter vertebral rotation, or any frontal or sagittal angles compared to habitual standing.
2. A larger effect would be detected on sagittal measurements compared to habitual standing as the arms are raised further above the shoulders, and,
3. The largest differences due to elevating the arms would be detected using sagittal angles compared to frontal or transverse measurements.

METHODS

Study Design

This was a cross-sectional study comparing spinal alignment between ten standing imaging positions.

Participants

Thirty non-scoliotic females, 60 females with AIS, and 10 males with AIS treated non-operatively were consecutively recruited from emailed ads, a specialized scoliosis clinic in Edmonton, Canada, and mail-out letters. Thirty females with AIS had single curves and 30 had double curves. Inclusion criteria for non-scoliotic participants included: able to stand unassisted for over five minutes, aged over 10 years old and with no evidence of scoliosis (curve angles <10°). Inclusion for both female and male AIS groups included: able to stand unassisted for over five minutes, aged 10 to 18 years old, treated non-operatively, and with curve angles >10°. All patients having had spine or torso surgery, trauma, lower extremity conditions affecting posture, upper extremity conditions limiting movements or wounds affecting the back were excluded. All participants 18 years of age provided a signed informed consent. Participants under the age of 18 provided assent and a signed parental consent was obtained. This project was approved by the Health Research and Ethics Board at the University of Alberta (PRO00111881).

Procedure

During a 1-hour long single assessment, participants wore a gown exposing the back. Height and weight were recorded. Levels C7 and S1 were identified and marked on the back. All participants were scanned twice using 3DUS in each of 10 standing positions in the following order: 1) habitual with arms down, 2) arms supported on bar anteriorly at 60° of shoulder flexion *(local EOS positioning)*, 3) fingers to clavicles, 4) fingers to chin, 5) fingers to zygomatic, 6) fingers to eyebrows, 7) shoulders abducted 90° hands open with thumb on shoulder, 8) hands on wall, 9) hands on block, and 10) hands unsupported. In positions 8-10 hands are above the shoulders. A description of positions is shown in Table 15. Each scan took 20-30 seconds. The last four positions listed would allow for the assessment of digital skeletal maturity.

3DUS Image Acquisition

The evaluator instructed participants to adopt each position by demonstrating and stating the standard instructions in Table 15. A Sonix Q+ system was used with a C5-2/60 convex curvilinear transducer. The acquisition parameters were standardized as follows: scan frequency 2.5MHz, gain 20%, reject 20, map 12, intensity 70db, frame rate 32 frames per second, clarity high, power 0, and time gain compensation used oblique two linear. Depth (6-9cm to ensure visibility of the lamina) and focus (at the depth level of laminae) were set according to the participant's size. The acquired scan was exported to create a 3D image file for off-line analysis using custom Matlab software (MIAS v10.3.26). The 3D volume images were obtained after the acquisition of the 2D ultrasound images registered in space by using the recorded position and orientation of the probe at the time of acquiring each image to position each pixel within the 3D volume. The MIAS program was used to rearrange the location of each pixel in the acquired images into regular 3D spacing and using an interpolation method using neighboring pixels to distribute the signal intensities throughout the 3D volume. Intra-rater reliability for curve angles obtained using 3DUS has been very good ($ICC_{(2,1)}$=0.86-0.96) with a low standard error of measurement (1.3 to 2.5^{o}) [80, 81]. Curve angles measured on US images are valid representations of radiographs with an inter-method error of only 3.3^{o} [81]. US kyphosis and lordosis measurements have also been found reliable [82]. After identifying the position of C7 and S1 the whole spine scan was acquired by sliding the curvilinear US probe down along the spinous process line from C7 to S1.

Table 15. Patient position and corresponding description for 10 positions used for 3DUS scans.

Position	Picture	Description
Habitual Standing		Participant stood naturally in a custom-built wooden frame. The feet were positioned in the holes of the frame. The probes of the frame were aligned at the level of the ASIS and the coracoid processes. Participants were standing in a natural position, not leaning forwards or backwards, looking straight ahead, with relaxed shoulders, and with arms dangling naturally at their side.
Arms supported at 60º flexion		Using the inclinometer iPhone app, an assistant ensured the arms were placed at 60º on the bar. The phone was placed on the outside of the arm for measurement. Both arms were checked and adjusted accordingly. We adjusted the position using the frame ASIS bar height as needed. Participants were standing in their natural position, not leaning forwards or backwards, looking straight ahead, toes to the edge of frame, with a stance shoulder width apart, with relaxed shoulders and arms slightly supported on bar. *Note: 60° from the body = 30° from the horizontal

Fingers to clavicle		Participant was standing in their natural position, not leaning forwards or backwards, looking straight ahead, toes to the edge of frame, with feet shoulder width apart, with relaxed shoulders, with the proximal knuckles slightly touching the clavicle.
Fingers to chin		Participant was standing in their natural position, not leaning forwards or backwards, looking straight ahead, toes to the edge of frame, with feet shoulder width apart, with relaxed shoulders, and knuckles slightly touching their chin.
Fingers to cheeks		Participant was standing in their natural position, not leaning forwards or backwards, looking straight ahead, with toes to the edge of frame, feet shoulder width apart, with relaxed shoulders, and knuckles slightly touching their cheekbones.

Fingers to eyebrows		Participant was standing in their natural position, not leaning forwards or backwards, looking straight ahead, with toes to the edge of frame, feet shoulder width apart, with relaxed shoulders, and knuckles slightly touching their eyebrows.
Arms abducted 90º		Participant was standing in their natural position, not leaning forwards or backwards, looking straight ahead, toes to the edge of frame, stance shoulder width apart, with relaxed shoulders. They brought their thumbs to touch the shoulders and touched the ears with the tips of their fingers. Participant's fingers were spread.
Hands on wall		The participant was standing in their natural position, not leaning forwards or backwards, looking straight ahead, feet were placed one tile square away from the wall, stance shoulder width apart, with relaxed shoulders. They placed their hands on the wall with wrists placed slightly higher than the height of their shoulders (evaluator was able to see wrists above the shoulder when behind the participant). Their fingers were visible beside the head.

Hands on blocks		The participant was standing in their natural position, not leaning forwards or backwards, looking straight ahead, feet were placed one tile square away from the wall, stance shoulder width apart, and with relaxed shoulders. They placed their hands on the blocks with wrists slightly higher than the height of their shoulders (evaluator was able to see wrists above the shoulder when standing behind the participant). Their fingers were visible beside the head. *Note: Lightly holding the blocks in place, not pushing the blocks into the wall.
Hands unsupported		The participant was standing in their natural position, not leaning forwards or backwards, looking straight ahead, feet were placed one square away from the wall, stance shoulder width apart, and with relaxed shoulders. Their hands were elevated and unsupported with wrists exposed to the evaluator. The thumbs were lightly contacting the cheekbones, fingers spread out, and fingers were visible beside the head.

Ultrasound Image Analysis and Extraction

Frontal Parameters

Our custom software, MIAS, was used for all image analysis and extraction of measurements. First, the center of the lamina (COL) on the right and left side of each vertebra was manually digitized on the coronal plane image. The curve angle was found by determining the angle between the most tilted laminas above and below the apex for each curve as shown in Figure 9A. A transverse view of the lamina aided in identification by displaying the depth of the reflective surface of the lamina for verification as shown in Figure 9B. The curve angle (if any) was found by determining the angle between the most tilted laminas above and below the apex for each curve. The level of the upper, apex, and lower-end vertebrae for all upper thoracic, thoracic, and lumbar curves was also extracted.

Transverse Parameters

AVR was automatically determined between the line going through the COLs and a horizontal reference, as shown in Figure 9B. Extraction of AVR included reading the measurement for all upper thoracic, thoracic, and lumbar vertebral levels by measuring the rotation of the vertebra directly above, at, and below the apex for all curves. The AVR of S1 was also recorded. The AVR Twist was measured by determining the difference between the average of the 3 most-rotated lamina to the left, and the 3 most-rotated lamina to the right. High intra-rater reliability (ICC>0.98, Mean absolute differences <1.2°) and accuracy (mean absolute difference vs gold standard (<1.7°) was demonstrated for AVR in a cadaveric study [75]. High intra-rater reliability has also been observed in-vivo for AVR ($ICC_{(2,1)}$ >0.95, mean absolute difference <0.7±0.7°) [77].

Sagittal Parameters

The mid-points of the lamina of T1-T2 and T11-T12 were digitized and connected via a line in the sagittal view to form a whole thoracic kyphosis angle. The mid-points of the lamina of T4-T5 and T11-T12 were digitized and connected by lines in the sagittal plane to form a T4/T5 – T11/T12 kyphosis angle (Figure 10A, B). Similarly, the mid-points of the lamina of L1-L2 and L4-L5 were connected by lines in the sagittal view to form a lordosis angle. On images without a T1 level completely visualized or in which substantial motion artifacts were evident, the T2-T3 pair was used to calculate whole kyphosis curve angle. The number of instances where the T2-T3 pair was used varied: habitual standing (10 instances), arms supported at 60° (7), fingers to clavicles (14), fingers to chin (11), fingers to zygomatic (11), fingers to eyebrows (10), shoulders abducted 90° (10), hands on wall (11), hands on block (9), and hands unsupported (15). A complete L5 COL line was present in all images.

Statistical Analysis

Means and standard deviations (SD) of continuous descriptive variables as well as frequencies of categorical descriptive variables were recorded. Separate mixed-model ANOVAs compared the effect of the 10 arm positions and the three female groups (non-scoliotic, and scoliosis with single or double curves) on the AVR twist, frontal, and sagittal angles. Sidak post-hoc pairwise comparisons were used to compare each arm position against the habitual standing position. Separate repeated measures ANOVA were used to explore the comparison of the effect of the 10 positions in the male participants. Pairwise comparisons for group by position interaction were examined for statistical significance by determining if the means of the position fall within the 95% CI of other positions. If the mean fell outside of the 95% CI, the affect was considered significant. Statistical significance level was set to 0.05.

Sample Size

Ninety participants divided equally among three groups and tested in 10 different positions achieves a power of 80% using a 5% level of significance to detect a moderate effect size (effect size f = 0.107) for the effect of positions, assuming a conservative correlation between repeated measures (r>0.5). For this study, a sample of 90 participants divided in 3 groups also achieves 80% power to detect a mean difference of 5 degrees, with a known standard deviation of differences of 7 degrees with a significance level of 0.005 adjusted for multiple comparisons between each position and habitual standing. The ten males were added to explore whether the results differ from females and to inform future studies, if needed.

FEMALE RESULTS

Participant Description

- Non-scoliotic Females

Thirty females were included with a mean age, height, and weight of 21±4 years, 164±5 cm, and 61±10 kg, respectively. In standing, their mean maximum curve angle was 1±3°, maximum AVR twist was 8±3°, whole thoracic kyphosis was 41±12°, and lordosis was 26±12°.

- o Females with AIS

Sixty females with AIS were included with a mean age, height, and weight of 14±2 years, 161±7 cm, and 52±8 kg, respectively. Thirty patients presented a single-curve pattern and 30 presented a double curve pattern. A summary of the spinal alignment measured in each group in habitual standing is reported hereafter. The mean maximum curve angle was 22±13° for single and

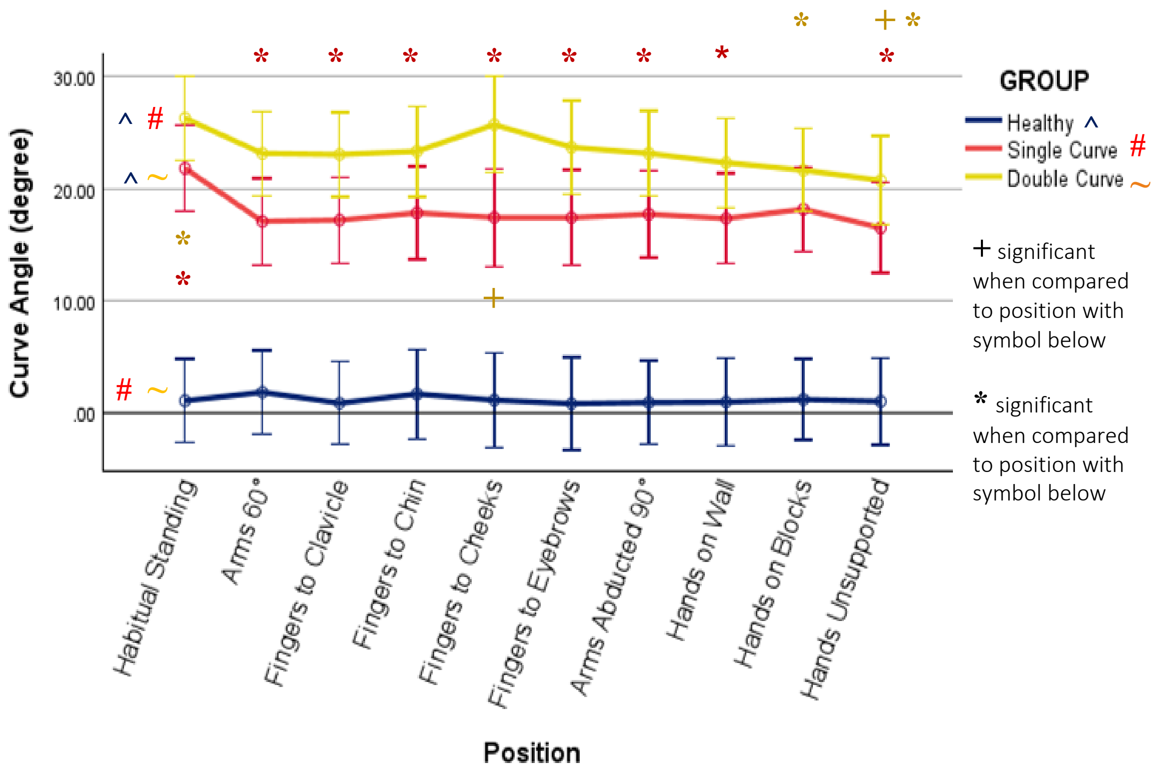
26±11° for double curves. Mean maximum AVR twist was 16±8° for single and 23±8° for double curves. Mean whole thoracic kyphosis was 42±10° for single and 38±13° for double curves, while mean lordosis was 28±12° for single and 26±15° for double curves, respectively.

Comparisons Among Positions

- Curve Angle

The mixed-model ANOVA revealed a significant group by position interaction (p=0.032), a significant effect of positions (p<0.001), and a signficant between-groups effect (p<0.001), shown in Figure 11. For each of the positions, non-scoliotic curves were always significantly smaller than the single and double curve groups. All positions, with the exception of hands on blocks, were significantly smaller in the single curve group compared to the double curves group (Mean difference (MD) range 4.2-8.3°). The non-scoliotic group showed no significant differences among positions. The single curve group showed significantly larger curves in habitual standing compared to all other positions(3.6-4.7°) with the exception of hands on blocks. The double curve group showed significantly larger curve angles in habitual standing than the hands on blocks(MD 4.6°) and hands unsupported(5.5°) positions. Additionally, fingers to cheeks was significantly larger than hands unsupported(5.0°) in the double curve group (Figure 11).

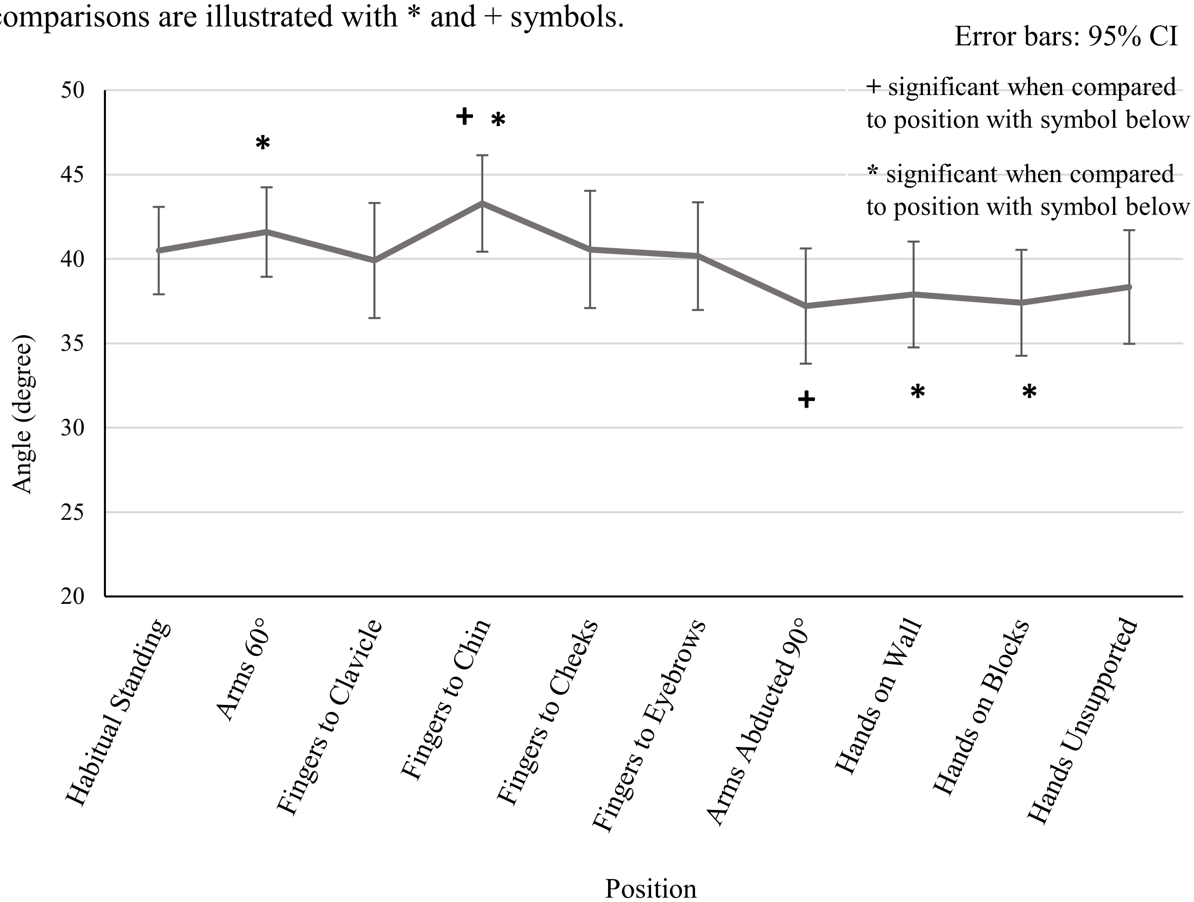
Figure 11. Effect of positions on mean maximum curve angle. All groups differed from one another. Significant interaction pairwise differences are illustrated with * and + symbols. Significant group differences illustrated with ^, #, ~ symbols.



- Whole Thoracic Kyphosis

There was no significant interaction between group and position (p=0.187) and no signficant effect between groups (p=0.321). Overall, there was a statistically significant effect of positions (p<0.001). Kyphosis was significantly smaller in hands on wall and hands on blocks compared to arms 60º(-3.7º,-4.2º, respectively), and fingers to chin(-5.4º,-5.9º, respectively). Kyphosis in fingers to chin was also significantly larger than in arms abducted 90º(6.1º), as shown in Figure 12. The position least comparable to standing was arms abducted 90º, but kyphosis was only 3.3º smaller.

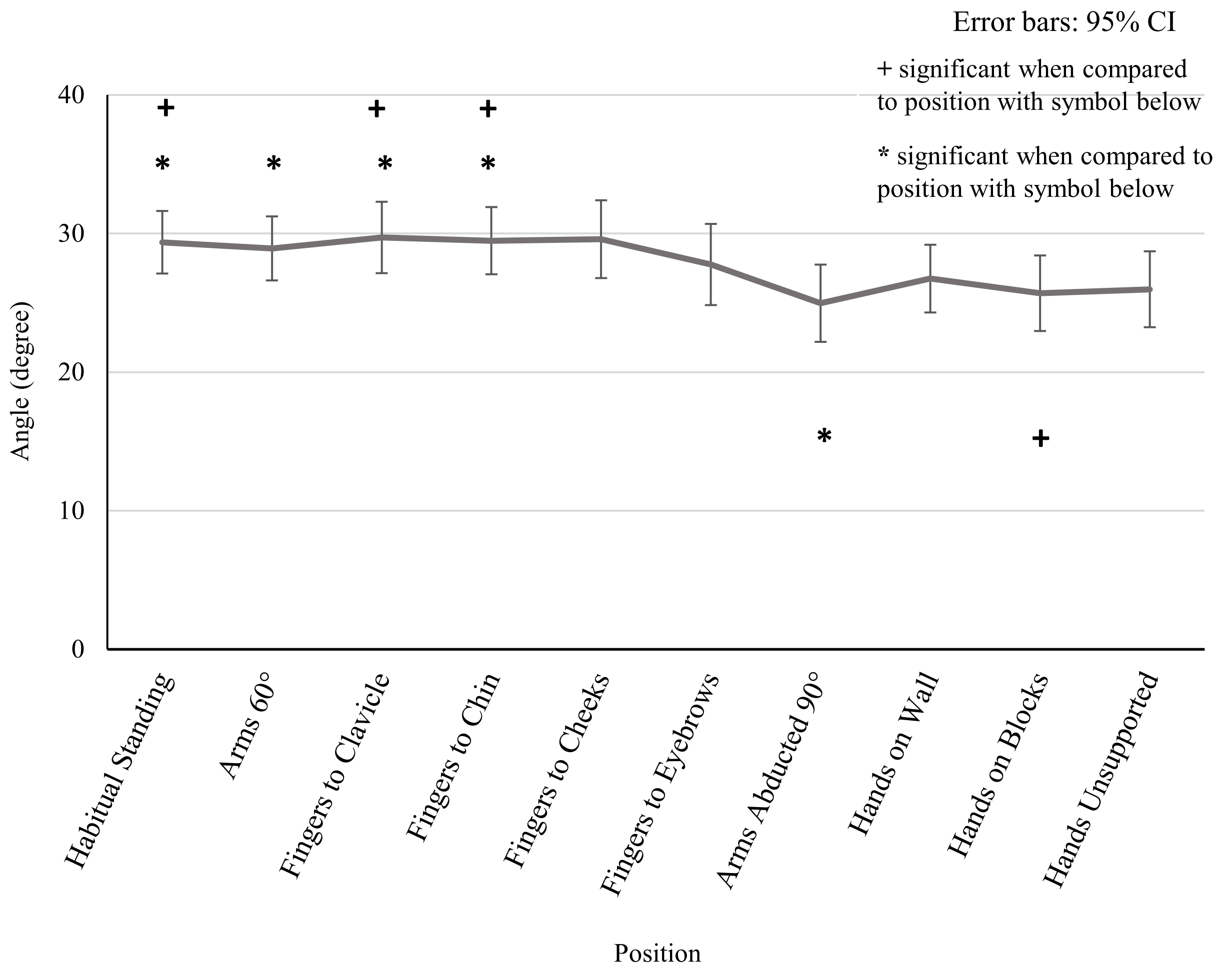
Figure 12. Effect of 10 positions on mean whole thoracic kyphosis. Significant pairwise comparisons are illustrated with * and + symbols.



- T4/T5-T11/T12 Kyphosis

There was no significant group by position interaction (p=0.71) and no signficant between-groups effect (p=0.126). There was a statistically significant effect of positions (p<0.001). Arms abducted 90º and hands on blocks were both significantly smaller than habitual standing(-4.4º,-3.7º, respectively), fingers to clavicle(-4.7º,-4.0º), and fingers to chin(-4.5º,-3.8º). Arms abducted 90º was additionally significantly smaller than arms 60º(-4.0º) as shown in Figure 13. The position least comparable to standing and smaller by 4.4º was arms abducted 90º.

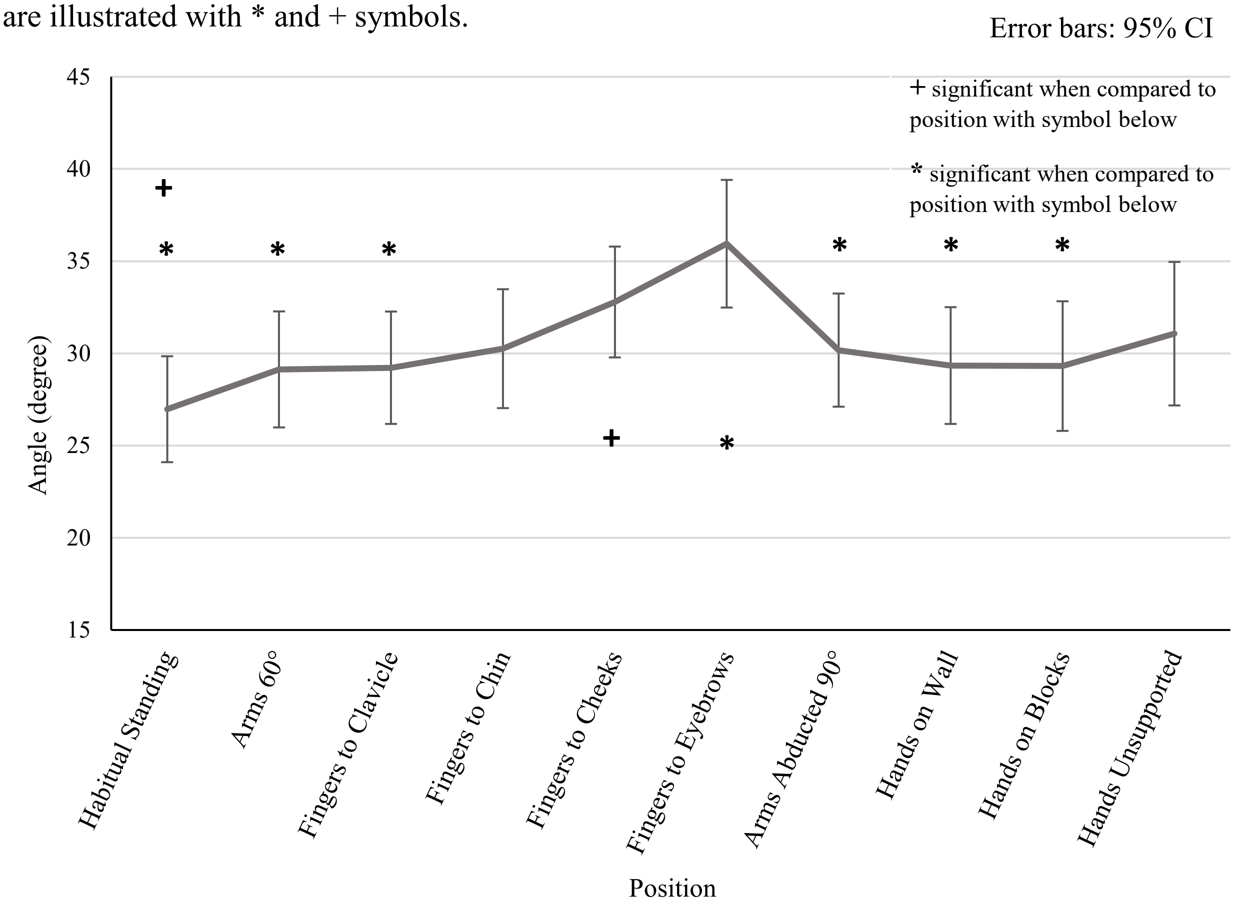
Figure 13. Effect of 10 positions on mean T4/T5 kyphosis angles. Significant pairwise comparisons are illustrated with * and + symbols.



- Lordosis

There was no significant group by position interaction (p=0.397) and no signficant between-groups effect (p=0.407). There was a statstically significant effect of positions (p<0.001). Fingers to eyebrows was significantly larger than habitual standing(9.0º), arms 60º(6.8º), fingers to clavicle(6.7º), arms abducted 90º(5.8º), hands on wall(6.6º), and hands on blocks(6.6º). as shown in Figure 14. Lordosis in fingers to cheeks was also found significantly larger than in habitual standing(5.8º).

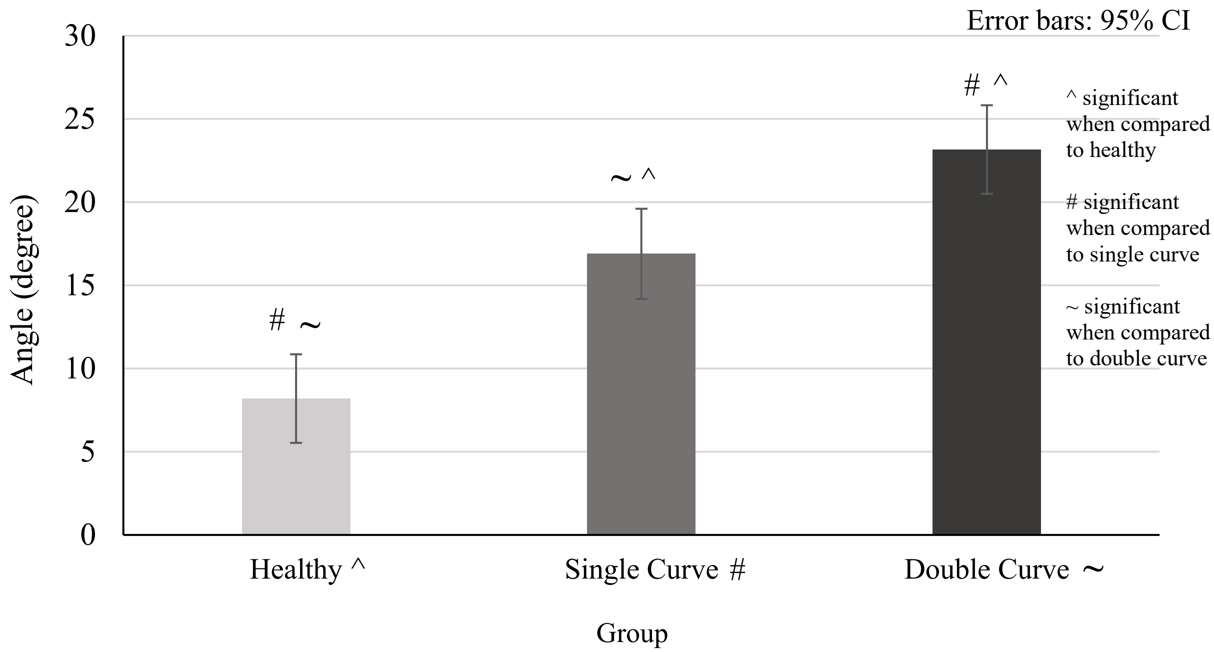
Figure 14. Effect of 10 arm positions on mean lordosis angles. Significant pairwise comparisons are illustrated with * and + symbols.



- AVR Twist

There was no significant group by position interaction (p=0.525) and no significant effect of positions (p=0.288). There was a statistically significant between-group effect (p<0.001) with all groups presenting different AVR twist from each other. Non-scoliotic was significantly smaller than the single curve and double curve groups(-8.7, -15.0, respectively). Further, the single-curve group had significantly smaller AVR twist than the double curve group(-6.3°) as shown in Figure 15.

Figure 15. Effect of 10 arm positions on mean AVR twist between groups. Significant group comparisons are illustrated with ^,#,~ symbols.



MALE RESULTS

Participant Description

Ten males with AIS were included with a mean age, height, and weight of 16±3 years, 174±11 cm, and 63±13 kg, respectively. One participant was excluded for presenting with hyper-kyphosis (>65°). Six males presented with single curves, and three presented with double curves. In standing, mean maximum curve angle was 21±12°, AVR twist was 18±10°, whole thoracic kyphosis was 51±14°, T4/T5 kyphosis was 31±17°, and lordosis was 38±10°.

Comparisons Among Positions

In males, no significant differences were found between positions for the curve angles, sagittal parameters and the AVR twist. The position least comparable to standing for curve angles was hands on blocks showing 7.1° larger. The position most comparable to standing was hands unsupported(3.0°). The positions with a curve angle mean difference of >5° were hands on blocks (7.1°) and arms abducted 90° (6.5°), as shown in Figure 16. For both whole thoracic and T4/T5 kyphosis, the position least comparable to standing was arms abducted 90°(by 18.1°, 10.2°, respectively). All positions with the exception of fingers to clavicle, chin, and cheeks had whole thoracic and T4/T5 kyphosis MDs >5° compared to habitual standing. Additionally, T4/T5 kyphosis MD for hands unsupported was <5º compared to standing. For lordosis, the position least comparable to standing was hands on blocks(7.7º). The positions with MDs >5º were arms 60º (10.8º), fingers to cheeks (-5.2º), hands on blocks (7.7º), and hands unsupported (6.0º). The position most comparable to standing for both whole thoracic and T4/T5 kyphosis was fingers to cheeks(0.5º, 1.0º, respectively) while for lordosis it was arms abducted 90º(0.7º). The effect of position on all sagittal parameters is shown in Figure 17. The position least comparable to standing for AVR twist was arms abducted 90º(1.6º) while the position most comparable to standing was fingers to eyebrows(0.1º), as shown in Figure 18. None of the positions had MDs >5º for AVR twist when compared to standing.

Figure 16. Effect of 10 arm positions on mean maximum curve angle.

Error bars: 95% CI

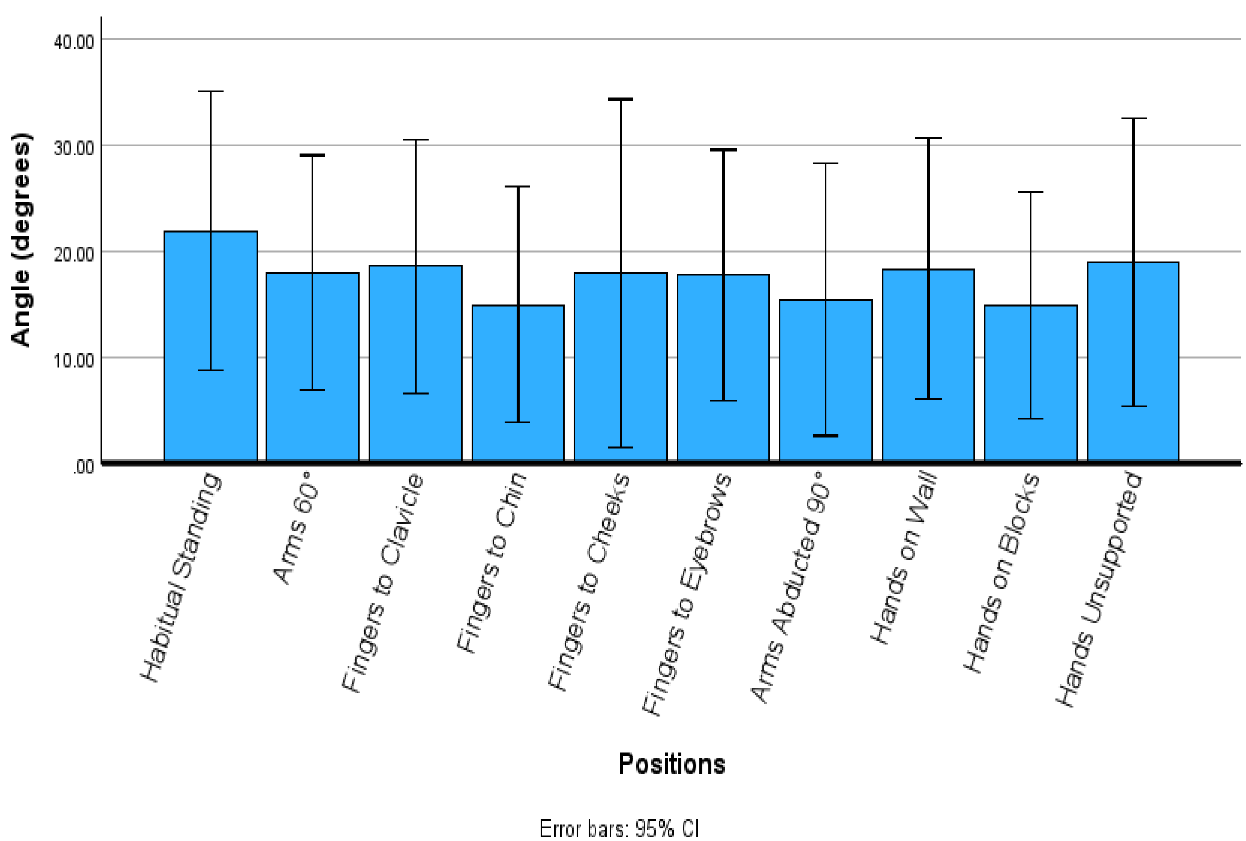


Figure 17. Effect of 10 arm positions on mean sagittal parameters (whole kyphosis, T4/T5 kyphosis, lordosis).

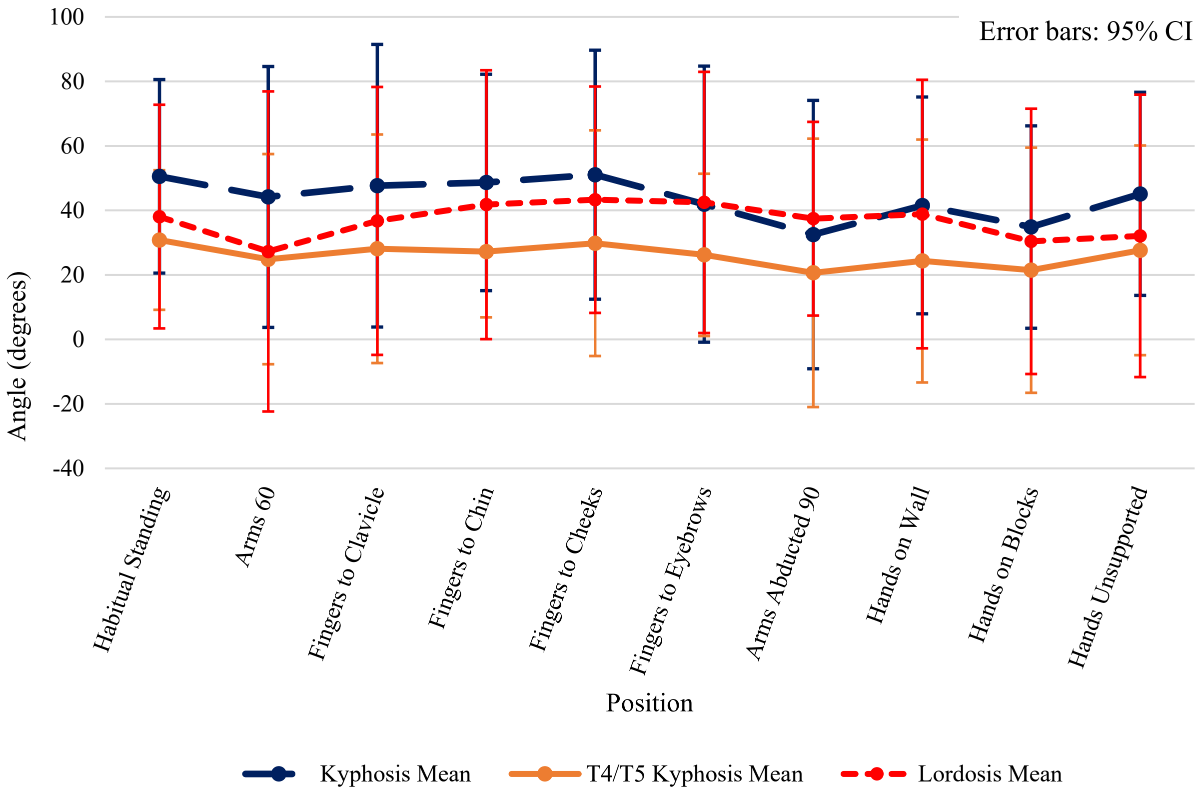
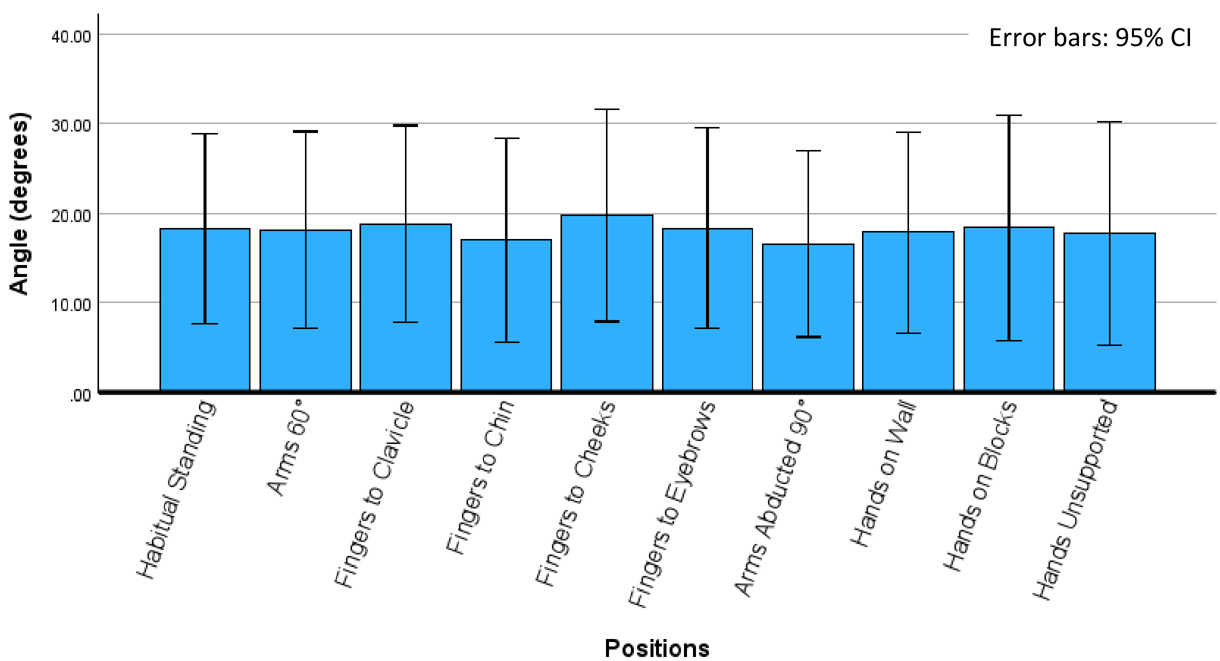


Figure 18. Effect of 10 arm positions on mean AVR twist angle.



DISCUSSION

The results of this study showed that there is not a particular position that is comparable to habitual standing for both groups of females with AIS with single and double curve. When the hands were raised above the shoulders and unsupported, there was an increase in lordosis angles, but no significant decreases in kyphosis. Notably, there were significant decreases in maximum curve angle with raising the arms, more important in the group with single curve. This may have implications in detection and management of scoliosis.

While our male sample was small and did not show any significant changes in spinal parameters, both sexes showed the largest decrease compared to habitual standing in both kyphosis parameters when positioned with the arms abducted 90º. Although not statistically significant, the male group similarly demonstrated decreases in kyphosis and increases in lordosis as the arms were raised anteriorly. The results for both sexes partially support our hypothesis that the arms raised above the shoulders would lead to the largest effects on sagittal parameters. In addition, our hypothesis did not anticipate our finding of considerable effects on frontal spinal parameters, nor did I hypothesize the larger impact of arm positioning observed in the single curve group.

The current studies found in our systematic review reporting on lordosis effects have a mixture of samples, including both non-scoliotic, children, adults, and AIS populations [1]. None of the prior literature including AIS participants separated the sample based on curve type. However, meta-analysis of the literature showed there were significant increases in lordosis and decreases in kyphosis when comparing the clavicle position to habitual standing [1]. The meta-analysis results differ from the present study which did not detect any significant effects on lordosis or kyphosis when comparing these two positions. Pasha et al. reported a significant decrease in both whole thoracic and T4/T5 kyphosis when comparing the hands on wall position to the clavicle position [12] but, the present study did not find any significant differences when directly comparing these two positions for any parameters evaluated. These differing results may be because our study included more variability in curve type and were analysed separately, compared to Pasha et al., who reported 95% of 38 participants had a Lenke 1 or 3 curve type and analysed them together [12]. The sample in the Pasha et al. paper was more severely affected, with a mean thoracic curve angle of 46º, where our greatest mean maximum curve for either double or single curve groups was 26º [12]. The current literature shows that there are significant posterior shifts in sagittal vertical axis (SVA) when comparing clavicle, hands on wall, active, and passive positions to standing, as well as comparing active and hands on wall to clavicle, and active compared to passive positions [8, 10, 12, 50, 51]. This shows that these positions may not be comparable to habitual standing, nor interchangeable. The present study did not assess changes in SVA for any position as this measurement has not yet been validated when using 3DUS.

The literature is limited and there is only one prior study to date that evaluated a position that would expose the hands for skeletal maturity [12]. Similarly, the studies reviewed did not evaluate all relevant parameters, such as maximum curve angle, since only two prior studies found assessed populations with AIS [10, 12]. Overall, the literature measured a limited number of parameters evaluated across a limited number of arm positions. This study aimed to fill these gaps by evaluating more arm positions (some which expose the hands for skeletal maturity) and documenting subsequent effects on a wide range of frontal, sagittal, and transverse spinal parameters.

When considering frontal spinal parameters, our study showed that changes in maximum curve angle are dependent on both curve type and arm position. Most notably, the single curve group showed more significant decreases in maximum curve angle when changing arm position compared to the double curve group. Within the single curve group, habitual standing was most accurately and exclusively represented by the hands on blocks position. Within the double curve group, habitual standing showed to be comparable to all positions excluding hands on blocks and hands unsupported. Interestingly, hands on blocks represented habitual standing posture within the single curve group, but not within the double curve group. Overall, there is not one position that represents habitual standing for both single and double curve groups. In the double curve group, the popular fingers to cheeks position could not be used interchangeably with hands unsupported. Nevertheless, as expected, all positions showed significant differences when compared between non-scoliotic, single, and double curve groups. These results reinforce the need to consider curve type when evaluating the effect of positions, as there is very limited research separating these groups currently [1]. It is also important to separate AIS patients from non-scoliotic controls when evaluating spinal measurements and determining the effect of positions.

When analyzing sagittal parameters, the results of whole thoracic, T4/T5 kyphosis, and lordosis were analogous. None of the sagittal parameters of interest demonstrated significant interactions between groups and positions, rather, the differences were consistently noted when comparing the mean differences of positions. Arms abducted 90º showed the greatest decrease in both whole thoracic and T4/T5 kyphosis and is therefore not representative of habitual standing in both our female and male samples. Although whole thoracic kyphosis showed that habitual standing did not significantly differ from any positions, T4/T5 kyphosis did demonstrate significant decreases compared to habitual standing measurements when in arms abducted 90º and hands on blocks in females. It is important to note that the positions that raise the arms anteriorly above the shoulders (fingers to clavicle, chin, cheeks, eyebrows) markedly increased lordosis angle point estimates as the arms were raised when compared to standing in both sexes. As the arms are elevated anteriorly, the body needs to sway back to keep the center of mass over the base of support which may be detectable by changes in lordosis. The extra effect as the arms are raised higher could be due to tension building and stretching soft tissues, such as the latissimus dorsi and glenohumeral joint, which may have effects on the spine and the rib case profile.

As expected from the scoliosis condition, AVR twist justifiably showed significant increases when comparing non-scoliotic controls to both single and double curve groups. The double curve group also had significantly larger mean AVR twist measurements compared to the single curve group. None of the positions within any group had considerable effects on AVR twist in both females and males, showing this parameter is not significantly influenced by the raising of the arms.

All female results for all spinal parameters that were not statistically significant did not reach thresholds that would be considered clinically significant. Likewise, all female results that are statistically significant reached thresholds of clinical significance. Therefore, the significant results reported reflect notable differences between the positions and suggest that it is important to standardize patient positioning within and between centers over time. This demonstrates that our group sample size and power were sufficient in detecting significant effects of arm position on spinal parameters. Our male sample size was not sufficient to detect as statistically significant differences that were clinically important. All spinal parameters within the male sample did reach thresholds of clinical significance, but the group size is too small to detect these differences as statistically significant. The results of this sample were to inform future studies.

Patient comfort was not directly recorded when imaging these positions, but it was observed that positions that hold the hands above the shoulders and unsupported (arms abducted 90° and hands unsupported) were harder for patients to remain still during US imaging. Most notably, males seemed to have large amounts of discomfort when in the arms abducted 90° position. This may have implications during radiography if patients are not able to hold steady in these positions for periods of time during imaging. Overall, hands unsupported was our most unstable position when analyzing the US imaging data, showing the most motion artifacts. Hands on wall and hands on blocks were the most reliable images of the arms-raised positions, showing the least motion artifacts and clear landmarks for analysis. Being one of the most reliable 3DUS positions, hands on wall represents habitual standing in every spinal parameter with the exception of mean maximum curve angle in the single curve group.

This study compares the largest number of arm positions in the literature to date. Similarly, this study assesses the largest number of parameters across females with AIS specifically. This study is the only research to date that evaluates arm positions that specifically expose the hands that could allow for skeletal maturity assessment. Since females were predominantly included in our sample due to the larger prevalence of AIS in females and found differences between curve types, it may be hard to generalize these findings to males with AIS, a sample in which the effect of curve type was not examined [13]. The results of our small sample of male AIS shows that there needs to be similar research conducted with a larger sample size. Further, this study did not include SVA as a primary parameter of interest. Further research evaluating this parameter is needed.

Our study shows that, out of the positions evaluated, there is not one singular position that can be deemed comparable to habitual standing and therefore used during radiography in patients with AIS. Sagittal differences among the arms elevated positions also showed that a number of the positions tested are similarly not interchangeable. In future research on comparing position, it is critical to separate single and double curve groups, as there were greater effects of arm positioning on single curve angles compared to those with double curves. It is also important to separate female and male groups when conducting similar research, as our results differed between the sexes. There is not one position that exposes the hands for skeletal maturity that best represented habitual standing for all groups. Across the positions that expose the hands, hands on blocks best represents standing within the single curve group, with the exception of a significant decrease in T4/T5 kyphosis. In the double curve group, hands on wall best represented habitual standing. Although statistical significance was not always detected, arms abducted 90º was evidently one of the least comparable to habitual standing for both sexes, and it is not recommend to use this position during radiography. Similarly, it is important to note that as the arms were raised higher anteriorly (fingers to clavicle, chin, cheeks, eyebrows), lordosis angles in both sexes became less representative of habitual standing. Therefore, the positions where the arms are closer to the shoulders (fingers to clavicle, chin) produce more accurate sagittal measurements.

CHAPTER 6 – THESIS DISCUSSION/ CONCLUSION

Summary of thesis

The primary objective of this research was to standardize patient positioning for radiography by finding an arm position that raises the arms in order to visualize all key sagittal landmarks, as well as expose the hands for skeletal maturity assessment. The aim was to find an arm position(s) that represents the habitual standing maximum curve angle, whole thoracic and T4/T5 kyphosis, lordosis, and AVR angles with the use of risk-free and reliable 3DUS imaging to quantitatively evaluate the effect of different arm positions. In order to ensure the data is producing reliable and accurate data analysis, a test-retest reliability study was performed. After performing the test-retest of three arms positions (habitual standing, fingers to clavicle, hands on wall) on 43 patients with AIS, adequate ICCs for research use for maximum curve angle, whole thoracic and T4/T5 kyphosis, and lordosis were shown. All AVR twist measurements produced the most reliable ICCs, adequate for individual use. Likewise, the hands on wall position was shown to produce the most reliable results. After concluding the analysis was producing adequate results, it was able to be concluded that our comparison results among 10 positions is reliable. Before beginning any data collection, it was crucial to summarize all of the current literature on this topic in order to compare and contrast our work with existing results.

Systematic review

The systematic review synthesized all current literature on the topic. The main findings were an overall scarcity of results on this topic, most namely literature lacked analyzing patients with AIS. Among the extracted data from a total of seven relevant papers, three common arm positions (standing, fingers to clavicle, arms raised and unsupported) were meta-analyzed for kyphosis, lordosis, and SVA results. Our main findings showed:

- Significant decreases in kyphosis, increases in lordosis, and significant posterior shifts in SVA when the fingers to clavicle position was compared to standing. Significant posterior shifts in SVA were also found when comparing positions where the arms are raised and unsupported compared to fingers to clavicle.
- Spinal parameters such as AVR and maximum curve angle were seldom recorded, only found in one study,

- The current literature did not report on positions that expose the hands for skeletal maturity assessment.
- From the literature review, it remained unclear which arm position best represents habitual standing, and if any could represent habitual standing.

Test-retest reliability

Test-retest reliability analysis of 43 patients with AIS in habitual standing, fingers to clavicle, and hands on wall was completed. Spinal measurements of interest included maximum curve angle, whole thoracic and T4/T5 kyphosis, lordosis, and AVR twist. A single evaluator performed the analysis for both the test and retest images, concluding:

- The hands on wall position yielded the most reliable images, with adequate ICCs for individual use among all parameters of interest (ICC>0.90). Fingers to clavicle produced the lowest ICC values, but ICCs were still acceptable for research use.
- All positions produced ICCs adequate for research use (ICC>0.70)
- AVR measurements from all positions showed excellent ICC calculations and the lowest SEM range (ICC>0.91, SEM<2.2)
- SEM for all parameters and positions remained smaller than the accepted clinical ranges.
- 3DUS provides a reliable alternative to radiographic imaging in patients with AIS, but improving image quality (motion artifacts, missing vertebrae), additional patient positioning reminders, and increasing evaluator experience may all be potential strategies to explore for minimizing error in US image analysis.

Our findings do not support the use of 3DUS imaging for all parameters for individual clinical inferences, however, considering the sources of error that arose in this study may inform future studies to ensure the best quality of imaging. It is suggested that future research using US imaging allows for adequate evaluator training and practice, further standardize the positioning with more landmarks to ensure there is limited forward and backward sway during images, and labelling of landmarks higher and lower than the anticipated end-point vertebrae to ensure that all key laminae are pictured.

Position comparisons

Maximum curve angle, whole thoracic and T4/T5 kyphosis, lordosis, and AVR twist were measured using 3DUS across 10 standing positions in 100 participants (30 female non-scoliotic, 30 female single-curve AIS, 30 female double-curve AIS, 10 male). Female participants were compared among subgroups (non-scoliotic, single-curve, double-curve) and males were analyzed separately to inform future research. The main findings were:

- Maximum curve angle was the sole parameter that showed a significant interaction effect between group and position. Hands on block exclusively represented habitual standing in the single-curve group, but not in the double-curve group. The single-curve group demonstrated larger effects of arm position on curve angle compared to habitual standing than the double-curve group or non-scoliotic.
- Whole thoracic, T4/T5 kyphosis, and lordosis showed significant effects of positions among all groups. Both kyphosis parameters concluded arms abducted 90º was the least representative of standing. Similarly, significant differences between positions show that not all positions can be used interchangeably when assessing kyphosis. Lordosis measurements demonstrated that fingers to eyebrows was least representative of standing. The further the arms were raised and unsupported, the greater the increase in lordosis and decrease in kyphosis angles.
- Significant differences between positions excludes the possibility of interchanging all and any positions.
- Male AIS showed similar results to the females groups, but a larger sample size and partition into single and double-curve groups is needed to detect significant differences in future research.
- There was not one exclusive position for all groups that represents habitual standing and/or exposes the hands for skeletal maturity assessment.

Previous to this research, there were only seven papers published that assessed similar parameters and positions in adolescents [1]. This paper filled in the gaps of information that was found to be missing from the current literature, including the assessment of all frontal, sagittal, and transverse spinal parameters, as well as the inclusion of both non-scoliotic and single/double-curve AIS groups. Additionally, this is the only paper to date that includes 10 positions for comparison. Increased sample size in a male group(s) is needed for future research in order to generalize these findings to the entire population. Similarly, SVA was not assessed in this paper, but has been shown to be effected by a change in arm position. Future research should correspondingly assess the effect on SVA when changing arm positions once this parameter has been validated for use with 3DUS.

Our paper differs from the meta-analysis performed among the existing literature on this topic [1]. In contrast to significant decreases in kyphosis and increases in lordosis, this paper concludes that the commonly used fingers to clavicle position remains an accurate representation of habitual standing in non-scoliotic and patients with AIS when assessing maximum curve angle, whole thoracic and T4/T5 kyphosis, lordosis, and AVR twist. Nevertheless, this paper did not assess the effect of positioning on SVA, which was shown in the literature to significantly shift posteriorly in the fingers to clavicle position [1]. This paper concluded that positions where the arms are raised and unsupported decrease kyphosis and increase lordosis angles compared to standing, which agrees with the current literature.

The clinical significance of this study is vast. First, these results will inform clinicians, radiologists, and health care centres as to which position is best to standardize AIS patients in when using stereo-radiographic imaging. Secondly, these results will inform orthotists as to which position to standardize in when scanning patients with AIS for custom-made orthoses for conservative treatment. If brace construction is inaccurate and uncomfortable for patients based on changing arm positioning during scanning, treatment outcomes may be unsuccessful. Likewise, if patients are consistently changing arm positions during imaging over the course of treatment, it may be hard to determine accurate curve degree and thus, progression over time. Lastly, allowing for the assessment of skeletal maturity via Sanders Scoring as well as Risser staging in one image by exposing the hands may limit radiation exposure to patients with AIS during low-dose imaging [96]. Correspondingly, this will allow for a more accurate prediction of skeletal growth by using both skeletal maturity assessment methods [4]. The position that exposes the hands that is most comparable to habitual standing, despite a significant decrease in curve angle in the double curve group, is hands on wall. If healthcare centres use consistent positioning during imaging for all patients, this position may still be a practical option clinically. Having more accurate radiographic imaging for patients with AIS can additionally provide more accurate treatment recommendations. If spinal parameters are being over and/or under-estimated due to an inconsistency in patient positioning during imaging, this could lead to incorrect treatment plans and less than ideal outcomes for patients. By extension, more accurate imaging can better inform clinicians of treatment plans for patients with AIS and furthermore, better patient outcomes.

Limitations

The systematic review search conducted in this paper, as previously mentioned, was specific to adolescent populations and limited to standing positions. By eliminating adult populations and sitting or lying positions, this limited the results in our library search. Although adolescent populations are most affected by scoliosis and treatment decisions are determined during these ages, it may still be important for future research to determine if current literature reports if adult populations with idiopathic scoliosis behave similarly to those with AIS.

As mentioned previously, our 3DUS arm comparisons study only obtained a total of ten males for sample. Although the intention was to inform future research, the results in this section cannot be interpreted as generalizations towards all males with AIS. This small sample size limited power and limited our ability to detect clinically important significant effects within this group. This small sample may also have increased the possible influence of outliers in our results. Future studies may wish to recruit a larger male sample.

Although using 3DUS provides a risk-free alternative to radiographs, data collection of a single image cannot provide sufficient test-retest reliability results for clinical inferences for maximum curve angle, whole thoracic kyphosis, T4/T5 kyphosis, and lordosis. Our reliability study shows that all of our results are, in fact, adequate for research use, but measurements taken using US are still influenced by the US operator/evaluator, scanning environment, and patient positioning. Future works may choose to focus on ways to further standardize these conditions as research towards using 3DUS progresses. Additionally, it would be beneficial to add a larger sample with groups to evaluate reliability differences on curve types and sexes.

Our sample included patients with AIS, and although all patients are considered adolescent by definition, this group considers patients who are still developmentally immature compared to those who are older within the same age classification. When considering muscle strength in a patient with AIS who is 10 years old compared to 18 years old, there could be considerable differences in biomechanical compensation when raising the arms due to the lack of muscle strength in younger ages. Assessing compensatory mechanisms in younger ages as a confounding factor when changing arm positions could be important in future research when comparing a large range of ages in those with AIS.

Future research directions

Our systematic review showed that the current literature relevant to this topic demonstrated significant effects on SVA compared to habitual standing when changing arm positions. As previously mentioned, further research on arm positioning and the effect on SVA in multiple positions using 3DUS should be quantified. The male sample in this paper was too small to detect significant changes and was rather intended to inform future research. Although similar effects on parameters were demonstrated in this small sample, it is important to know if this information can be generalized to the entirety of the AIS population, males, and females alike. In addition to the investigation of males with AIS, these papers should similarly separate single and double-curve patients, as this research noted significant differences between curve types. Specifying the effect on upper-thoracic, thoracic, thoracolumbar, and lumbar curves on patient positioning using 3DUS is still unknown. Further research on these groups may reveal differences.

Due to our results showing conflicting effects on curve angle between single and double curve groups, it would be beneficial to include further positions that expose the hands where the arms are supported and below the shoulders that may better reflect habitual standing. Additionally, it may be important to describe in future research how different arm positions affect patient comfort and whether or not they can feasibly be held during radiographic imaging. This paper did not measure patient comfortability, but it was noted by evaluator's that the arms abducted 90^{o} was difficult for some patients to hold during the scan, most notably in males. Future design can account for patient comfort, as an uncomfortable position could affect accuracy when collecting data and furthermore, during radiographic imaging.

Since the hands on wall position produced ICCs adequate for individual use among all parameters of interest in our reliability paper, validation of frontal, sagittal, and transverse measurements could be conducted through comparisons with measurements on posterior-anterior (PA) and lateral radiographs. Similarly, AVR twist measurements can be validated comparing PA and lateral radiographs in all of the positions investigated.

Conclusion

The completion of this research project has filled in many gaps of a seldom-reported topic. This thesis has provided clinicians of many practices, patients, and educators on the effect and test-retest reliability of commonly used arm positioning during radiography on spinal parameters assessed using 3DUS. This project helped show that US image measurements in common standing positions are reliable for future research use, and possible clinical use. Although a position that exposes the hands for skeletal maturity assessment that reflects habitual standing among all groups was not found, it can be concluded that positions where the arms are raised and unsupported are least comparable to standing. Furthermore, the higher the arms are raised, the more kyphosis angles increase, and lordosis angles decrease. The hands on wall position is recommended for use during radiography in patients with AIS, as this position provided reliable 3DUS measurements, best minimizes changes in the spine when assessing all parameters, and would expose the hands for skeletal maturity assessment. Additionally, this position provides support for the arms and could best limit the use of compensatory mechanisms for patients with varying muscle strengths. Since these results concluded more significant effects on spinal parameters than were initially hypothesized, it is imperative for healthcare centers who utilize low-dose stereo radiographic systems to work towards a consensus and work at minimising variability in positioning within and across all centers.

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APPENDICES

Appendix A: Search Strategies

Appendix A.1. CINHAL Search Strategy.

Search Terms	
S1	idiopathic scoliosis
S2	(MH "Spinal Curvatures+")
S3	spin* disorder or spin* deform*
S4	S1 OR S2 OR S3
S5	"Coronal alignment"
S6	"Sagittal alignment"
S7	"Cobb angle*" OR "Cobb Degree*"
S8	"Curve angle*" OR "Curvature* angle*"
S9	"Kyphosis"
S10	"Lordosis"
S11	"Rotation angle*" OR "Vertebr* rotation"
S12	"Coronal *balance*"
S13	"Decompensation"
S14	"Sagittal balance"
S15	S5 OR S6 OR S7 OR S8 OR S9 OR S10 OR S11 OR S12 OR S13 OR S14
S16	"Arm position*"
S17	(MH "Patient Positioning") OR "patient position*"
S18	(MH "Upper Extremity+") OR "Upper Limb*" OR "Upper Extremit*"

S19	"(Finger* OR hand* OR knuckle*) N3 (chin OR eye* OR forehead OR cheek* OR zygomatic OR ear* OR clavicle* OR nose)"
S20	S16 OR S17 OR S18 OR S19
S21	S4 AND S15 AND S20
S22	(MH "Diagnostic Imaging") OR (MH "Imaging, Three-Dimensional+") OR (MH "Magnetic Resonance Imaging") OR (MH "Radiography") OR (MH "Fluoroscopy") OR (MH "Radiography, Thoracic") OR (MH "Ultrasonography")
S23	Radiograph* OR fluoroscopy OR Ultrasonogr* OR Echography OR Magnetic resonance imag* OR MRI
S24	S22 OR S23
S25	S21 AND (S22 OR S23 OR S24)
S26	(MH "Cerebral Palsy") OR ""cerebral palsy""
S27	(MH "Muscular Dystrophy+") OR (MH "Myotonic Dystrophy") OR ""muscular dystrophy"" OR (MH "Muscular Dystrophy, Emery-Dreifuss") OR (MH "Muscular Dystrophy, Duchenne+") OR (MH "Becker Muscular Dystrophy") OR (MH "Muscular Dystrophy, Facioscapulohumeral") OR (MH "Muscular Dystrophy, Oculopharyngeal")
S28	(MH "Arthroplasty+") OR "arthroplasty"
S29	(MH "Marfan Syndrome") OR ""marfan syndrome""
S30	(MH "Osteogenesis Imperfecta") OR ""osteogenesis imperfecta""
S31	S26 OR S27 OR S28 OR S29 OR S30
S32	S25 NOT S31
S33	(MH "Case Studies") OR ""Case Report""
S34	S32 NOT S33

TOTAL: 59 papers
Ran: August 23, 2021

Appendix A.2. Embase Search Strategy.

Search Terms
1. Idiopathic Scoliosis.mp. or exp idiopathic scoliosis/
2. Scoliosis.mp. or exp scoliosis/
3. Spin* Disorder*.mp.
4. Spin* deform*.mp.
5. 1 or 2 or 3 or 4
6. Radiograph*.mp. or exp X ray film/ or exp radiography/
7. exp echography/ or Ultrasound Imaging.mp.
8. Fluoroscopy.mp. or exp fluoroscopy/
9. exp nuclear magnetic resonance imaging/ or Standing MRI.mp.
10. 6 or 7 or 8 or 9
11. 5 and 10
12. Coronal alignment.mp.
13. Sagittal alignment.mp.
14. exp Cobb angle/ or Cobb Angle*.mp.
15. Curve angle*.mp.
16. exp kyphosis/ or Kyphosis angle*.mp.
17. exp rotation/ or Rotation angle*.mp.
18. exp lordosis/ or Lordosis angle*.mp.
19. Coronal balance.mp.
20. Decompensation.mp.
21. Sagittal balance.mp.
22. 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21
23. exp patient positioning/ or Arm positioning.mp.
24. exp body position/ or Position*.mp.

25. Upper Extremity.mp. or exp upper limb/
26. 23 or 24
27. 25 and 26
28. ((Finger* or hand* or knuckle*) adj2 (chin or eye* or forehead or cheek* or zygomatic or ear* or clavicle* or nose)).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword, floating subheading word, candidate term word]
29. 23 or 24 or 27 or 28
30. 5 and 10 and 22 and 29
31. Cerebral palsy.ti. or exp cerebral palsy/
32. exp progressive muscular dystrophy/ or exp myotonic dystrophy protein kinase/ or exp facioscapulohumeral muscular dystrophy/ or Dystrophy.ti. or exp muscular dystrophy/ or exp Fukuyama congenital muscular dystrophy/ or exp Duchenne muscular dystrophy/ or exp Becker muscular dystrophy/ or exp myotonic dystrophy/ or exp Emery Dreifuss muscular dystrophy/ or exp dystrophy/
33. exp arthroplasty/ or Arthroplasty.ti.
34. Marfan syndrome.ti. or exp Marfan syndrome/
35. 31 or 32 or 33 or 34
36. 30 not 35
37. limit 36 to (human and english language)
38. Osteogenesis imperfecta.ti. or exp osteogenesis imperfecta/
39. 37 not 38
40. Case Report.mp. or exp case report/
41. 39 not 40
Total: 316 papers
Ran: August 19, 2021

Appendix A.3. Web of Science Search Strategy.

Search Terms
1. Idiopathic scoliosis (Topic)
2. Spinal Curvatures (Topic)

3. TS=(Scoliosis OR "Spin* deform*" Or "spin* disorder*")
4. #1 OR #2 OR #3
5. TS=(Radiograph* OR Fluoroscopy OR Ultrasonogr* OR Echography or Magnetic resonance imaging OR MRI OR EOS Imaging)
6. TS=(Three-Dimensional Imaging)
7. TS=(nuclear magnetic resonance imaging)
8. #5 OR #6 OR #7
9. #4 AND #8
10. TS=(Coronal Alignment OR Sagittal alignment)
11. TS=(Cobb angle*)
12. TS=(Curve angle*)
13. TS=(Kyphosis OR Lordosis)
14. TS=(Kyphosis angle* OR Lordosis angle*)
15. TS=(Rotation angle*)
16. TS=(Vertebr* rotation)
17. TS=(Postural Balance OR Coronal Balance or Sagittal Balance)
18. TS=(Decompensation)
19. #10 OR #11 OR #12 OR #13 OR #14 OR #15 OR #16 OR #17 OR #18
20. TS=(Arm position*)
21. TS=(Body position)
22. TS=(Patient Positioning)
23. TS=(Upper limb OR Upper Extremity)
24. TS=((Finger* or hand* or knuckle*) NEAR/2 (chin or eye* or forehead or cheek* or zygomatic or ear* or clavicle* or nose))
25. #20 OR #21 OR #22 OR #23 OR #24
26. #9 AND #19 AND #25
27. TS=(Cerebral Palsy)
28. TS=(Muscular dystrophy OR progressive muscular dystrophy OR myotonic dystrophy protein kinase or facioscapulohumeral muscular dystrophy OR Dystrophy OR Fukuyama congenital muscular dystrophy OR Duchenne muscular dystrophy OR Becker

muscular dystrophy OR myotonic dystrophy OR Emery Dreifuss muscular dystrophy OR dystrophy)
29. TS=(Osteogenesis imperfecta)
30. TS=(Marfan Syndrome)
31. TS=(Arthroplasty)
32. #27 Or #28 OR #29 OR #30 OR #31
33. #26 NOT #32
34. TS=(Case report)
35. #33 NOT #34
Total: 747 papers
Ran: August 24, 2021

Appendix B: Consent Documents

Appendix B.1. Consent Form for Healthy Participants who are >18 years old.

UNIVERSITY OF
ALBERTA

Department of Physical Therapy
Faculty of Rehabilitation Medicine

2-50 Corbett Hall
Edmonton, Alberta, Canada T6G 2G4
Tel: 780.492.5983
Fax: 780.492.4429

HEALTHY PARTICIPANT CONSENT FORM

<u>Title of Study:</u> 3DUS Examination of the Effect of Arm Position on the Spine Alignment

Principal Investigator: University of Alberta
Eric Parent, *PT, M.Sc., Ph.D.* 780 492 8889

Research/Study Coordinator(s):
Brianna Fehr, *B.Sc., M.Sc.* 780 248 1857
Kathleen Shearer coordinator 780 993 6224

Why am I being asked to take part in this research study?

You are being asked to participate in this research study because we are looking for the most effective way to produce accurate spine images for adolescents with scoliosis using 3D Ultrasound technology. Using 3D Ultrasound as opposed to an X-ray for diagnostic imaging eliminates the risk of exposure to radiation. By participating in this study, we will be able to determine the arm position needed in diagnostic imaging that will best depict the habitual standing posture, as well as expose the hands in order to determine skeletal maturity. Volunteers will be asked to perform 10 different arm positions in a random order, while a research assistant will use ultrasound to record the spinal alignment for each position. 60 female volunteers with idiopathic scoliosis will participate in this study, as well as 30 female healthy control participants.

What is the reason for doing the study?
The goal of this study is to:

1. To determine which postures used to acquire simultaneous frontal and lateral spine images best represent habitual standing posture as measured using the angle of vertebral rotation (AVR), frontal and sagittal curve angles; and
2. To identify whether any of the arm positions presents habitual spine alignment and could allow skeletal maturity assessment.

What will I be asked to do?
Physical Exam:

You will be asked to take part in a 1.5-hour long ultrasound imaging appointment, where you will first answer some questions about your age. We will measure your height and weight. We will then describe 10 different arm positions that must be performed in a random order. These positions include: 1) habitual with arms down, 2) arms supported on bar anteriorly at 60-degree flexion (local EOS positioning), 3) fingers to clavicles, 4) fingers to chin, 5) fingers to zygomatic (cheek bone), 6) fingers to eyebrows, 7) arms abducted 90-degrees, hands open with thumb on shoulder, 8) hands on wall, 9) hands on block, 10) hands unsupported. In 8-10 hands are above the shoulders. The scan for each position will take 20-30 seconds each. You will change into a hospital gown in order to expose the back for imaging. For this exam, the evaluator will apply gel over your back and follow your spine with the scanning probe. 3D Ultrasound imaging exams will be done in the Clinical Science Building in room 2-164. The Ultrasound imaging allows to measure your spine alignment without radiation.

Covid-19 procedures:

Due to the nature of this study, the ability to maintain 2m or more of physical distance is not possible. As such, all visits will be conducted with several additional measures in place. Prior to arriving at the lab, both researchers and research participants will need to pass the Covid-19 screening tool provided by the Government of Alberta and Alberta Health Services. Participants will be asked to wash their hands prior to entering the lab, and hand sanitizer will be available in the lab itself. Researchers will be wearing masks, face shields and gowns for the duration of the visit where physical distancing measures cannot be maintained. Participants will need to wear a mask throughout the entirety of the visit. The research lab and all equipment will be cleaned and disinfected regularly after patient visits.

What are the risks and discomforts?

The test procedures are non-invasive. There are no known short and long term risks associated with the use of ultrasound imaging. In very rare cases, a participant may feel lightheaded or dizzy during testing. In this situation, we will pause the session and take a break until you feel comfortable enough to proceed, if you wish to do so. We will actively communicate with you during the session to ensure you are feeling well and safe. Participation will not affect your treatment. You may feel fatigue from doing the testing and they can ask for a rest at any time. It is not possible to know all of the risks that may happen in a study, but the researchers have taken all reasonable safeguards to minimize any known risks to a study participant. If anything warrants attention the appropriate procedures will be followed.

Covid-19: You will have an increased risk to Covid-19 as it will not be possible to maintain 2 meters or more of physical distancing throughout your appointment. We have put in place several protocols as mandated by the Government of Alberta and the University of Alberta to help keep you safe during the physical exam.

What are the benefits to me?

We will know which arm position best leads to the correct imaging of your spine. However, you may not get any immediate benefit from being in this research study.

This study may help people with scoliosis in the future. We will find out which position of the arms during spine imaging will most accurately show their curve, as well as expose their hands to determine skeletal maturity.

Do I have to take part in the study?

Being in this study is your choice. Participation is completely voluntary at all points during the study. If you decide to be in the study, you can change your mind and stop being in the study at any time. It will in no way affect the care that you are entitled to. During the study you can ask to stop at any time.

Will I be paid to be in the research?

A compensation of $10 will be provided to compensate you for the time, the travel, and parking expenses. Compensation will be provided even if you choose to withdraw partway through the exam.

Will my information be kept private?

During the study we will be collecting data about you. We will do everything we can to make sure that this data is kept private. No data relating to this study that includes your name will be released outside of the researcher’s office or published by the researchers. Sometimes, by law, we may have to release your information with your name so we cannot guarantee absolute privacy. However, we will make every legal effort to make sure that your information is kept private.

During research studies, it is important that the data we get is accurate. For this reason, your health data, including your name, may be looked at by people from the University of Alberta and the Health Research Ethics Board.

After the study is done, we will still need to securely store your health data that was collected as part of the study. At the University of Alberta, we keep data stored for a minimum of 5 years after the end of the study.

If you leave the study, we will not collect new health information, but we may need to keep the data that we have already collected. You can ask that your data be removed from our study until we complete our analysis. Simply call us or email us to ask for your data to be removed.

What if I have questions?

If you have any questions about the research now or later, please contact **Dr. Eric Parent at 780 499 8889 or Kathleen Shearer at 780 993 6224**. If you have any questions regarding your right as a research participant, you may contact the Health Research Ethics Board at 780-492-2615. This office has no affiliation with the study investigators.

Appendix B.2. Assent Form for Healthy Participants who are <18 years old.

/ UNIVERSITY OF ALBERTA

Department of Physical Therapy

Faculty of Rehabilitation Medicine

2-50 Corbett Hall Tel: 780.492.5983

Edmonton, Alberta, Canada T6G 2G4 Fax: 780.492.4429

Title of Study: 3DUS Examination of the Effect of Arm Position on the Spine Alignment

Principal Investigator:	*Eric Parent, PT, Ph.D.*	*780 492 8889*
Research/Study Coordinator(s):	*Kathleen Shearer*	*780 993 6224*
	Brianna Fehr	*587 223 5898*

What is a research study?

A research study is a way to find out new information about something. Children do not need to be in a research study if they don't want to.

Why are you being asked to be part of this research study?

You are being asked to take part in this research study because we are trying to learn more about arm positioning during imaging of the spine. We are asking you to be in the study because you have scoliosis. About 90 children will be in this study.

If you join the study what will happen to you?

You will come visit us to the lab only once. Your exam will last about 1.5 hours. We will use an ultrasound imager to scan your back during 10 tasks. You will change into comfortable exercise shorts or pants and a hospital gown, with the back open during scanning. For each scan, the examiners will apply gel on your spine and give instructions on the position. We will scan your full spine in about 20-30 seconds. We will slide a probe over your skin from the neck down to the end of the spine. During the scans you will breathe normally and try each arm position. In between each scan you will wait a few minutes while we save the images. You will feel a gentle pressure from the probe sliding over the skin during scanning.

The scanning positions include: natural with arms down, arms supported on bar at 60-degree flexion, fingers to clavicles, fingers to chin, fingers to jaw, fingers to eyebrows, arms out at 90-degrees, hands open with thumb on shoulder, hands on wall, hands on block, hands unsupported. In 8-10 hands are above shoulders.

Covid-19 procedures:
Because of the Covid-19 pandemic there is a risk of infection. During the study we cannot maintain 2m of social distance. However, we use prevention measures. All will need to pass the Covid-19 screening questions. You will be asked to wash your hands before entering the lab. Hand sanitizer will be available in the lab. Researchers will be wearing a mask, face shield, and a gown. You will need to wear a mask during your visit. The research lab and equipment will be cleaned and disinfected before and after your visit.

Will any part of the study hurt?
The imager test is safe and not painful. You may feel fatigue from doing the activities and you can ask for a rest at any time. If you do not feel well at any point during the study you can let us know and we will stop. We will only continue with the study if you want to continue.

Will the study help you?
We will know more about which arm position would be best for your future spine images.

Will the study help others?
This study might find out things that will help other children with scoliosis someday.
We will find out arm positions for others with scoliosis who need spine imaging.

What do you get for being in the study?
You and your parents will get $10 for the entire study.

Do you have to be in the study?
You do not have to be in the study. It's up to you. No one will be upset if you don't want to do this study. If you join the study, you can change your mind and stop being part of it at any time. All you have to do is tell us. It's okay, the researchers and your parents won't be upset.

What choices do you have if you say no to this study?
This study is extra, so if you don't want to do it nothing else will change.

Do your parents know about this study?
This study was explained to your parents, and they said that we could ask you if you want to be in it. You can talk this over with them before you decide.

Who will see the information collected about you?
The information collected about you during this study will be kept safely locked up. Nobody will know it except the people doing the research.
The study information about you will not be given to your parents. The researchers will not tell your friends or anyone else.

What if you have any questions?

You can ask any questions that you may have about the study. If you have a question later that you didn't think of now, either you can call or have your parents call **Dr. Eric Parent 780 492 8889 or Kathleen Shearer at 780 993 6224.**

Other information about the study.

- If you decide to be in the study, please write your name below.
- You will be given a copy of this paper to keep.

☐ Yes, I will be in this research study. ☐ No, I don't want to do this.

Child's name	Signature	Date
Person obtaining Assent	Signature	Date

Appendix B.3. Consent form for Parents of Healthy Participants <18 years old.

UNIVERSITY OF ALBERTA

Department of Physical Therapy

Faculty of Rehabilitation Medicine

2-50 Corbett Hall Tel: 780.492.5983

Edmonton, Alberta, Canada T6G 2G4 Fax: 780.492.4429

PARENTAL CONSENT FORM HEALTHY

Title of Study: 3DUS examination of the effect of arm position on the spine alignment

Principal Investigator:	*Eric Parent, PT, Ph.D.*	*780 492 8889*
Research/Study Coordinator:	*Kathleen Shearer*	*780 993 6224*
	Brianna Fehr	*780 248 1857*

Why is your child being asked to take part in this research study?

Your child is invited to participate because they have a healthy spine. The goal of this study is to test which arm position will best show a child's scoliosis during spine imaging.

We will recruit 90 participants in this study.

Before you make a decision, a researcher will go over this form with you. Please ask questions if you feel anything needs to be made clearer. You will be given a copy of this form for your records.

What is the reason for doing the study?

We have a poor understanding of how to best capture the most accurate image of the spine during imaging.

The goal of this study is to:

1. To determine which postures used to acquire simultaneous frontal and lateral spine images best represent habitual standing posture as measured using the angle of vertebral rotation (AVR), frontal and sagittal curve angles; and
2. To identify whether any of the arm positions presents habitual spine alignment and could allow skeletal maturity assessment.

This study will use safe and non-invasive ultrasound imaging testing strategy developed by our team to assess the 3D orientation of the whole spine.

What will your child be asked to do?

Your child will attend a single visit to the Scoliosis Ultrasound Imaging lab in the University of Alberta Hospital. This exam will last approximately 1.5 hour. We will begin by fully explaining the study and signing the consent document. Your child will then change into comfortable exercise shorts or pants and a hospital gown with the back open. Your child will first answer some questions about their age. We will measure your child's height and weight. Your child's spine will then be scanned 10 times as listed below. For each scan, the examiners will apply some ultrasound gel on the spine and be given instructions from a therapist on how to maintain the position. We will calibrate the ultrasound imager by touching the base of the neck and the lower end of the spine. We will then scan the full spine in about 20-30 seconds. The scan consists of sliding a probe over the skin from the neck down to the level where the spine meets with the base of the hips. During the scans your child will breathe normally. In between each scan your child will wait a few minutes while we save the images. Your child will feel a gentle pressure from the probe sliding over the skin.

The scanning positions include: 1) habitual with arms down, 2) arms supported on bar anteriorly at 60-degree flexion (local EOS positioning), 3) fingers to clavicles, 4) fingers to chin, 5) fingers to zygomatic (cheek bone), 6) fingers to eyebrows, 7) arms abducted 90-degrees, hands open with thumb on shoulder, 8) hands on wall, 9) hands on block, 10) hands unsupported. In 8-10 hands are above shoulders.

All the tests in this study are done for research only. Your child will not have to complete an EOS radiograph exam during this visit.

<u>Covid-19 procedures</u>

Due to the nature of this study, the ability to maintain 2m or more of physical distance is not possible. As such, all visits will be conducted with several additional measures in place. Prior to arriving at the lab, both researchers and research participants will need to pass the Covid-19 screening tool provided by the Government of Alberta and Alberta Health Services. Participants will be asked to wash their hands prior to entering the lab, and hand sanitizer will be available in the lab itself. Researchers will be wearing masks, face shields and gowns for the duration of the visit where physical distancing measures cannot be maintained. Participants will need to wear a mask throughout the entirety of the visit. The research lab and all equipment will be cleaned and disinfected regularly after patient visits.

What are the risks and discomforts?

The test procedures are non-invasive. There are no known short and long term risks associated with the use of ultrasound imaging. In very rare cases, a participant may feel lightheaded or dizzy during testing. In this situation, we will pause the session and take a break until your child feels comfortable enough to proceed, if they wish to do so. We will actively communicate with your child during the session to ensure they are feeling well and safe. Participation will not affect your child's treatment. Your child may feel fatigue from doing the testing and they can ask for a rest at any time. It is not possible to know all of the risks that may happen in a study, but the researchers have taken all reasonable safeguards to minimize any known risks to a study participant. If anything warrants attention the appropriate procedures will be followed.

Covid-19: Your child will have an increased risk to Covid-19 as it will not be possible to maintain 2 meters or more of physical distancing throughout your appointment. We have put in place several protocols as mandated by the Government of Alberta and the University of Alberta to help keep your child safe during the physical exam.

What are the benefits to your child?

We will know which arm position best leads to the correct imaging of a child's spine. However, your child may not get any immediate benefit from being in this research study.

This study may help other people with scoliosis in the future. We will find out which position of the arms during spine imaging will most accurately show a child's scoliosis curve, as well as expose the hands to determine skeletal maturity.

Does your child have to take part in the study?

Being in this study is your child's choice. Participation is completely voluntary at all points during the study. If your child decides to be in the study, they can change their mind and stop being in the study at any time. It will in no way affect the care that your child is entitled to. During the study your child can ask to stop at any time.

Will your child be paid for their participation in the research?

A compensation of $10 will be provided to compensate your child for the time, the travel, and parking expenses. Compensation will be provided even if your child chooses to withdraw partway through the exam.

Will your child's information be kept private?

During the study we will be collecting data about your child. We will do everything we can to make sure that this data is kept private. No data relating to this study that includes your child's name will be released outside of the researcher's office or published by the researchers. Sometimes, by law, we may have to release your child's information with your child's name so we cannot guarantee absolute privacy. However, we will make every legal effort to make sure that your child's information is kept private.

During research studies, it is important that the data we get is accurate. For this reason, your child's health data, including your child's name, may be looked at by people from the University of Alberta and the Health Research Ethics Board.

After the study is done, we will still need to securely store your child's health data that was collected as part of the study. At the University of Alberta, we keep data stored for a minimum of 5 years after the end of the study.

If you leave the study, we will not collect new health information, but we may need to keep the data that we have already collected. You can ask that your data be removed from our study until we complete our analysis. Simply call us or email us to ask for your data to be removed.

What if I or my child have questions?
If you have any questions about the research now or later, please contact **Dr. Eric Parent 780 499-8889 or Kathleen Shearer at 780 993 6224**. If you have any questions regarding your child's rights as a research participant, you may contact the Health Research Ethics Board at 780-492-2615. This office has no affiliation with the study investigators.

UNIVERSITY OF
ALBERTA

Department of Physical Therapy
Faculty of Rehabilitation Medicine

2-50 Corbett Hall
Edmonton, Alberta, Canada T6G 2G4
Tel: 780.492.5983
Fax: 780.492.4429

PARENTAL CONSENT

Title of Study: Determining the immediate effect of postural advice using 3D non-invasive Ultrasound Imaging

Principal Investigator:	*Eric Parent, PT, Ph.D.*	*780 492 8889*
Research/Study Coordinator:	*Kathleen Shearer*	*780 993 6224*
	Brianna Fehr, *B.Sc., M.Sc.*	780 248 1857

	Yes	No
Do you understand that your child has been asked to be in a research study?	☐	☐
Have you read and received a copy of the attached Information Sheet?	☐	☐
Do you understand the benefits and risks involved in taking part in this research study?	☐	☐
Have you had an opportunity to ask questions and discuss this study?	☐	☐
Do you understand that your child is free to leave the study at any time, without having to give a reason and without affecting their future care?	☐	☐

Has the issue of confidentiality and privacy been explained to you?	☐	☐
Do you understand who will have access to your child's study records?	☐	☐
Who explained this study to you? ____		

I agree for my child to take part in this study:

Signature of Research Participant's Parent _______________________________________

(Printed Name) ____

Date:_____________________________

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

This should be signed by the person who is conducting the informed consent discussion (if that is not the Investigator – the person that obtained the consent needs to sign here)

Signature of Investigator or Designee _______________________________ Date __________

THE INFORMATION SHEET MUST BE ATTACHED TO THIS CONSENT FORM AND A COPY GIVEN TO THE RESEARCH PARTICIPANT

Appendix B.4 Assent form for scoliosis participants <18 years old.

UNIVERSITY OF ALBERTA

Department of Physical Therapy
Faculty of Rehabilitation Medicine

2-50 Corbett Hall

Tel: 780.492.5983

Edmonton, Alberta, Canada T6G 2G4

Fax: 780.492.4429

Title of Study: 3DUS Examination of the Effect of Arm Position on the Spine Alignment

Principal Investigator:	Eric Parent, PT, Ph.D.	780 492 8889
Research/Study Coordinator(s):	Kathleen Shearer	780 993 6224
	Brianna Fehr	780 248 1857

What is a research study?

A research study is a way to find out new information about something. Children do not need to be in a research study if they don't want to.

Why are you being asked to be part of this research study?

You are being asked to take part in this research study because we are trying to learn more about arm positioning during imaging of the spine. We are asking you to be in the study because you have scoliosis. About 90 children will be in this study.

If you join the study what will happen to you?
You will come visit us to the lab only once. Your exam will last about 1.5 hours. We will use an ultrasound imager to scan your back during 10 tasks. You will be scanned 3 extra times during tasks you've done before. You will change into comfortable exercise shorts or pants and a hospital gown, with the back open during scanning. For each scan, the examiners will apply gel on your spine and give instructions on the position. We will scan your full spine in about 20-30 seconds. We will slide a probe over your skin from the neck down to the end of the spine. During the scans you will breathe normally and try each arm position. In between each scan you will wait a few minutes while we save the images. You will feel a gentle pressure from the probe sliding over the skin during scanning.

The scanning positions include: natural with arms down, arms supported on bar at 60-degree flexion, fingers to clavicles, fingers to chin, fingers to jaw, fingers to eyebrows, arms out at 90-degrees, hands open with thumb on shoulder, hands on wall, hands on block, hands unsupported. In 8-10 hands are above shoulders. You will be scanned 3 extra times: once in natural with arms down, once in fingers to clavicle, and once in hands on wall.

Covid-19 procedures:
Because of the Covid-19 pandemic there is a risk of infection. During the study we cannot maintain 2m of social distance. However, we use prevention measures. All will need to pass the Covid-19 screening questions. You will be asked to wash your hands before entering the lab. Hand sanitizer will be available in the lab. Researchers will be wearing a mask, face shield, and a gown. You will need to wear a mask during your visit. The research lab and equipment will be cleaned and disinfected before and after your visit.

Will any part of the study hurt?
The imager test is safe and not painful. You may feel fatigue from doing the activities and you can ask for a rest at any time. If you do not feel well at any point during the study you can let us know and we will stop. We will only continue with the study if you want to continue.

Will the study help you?
We will know more about which arm position would be best for your future spine images.

Will the study help others?
This study might find out things that will help other children with scoliosis someday.
We will find out arm positions for others with scoliosis who need spine imaging.

What do you get for being in the study?
You and your parents will get $25 for the entire study.

Do you have to be in the study?

You do not have to be in the study. It's up to you. No one will be upset if you don't want to do this study. If you join the study, you can change your mind and stop being part of it at any time. All you have to do is tell us. It's okay, the researchers and your parents won't be upset.

What choices do you have if you say no to this study?
This study is extra, so if you don't want to do it nothing else will change.

Do your parents know about this study?
This study was explained to your parents and they said that we could ask you if you want to be in it. You can talk this over with them before you decide.

Who will see the information collected about you?
The information collected about you during this study will be kept safely locked up. Nobody will know it except the people doing the research.
The study information about you will not be given to your parents. The researchers will not tell your friends or anyone else.

What if you have any questions?
You can ask any questions that you may have about the study. If you have a question later that you didn't think of now, either you can call or have your parents call Dr. Eric Parent 780 492 8889 or Kathleen Shearer at 780 993 6224.

Other information about the study.
- If you decide to be in the study, please write your name below.
- You will be given a copy of this paper to keep.

☐ Yes, I will be in this research study. ☐ No, I don't want to do this.

Child's name	Signature	Date
Person obtaining Assent	Signature	Date

Appendix B.5: Parental consent for participants <18 years old.

PARENTAL CONSENT FORM SCOLIOSIS

Title of Study: 3DUS examination of the effect of arm position on the spine alignment

Principal Investigator:	Eric Parent, PT, Ph.D.	780 492 8889
Research/Study Coordinator:	Kathleen Shearer	780 993 6224
	Brianna Fehr	780 248 1857

Why is your child being asked to take part in this research study?
Your child is invited to participate because they have scoliosis. The goal of this study is to test which arm position will best show a child's scoliosis during spine imaging.

We will recruit 90 participants in this study.

Before you make a decision, a researcher will go over this form with you. Please ask questions if you feel anything needs to be made clearer. You will be given a copy of this form for your records.

What is the reason for doing the study?
We have a poor understanding of how to best capture the most accurate image of the spine during imaging.

The goal of this study is to:
1. To determine which postures used to acquire simultaneous frontal and lateral spine images best represent habitual standing posture as measured using the angle of vertebral rotation (AVR), frontal and sagittal curve angles; and
2. To identify whether any of the arm positions presents habitual spine alignment and could allow skeletal maturity assessment.

This study will use safe and non-invasive ultrasound imaging testing strategy developed by our team to assess the 3D orientation of the whole spine.

What will your child be asked to do?
Your child will attend a single visit to the Scoliosis Ultrasound Imaging lab in the University of Alberta Hospital. This exam will last approximately 1.5 hour. We will begin by fully explaining the study and signing the consent document. Your child will then change into comfortable exercise shorts or pants and a hospital gown with the back open. You child will first answer some questions about their age and about the treatments received for their scoliosis. We will measure your child's height and weight and determine their scoliosis curve type. Your child's spine will then be scanned 10 times as listed below, and 3 of the positions listed will be re-scanned. For each scan, the examiners will apply some ultrasound gel on the spine and be given instructions from a therapist on how to maintain the position. We will calibrate the ultrasound imager by touching the base of the neck and the lower end of the spine. We will then scan the full spine in about 20-30 seconds. The scan consists of sliding a probe over the skin from the neck down to the level where the spine meets with the base of the hips. During the scans your child will breathe normally. In between each scan your child will wait a few minutes while we save the images. Your child will feel a gentle pressure from the probe sliding over the skin.

The scanning positions include: 1) habitual with arms down, 2) arms supported on bar anteriorly at 60-degree flexion (local EOS positioning), 3) fingers to clavicles, 4) fingers to chin, 5) fingers to zygomatic (cheek bone), 6) fingers to eyebrows, 7) arms abducted 90-degrees, hands open with thumb on shoulder, 8) hands on wall, 9) hands on block, 10) hands unsupported. In 8-10 hands are above shoulders. Positions 1) habitual with arms down, 3) fingers to clavicle, and 8) hands on wall, will be re-scanned following completion of the first scans.

All the tests in this study are done for research only. Your child will not have to complete an EOS radiograph exam during this visit.

Covid-19 procedures

Due to the nature of this study, the ability to maintain 2m or more of physical distance is not possible. As such, all visits will be conducted with several additional measures in place. Prior to arriving at the lab, both researchers and research participants will need to pass the Covid-19 screening tool provided by the Government of Alberta and Alberta Health Services. Participants will be asked to wash their hands prior to entering the lab, and hand sanitizer will be available in the lab itself. Researchers will be wearing masks, face shields and gowns for the duration of the visit where physical distancing measures cannot be maintained. Participants will need to wear a mask throughout the entirety of the visit. The research lab and all equipment will be cleaned and disinfected regularly after patient visits.

What are the risks and discomforts?

The test procedures are non-invasive. There are no known short and long term risks associated with the use of ultrasound imaging. In very rare cases, a participant may feel lightheaded or dizzy during testing. In this situation, we will pause the session and take a break until your child feels comfortable enough to proceed, if they wish to do so. We will actively communicate with your child during the session to ensure they are feeling well and safe. Participation will not affect your child's treatment. Your child may feel fatigue from doing the testing and they can ask for a rest at any time. It is not possible to know all of the risks that may happen in a study, but the researchers have taken all reasonable safeguards to minimize any known risks to a study participant. If anything warrants attention the appropriate procedures will be followed.

Covid-19: Your child will have an increased risk to Covid-19 as it will not be possible to maintain 2 meters or more of physical distancing throughout your appointment. We have put in place several protocols as mandated by the Government of Alberta and the University of Alberta to help keep your child safe during the physical exam.

What are the benefits to your child?

We will know which arm position best leads to the correct imaging of your child's spine. However, your child may not get any immediate benefit from being in this research study.

This study may help other people with scoliosis in the future. We will find out which position of the arms during spine imaging will most accurately show your child's curve, as well as exposing the hands to determine skeletal maturity.

Does your child have to take part in the study?

Being in this study is your child's choice. Participation is completely voluntary at all points during the study. If your child decides to be in the study, they can change their mind and stop being in the study at any time. It will in no way affect the care that your child is entitled to. During the study your child can ask to stop at any time.

Will your child be paid for their participation in the research?
A compensation of $25 will be provided to compensate your child for the time, the travel, and parking expenses. Compensation will be provided even if your child chooses to withdraw partway through the exam.

Will your child's information be kept private?
During the study we will be collecting data about your child. We will do everything we can to make sure that this data is kept private. No data relating to this study that includes your child's name will be released outside of the researcher's office or published by the researchers. Sometimes, by law, we may have to release your child's information with your child's name so we cannot guarantee absolute privacy. However, we will make every legal effort to make sure that your child's information is kept private.

During research studies, it is important that the data we get is accurate. For this reason, your child's health data, including your child's name, may be looked at by people from the University of Alberta and the Health Research Ethics Board.

After the study is done, we will still need to securely store your child's health data that was collected as part of the study. At the University of Alberta, we keep data stored for a minimum of 5 years after the end of the study.

If you leave the study, we will not collect new health information, but we may need to keep the data that we have already collected. You can ask that your data be removed from our study until we complete our analysis. Simply call us or email us to ask for your data to be removed.

What if I or my child have questions?
If you have any questions about the research now or later, please contact Dr. Eric Parent 780 499-8889 or Kathleen Shearer at 780 993 6224. If you have any questions regarding your child's rights as a research participant, you may contact the Health Research Ethics Board at 780-492-2615. This office has no affiliation with the study investigators.

UNIVERSITY OF ALBERTA

Department of Physical Therapy
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2-50 Corbett Hall

Tel: 780.492.5983

Edmonton, Alberta, Canada T6G 2G4

Fax: 780.492.4429

PARENTAL CONSENT

Title of Study: Determining the immediate effect of postural advice using 3D non-invasive Ultrasound Imaging

Principal Investigator: Eric Parent, PT, Ph.D. 780 492 8889
Research/Study Coordinator: Kathleen Shearer 780 993 6224
Brianna Fehr, B.Sc., M.Sc. 780 248 1857

	Yes	No
Do you understand that your child has been asked to be in a research study?	•	•
Have you read and received a copy of the attached Information Sheet?	•	•
Do you understand the benefits and risks involved in taking part in this research study?	•	•
Have you had an opportunity to ask questions and discuss this study?	•	•
Do you understand that your child is free to leave the study at any time, without having to give a reason and without affecting their future care?	•	•
Has the issue of confidentiality and privacy been explained to you?	•	•
Do you understand who will have access to your child's study records?	•	•

Who explained this study to you? ____

I agree for my child to take part in this study:

Signature of Research Participant's Parent

____

(Printed Name) ____

Date:________________________________

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.
This should be signed by the person who is conducting the informed consent discussion (if that is not the Investigator – the person that obtained the consent needs to sign here)
Signature of Investigator or Designee__________________________________ Date __________

THE INFORMATION SHEET MUST BE ATTACHED TO THIS CONSENT FORM AND A COPY GIVEN TO THE RESEARCH PARTICIPANT

Appendix B.6: Consent form for participants 18 years old.

PARTICIPANT CONSENT FORM SCOLIOSIS

Title of Study: 3DUS Examination of the Effect of Arm Position on the Sagittal Profile

Principal Investigator: University of Alberta
Eric Parent, PT, M.Sc., Ph.D. 780 492 8889

Research/Study Coordinator(s):
Brianna Fehr, B.Sc., M.Sc. 780 248 1857
Kathleen Shearer coordinator 780 993 6224

Why am I being asked to take part in this research study?
You are being asked to participate in this research study because we are looking for the most effective way to produce accurate spine images for adolescents with scoliosis using 3D Ultrasound technology. Using 3D Ultrasound as opposed to an X-ray for diagnostic imaging eliminates the risk of exposure to radiation. By participating in this study, we will be able to determine the arm position needed in diagnostic imaging that will best depict the habitual standing posture, as well as expose the hands in order to determine skeletal maturity. Volunteers will be asked to perform 10 different arm positions in a random order, while a research assistant will use ultrasound to record the spinal alignment for each position. 60 female volunteers with idiopathic scoliosis will participate in this study, as well as 30 female healthy control participants.

What is the reason for doing the study?
The goal of this study is to:
1. To determine which postures used to acquire simultaneous frontal and lateral spine images best represent habitual standing posture as measured using the angle of vertebral rotation (AVR), frontal and sagittal curve angles; and
2. To identify whether any of the arm positions presents habitual spine alignment and could allow skeletal maturity assessment.

What will I be asked to do?
Physical Exam:

You will be asked to take part in a 1.5-hour long ultrasound imaging appointment, where you will first answer some questions about your age and about the treatments received for your scoliosis. We will measure your height and weight and determine your scoliosis curve type. We will then describe 10 different arm positions that must be performed in a random order, and 3 of the positions listed will be re-scanned. These positions include: 1) habitual with arms down, 2) arms supported on bar anteriorly at 60-degree flexion (local EOS positioning), 3) fingers to clavicles, 4) fingers to chin, 5) fingers to zygomatic (cheek bone), 6) fingers to eyebrows, 7) arms abducted 90-degrees, hands open with thumb on shoulder, 8) hands on wall, 9) hands on block, 10) hands unsupported. In 8-10 hands are above the shoulders. Positions 1) habitual with arms down, 3) fingers to clavicle, and 8) hands on wall, will be re-scanned following completion of the first scans.The scan for each position will take 20-30 seconds each. You will change into a hospital gown in order to expose the back for imaging. For this exam, the evaluator will apply gel over your back and follow your spine with the scanning probe. 3D Ultrasound imaging exams will be done in the Clinical Science Building in room 2-164. The Ultrasound imaging replaces the radiograph to measure your scoliosis curves without radiation. You will not have to complete an EOS radiograph exam during this visit.

Covid-19 procedures:

Due to the nature of this study, the ability to maintain 2m or more of physical distance is not possible. As such, all visits will be conducted with several additional measures in place. Prior to arriving at the lab, both researchers and research participants will need to pass the Covid-19 screening tool provided by the Government of Alberta and Alberta Health Services. Participants will be asked to wash their hands prior to entering the lab, and hand sanitizer will be available in the lab itself. Researchers will be wearing masks, face shields and gowns for the duration of the visit where physical distancing measures cannot be maintained. Participants will need to wear a mask throughout the entirety of the visit. The research lab and all equipment will be cleaned and disinfected regularly after patient visits.

What are the risks and discomforts?

The test procedures are non-invasive. There are no known short and long term risks associated with the use of ultrasound imaging. In very rare cases, a participant may feel lightheaded or dizzy during testing. In this situation, we will pause the session and take a break until you feel comfortable enough to proceed, if you wish to do so. We will actively communicate with you during the session to ensure you are feeling well and safe. Participation will not affect your treatment. New positions may produce some muscle soreness like any exercise after a period without training. This is normal. The best care is to remain active and continue normal activities. You may feel fatigue from doing the testing and they can ask for a rest at any time. It is not possible to know all of the risks that may happen in a study, but the researchers have taken all reasonable safeguards to minimize any known risks to a study participant. If anything warrants attention the appropriate procedures will be followed.

Covid-19: You will have an increased risk to Covid-19 as it will not be possible to maintain 2 meters or more of physical distancing throughout your appointment. We have put in place several protocols as mandated by the Government of Alberta and the University of Alberta to help keep you safe during the physical exam.

What are the benefits to me?

We will know which arm position best leads to the correct imaging of your spine. However, you may not get any immediate benefit from being in this research study.

This study may help other people with scoliosis in the future. We will find out which position of the arms during spine imaging will most accurately show your curve, as well as exposing the hands to determine skeletal maturity.

Do I have to take part in the study?

Being in this study is your choice. Participation is completely voluntary at all points during the study. If you decide to be in the study, you can change your mind and stop being in the study at any time. It will in no way affect the care that you are entitled to. During the study you can ask to stop at any time.

Will I be paid to be in the research?
A compensation of $25 will be provided to compensate you for the time, the travel, and parking expenses. Compensation will be provided even if you choose to withdraw partway through the exam.

Will my information be kept private?
During the study we will be collecting data about you. We will do everything we can to make sure that this data is kept private. No data relating to this study that includes your name will be released outside of the researcher's office or published by the researchers. Sometimes, by law, we may have to release your information with your name so we cannot guarantee absolute privacy. However, we will make every legal effort to make sure that your information is kept private.

During research studies, it is important that the data we get is accurate. For this reason, your health data, including your name, may be looked at by people from the University of Alberta and the Health Research Ethics Board.

After the study is done, we will still need to securely store your health data that was collected as part of the study. At the University of Alberta, we keep data stored for a minimum of 5 years after the end of the study.

If you leave the study, we will not collect new health information, but we may need to keep the data that we have already collected. You can ask that your data be removed from our study until we complete our analysis. Simply call us or email us to ask for your data to be removed.

What if I have questions?
If you have any questions about the research now or later, please contact Dr. Eric Parent at 780 499 8889 or Kathleen Shearer at 780 993 6224. If you have any questions regarding your right as a research participant, you may contact the Health Research Ethics Board at 780-492-2615. This office has no affiliation with the study investigators.

UNIVERSITY OF ALBERTA

Department of Physical Therapy
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CONSENT

Principal Investigator: Eric Parent, PT, Ph.D. 780 492 8889

Research/Study Coordinator: Kathleen Shearer 780 993 6224
Brianna Fehr, B.Sc., M.Sc. 780 2481857

	Yes	No
Do you understand that you have been asked to be in a research study?	•	•
Have you read and received a copy of the attached Information Sheet?	•	•
Do you understand the benefits and risks involved in taking part in this research study?	•	•
Have you had an opportunity to ask questions and discuss this study?	•	•
Do you understand that you are free to leave the study at any time, without having to give a reason and without affecting your future care?	•	•
Has the issue of confidentiality and privacy been explained to you?	•	•
Do you understand who will have access to your study records?	•	•

Who explained this study to you? ____

I agree to take part in this study:

Signature of Research Participant ____

(Printed Name)
____

Date:______________________________

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.
This should be signed by the person who is conducting the informed consent discussion (if that is not the Investigator – the person that obtained the consent needs to sign here)
Signature of Investigator or Designee:________________________________ Date: __________

THE INFORMATION SHEET MUST BE ATTACHED TO THIS CONSENT FORM AND A COPY GIVEN TO THE RESEARCH PARTICIPANT