



# Don't forget the pelvis: accounting for pelvic rotation in the preoperative assessment of adolescent idiopathic scoliosis

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**Background:** Accurate radiographic assessment of adolescent idiopathic scoliosis (AIS) is crucial to achieving surgical correction, yet pelvic rotation may alter measurements. In Lenke Type 1/2 AIS patients, we conducted a pilot study to assess how pelvic rotation (i.e., the patient's position in the X-ray scanner) affected sagittal, coronal, and rotational measurements.

**Methods:** A retrospective, pilot study of Type 1/2 AIS patients was undertaken. Demographics and three-dimensional (3D) SterEOS imaging were obtained. Measurements were compared between two scenarios: (I) radio plane—patient's natural position in the scanner; and (II) patient plane—patient's position after correcting to the transverse plane. Sagittal, coronal, and rotational measurements were compared, including: thoracic kyphosis (TK), lumbar lordosis (LL), main thoracic (MT) and thoracolumbar/lumbar (TL-L) Cobb, and apical vertebral rotation (AVR) in the proximal thoracic (PT), MT, and TL/L regions.

**Results:** Of 15 patients, average age was 15.7 years and 67% were female. Average baseline pelvic obliquity was 4.0 mm and pelvis rotation was 5.1°. Significant differences were seen between the radio *vs.* patient plane, respectively, in the following three measurements: TK, LL, and AVR: (I) TK (T1-12: 36.5° *vs.* 32.8°,  $P=0.003$ ; T4-12: 28.4° *vs.* 22.7°,  $P<0.001$ ); (II) LL (L1-5: 46.6° *vs.* 42.8°,  $P=0.002$ ; L1-S1: 58.2° *vs.* 55.1°,  $P=0.003$ ); (III) AVR (PT-AVR: 4.0° *vs.* 8.2°,  $P=0.003$ ; MT-AVR: -14.8° *vs.* -10.5°,  $P=0.004$ ; TL/L-AVR: (4.5° *vs.* 8.7°,  $P=0.003$ ). No significant differences were seen in coronal Cobb angles.

**Conclusions:** After accounting for pelvic rotation, sagittal and rotational measurements were significantly altered. These results have implications for measurement accuracy, surgical decision-making, and postoperative monitoring.

**Keywords:** Pelvic rotation; adolescent idiopathic scoliosis; three-dimensional (3D) imaging; EOS imaging; patient plane

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## Introduction

Adolescent idiopathic scoliosis (AIS) causes three-dimensional (3D) deformity in the coronal, sagittal, and axial

planes. Although cosmetic deformities are most noticeable in the thoracic region, causing shoulder imbalance and rib asymmetry, malalignment extends down to the pelvis. The altered pelvic position in AIS can be equally concerning

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to patients and also alters gait kinematics (1,2). In order to keep the trunk centered over the pelvis, the pelvis often rotates to the convex side of the major curve (1). Anatomic studies have confirmed unequal ilium widths between the convex and concave sides in untreated AIS patients, indicating significant pelvic rotation (3,4).

Despite the 3D abnormality of AIS, preoperative assessment is restricted to the two-dimensional (2D) plane. These 2D measurements form the basis of surgical decision making. However, it has been shown that the pelvic rotation in AIS may compromise a surgeon's ability to obtain reliable radiographic assessments (5,6). Pelvic rotation can lead to patients being malpositioned in the X-ray scanner, thus shifting preoperative measurements (5,6). Prior studies have shown that these measurement errors may be more pronounced as curves become more severe (4,6). However, little is known about which measurements—sagittal, coronal, or rotational—are most affected and the magnitude of such error (5).

Given the 3D deformity seen in AIS, further study of how pelvic rotation impacts radiographic measurements is needed. In a group of Lenke Type 1/2 AIS patients, we conducted a pilot study to assess the study question of how pelvic rotation (i.e., the patient's position in the X-ray scanner) affected the surgeon's ability to record sagittal, coronal and rotational measurements. We hypothesized that the patient's degree of pelvic rotation (i.e., the amount of rotation in the X-ray scanner), would significantly affect all radiographic measurements. We present the following article in accordance with the STROBE reporting checklist (available at <http://dx.doi.org/10.21037/jss-20-675>).

## Methods

### *Study design and patient population*

A retrospective, pilot, cross-sectional study of patients undergoing AIS surgery from 2017–2018 was undertaken. All patients carried a diagnosis of AIS, had a Type 1/2 curve, and had complete, full-length preoperative X-rays. Patients were excluded if they had Types 3–6 curves or did not have the requisite imaging. Though all patients underwent surgery, only preoperative imaging was used for the current study. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by institutional/regional/national ethics/committee/ethics board of Columbia University (No.: AAAQ18122) and individual consent for this retrospective analysis was waived.

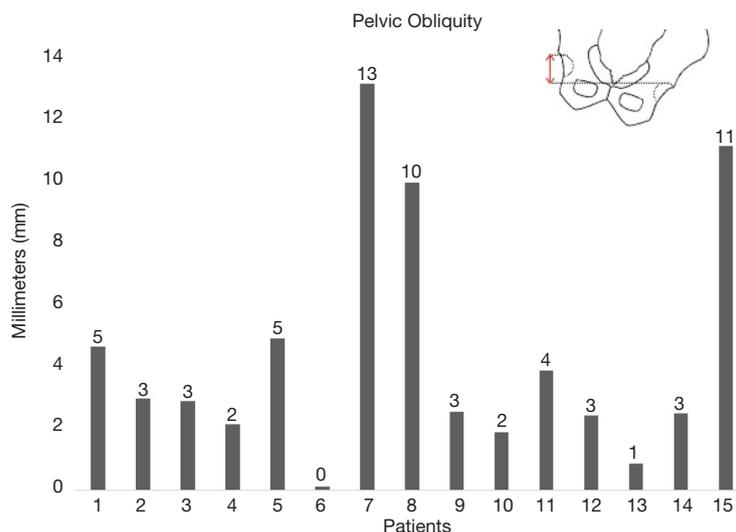
### *Data collection*

Basic demographic information was obtained for all patients from electronic medical records. Though only preoperative radiographic information was analyzed, the upper instrumented vertebrae (UIV), lower instrumented vertebrae (LIV), and levels fused were recorded to show that each patient had severe enough scoliosis to warrant surgical correction. All imaging was obtained with SterEOS technology (EOS imaging, Paris, France). From the low-dose, 2D, standing radiographs, surgeons and EOS technicians identified anatomical landmarks (both femoral heads and T1/L5 superior/inferior endplates) to render 3D images of the spine and pelvis (7,8). No custom code is required, and the only measuring required is to identify the aforementioned landmarks, and from these landmarks, all radiographic measurements can be obtained. The generated 3D image can then be adjusted for shape of the curve and width of the vertebral bodies. EOS generated 3D reconstructions have been shown to be accurate in comparison to the gold standard of computed tomography (CT) rendered 3D images (9,10).

### *Radiographic measurements*

All patients underwent full-length imaging under the same protocol, being told to stand straight in the scanner as they would, in a normal, comfortable posture. Measurements were taken in one of two scenarios, both in the 3D plane: (I) the radio plane and (II) the patient plane. Measurements in the radio plane were obtained based on the patient's natural position in the scanner, without accounting for any malposition or asymmetry. Conversely, the patient plane was obtained after identifying key anatomical landmarks and rotating the patient from their original position in the scanner to a plane perpendicular to the transverse plane. The patient plane is the actual source of all radiographic information used for clinical care. In summary, evaluating the difference between these two planes allowed us to determine the impact of pelvic rotation on subsequent radiographic measurements (i.e., how much the patient's position in the X-ray scanner altered measurements) (6).

In both planes, several radiographic measurements were collected. The pelvic orientation measurements were: pelvic obliquity (millimeters) and pelvis axial rotation. The sagittal plane measurements were: thoracic kyphosis (TK) and lumbar lordosis (LL). The coronal plane measurements were: coronal Cobb angles of main thoracic (MT) and thoracolumbar/lumbar (TL/L) curves, and apical vertebral



**Figure 1** Pelvic obliquity of each patient.

rotation (AVR) in the proximal thoracic (PT-AVR), main thoracic (MT-AVR), thoracolumbar/lumbar (TL/L-AVR) regions. Of note, two subsets of TK (T1-12/T4-12) and LL (L1-5, L1-S1) were assessed.

Due to the fact that a validated computer algorithm produced all measurements after identification of anatomical landmarks, and previous studies have shown excellent reliability and accuracy of 3D EOS measurements compared to both 2D and CT measurements (9,11-14), we did not feel an internal reliability or accuracy assessment was necessary.

### Statistical analysis

Continuous data was presented as the mean  $\pm$  standard deviation, and count data as n (%). Paired student's *t*-tests were used to assess the differences in each radiographic outcome between the radiographic and patient plane. A Shapiro-wilk test was performed for the AVR, and given that  $P=0.372$ , the null hypothesis of a normally distributed sample was not rejected, and normality was assumed. Despite the small sample, given the normal distribution, *t*-tests were deemed appropriate. All statistical analyses were performed in STATA version 14 (StataCorp LP, College Station, Texas).

## Results

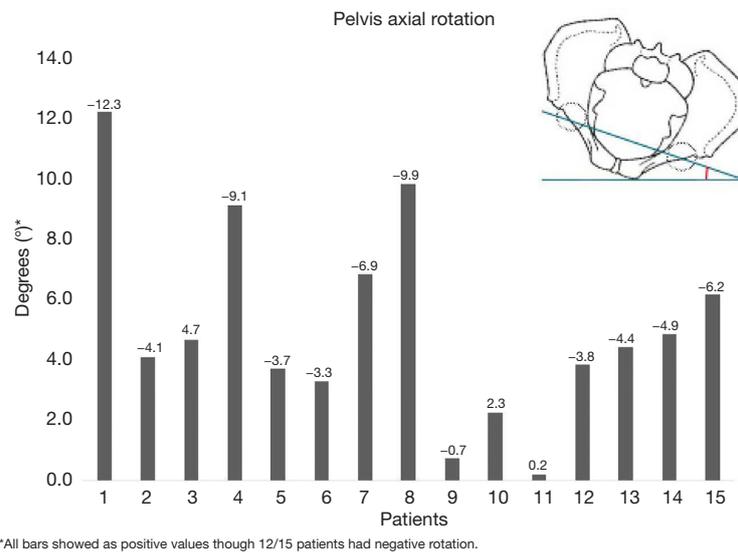
### Demographics

A total of 15 patients were included in the current pilot

study with an average age of  $15.7 \pm 1.2$  years and 66.7% were female. The preoperative mean (standard deviation) pelvic obliquity was 4.0 mm (3.8) (*Figure 1*) and pelvic rotation was  $5.1^\circ$  (3.3) (*Figure 2*). Though no postoperative measurements were used for the current study, all patients had severe enough scoliosis that required surgical intervention with the most common UIV of T3 (60.0%), the most common LIV of L1 (53.3%), and mean levels fused was 10.5 (*Table 1*).

### Radiographic outcomes (*Table 2, Figures 1,2*)

When comparing the radio and patient plane, significant differences were seen in sagittal and rotational measurements but not coronal measurements (*Table 2*). Both measures of TK (T1-12/T4-12) and LL (L1-5/L1-S1) values were significantly different between planes. TK differed in both subsets: T1-12:  $36.5^\circ$  vs.  $32.8^\circ$  ( $P=0.003$ ); T4-12:  $28.4^\circ$  vs.  $22.7^\circ$  ( $P<0.001$ ). Similarly, LL differed in both subsets: L1-5:  $46.6^\circ$  vs.  $42.8^\circ$ , ( $P=0.002$ ); L1-S1:  $58.2^\circ$  vs.  $55.1^\circ$  ( $P=0.003$ ). All three measurements of AVR differed significantly between planes: PT-AVR:  $4.0^\circ$  vs.  $8.2^\circ$ , ( $P=0.003$ ); MT-AVR:  $-14.8^\circ$  vs.  $-10.5^\circ$ , ( $P=0.004$ ); TL/L-AVR:  $4.5^\circ$  vs.  $8.7^\circ$ , ( $P=0.003$ ). No significant differences were seen in either of the coronal Cobb angles. Absolute values of TK/LL in the radio and patient plane are seen (*Figures 3,4*), whereas change values (difference between radio and patient plane) are seen for three rotational measures of PT-AVR, MT-AVR, TL/L-AVR (*Figure 5*).



**Figure 2** Pelvic rotation in radio plane prior to correction to patient plane of 0°.

**Table 1** Demographics of pilot study population

Characteristic	N=15
Age, mean (SD)	15.7 (1.2)
Female, n (%)	10 (66.7)
Pelvic obliquity (mm), mean (SD)	4.0 (3.8)
Pelvic axial rotation (°), mean (SD)	5.1 (3.3)
UIV, n (%)	
T2	4 (26.7)
T3	9 (60.0)
T4	2 (13.3)
LIV, n (%)	
T12	2 (13.3)
L1	8 (53.3)
L2	2 (13.3)
L3	3 (20.0)
Levels fused, mean (SD)	10.5 (1.2)

## Discussion

Despite AIS deformity occurring in three planes, the preoperative and postoperative assessment of AIS remains rooted in 2D. To maintain accurate and valid measurements, it is imperative that 2D assessments account for the unique 3D characteristics each AIS patient. The current analysis

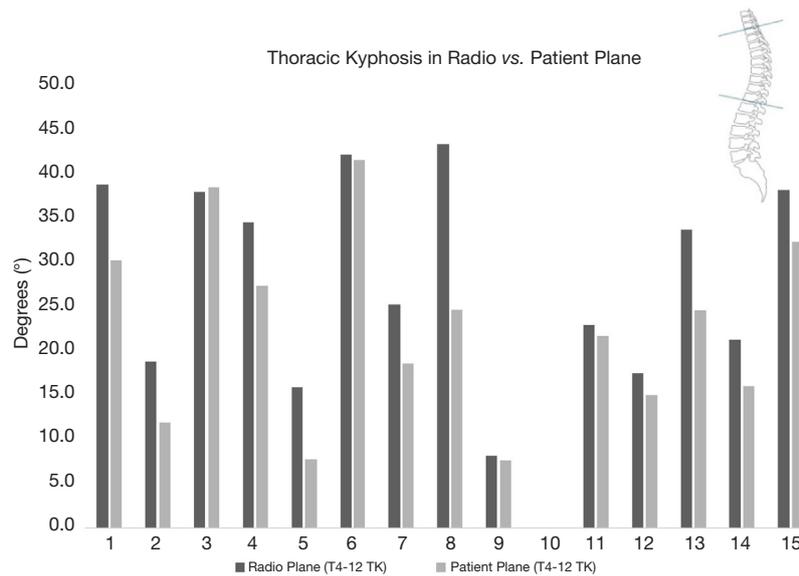
revealed that an average of 5.1° of pelvic rotation occurred in each AIS patient before correction to the patient plane. Sagittal and rotational parameters of TK, LL, and AVR were significantly altered due to the pelvic rotation (i.e., the patient's position in the X-ray scanner), whereas coronal measurements were not significantly impacted. These results have implications for obtaining accurate measurements in the treatment of AIS, surgical decision-making, postoperative monitoring, and surgeon-to-surgeon communication.

Pelvic rotation is routinely encountered in AIS. Gum *et al.* (15) studied 239 AIS Type 1-6 patients and found that the ratio of left to right iliac widths was 0.95, meaning that pelvic rotation was present (ratio≠1 indicated asymmetry). The authors postulated that pelvic rotation was compensatory, but regardless of the true etiology, clinically significant pelvic rotation occurred in their large AIS cohort. Additional anatomic studies have confirmed asymmetric ilia width in 42 female AIS patients (3). Pelvic rotation also manifests as abnormal gait in AIS patients (2). Nishida and colleagues (1) studied gait kinematics in 18 AIS patients and found that preoperative pelvic orientation deviated 4.0° to the convex side and trunk rotation was negatively correlated with pelvic rotation ( $R=-0.64$ ,  $P\leq 0.01$ ), indicating the pelvis rotated to the opposite side of the major curve in order for the spine to maintain balanced over the pelvis. All pelvic rotation abnormalities improved significantly after surgery, further highlighting the importance of noticing this abnormality in the preoperative setting (1).

**Table 2** Sagittal, coronal, and rotational measurements in the radio and patient plane

	Radio plane	Patient plane	P value
<b>Sagittal</b>			
Thoracic kyphosis (°), mean (SD)			
T1-12	36.5 (11.3)	32.8 (12.0)	0.003*
T4-12	28.4 (11.2)	22.7 (10.6)	<0.001*
Lumbar lordosis (°), mean (SD)			
L1-5	46.6 (11.3)	42.8 (13.3)	0.002*
L1-S1	58.2 (9.3)	55.1 (10.1)	0.003*
<b>Coronal</b>			
Coronal Cobb (°), mean (SD)			
MT	52.9 (15.2)	51.9 (14.9)	0.186
TL/L	33.8 (12.1)	34.6 (13.2)	0.458
<b>Rotational</b>			
Apical vertebral rotation (°), mean (SD)			
PT-AVR	4.0 (3.6)	8.2 (4.4)	0.003*
MT-AVR	-14.8 (12.4)	-10.5 (11.7)	0.004*
TL/L-AVR	4.5 (6.9)	8.7 (6.9)	0.003*

\*denotes statistical significance.



**Figure 3** Thoracic kyphosis (T4-12) between radio and patient plane.

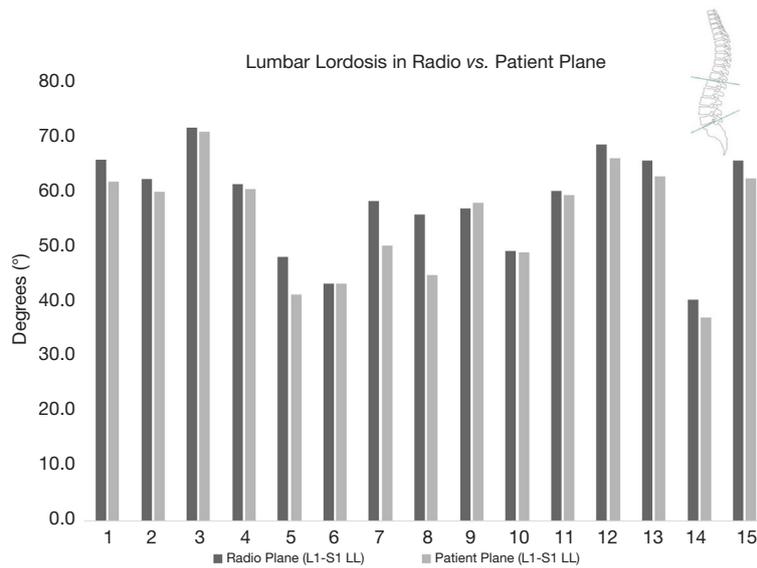


Figure 4 Lumbar lordosis (L1-S1) between radio and patient plane.

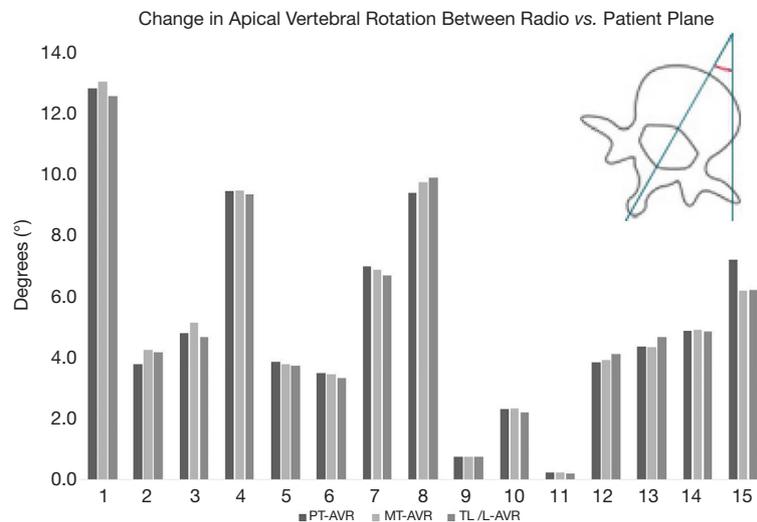


Figure 5 Change in apical vertebral rotation between radio vs. patient plane.

Our results show that sagittal and rotational radiographic measurements were significantly altered when pelvic rotation is corrected for. Pasha and colleagues (5) similarly found altered sagittal measurements in 36 AIS patients, where the radio vs. patient plane measurements for TK were 35.9° and 33.6°, respectively, and LL was 59.5° and 57.5°, respectively, which are almost identical to our results (5). Additionally, correcting for the patient’s alignment in the X-ray scanner improved correlation

between 2D and 3D measurements (5). Also similar to the current findings, coronal measurements were not affected. Several authors have also shown that the impact of pelvic rotation on sagittal measurements is more pronounced in more severe curves. A second study by Pasha *et al.* (6) showed that in 73 AIS patients, the amount of pelvic rotation present was stronger when TK was greater than 40° and LL was greater than 60°. Stylianides and colleagues (4) compared controls, moderate AIS patients,

and severe AIS patients and found that iliac spine geometry was significantly altered in the severe AIS group compared to the control and moderate AIS groups. The authors hypothesized that asymmetrical bone growth may have contributed to the pelvic rotation seen in AIS (4). Our study offers additional insight that rotational assessments are also impacted by pelvic rotation. Pelvic rotation not only impacted AVR in the principle, and instrumented MT curve, but also the less pronounced and uninstrumented PT and TL/L curves. These results and prior studies reinforce the same conclusions—pelvic rotation has implications for both the sagittal and rotational measurements (5).

Future studies can use the results of our pilot analysis to correlate both the 3D radio and patient plane measurements to more traditional 2D assessments. Knowing how more accurate 3D images compares to 2D assessment can aid surgeons in surgical planning and postoperative monitoring. Moreover, additional analyses should be considered in other scoliosis settings such as Type 3–6 AIS curves, early onset scoliosis, neuromuscular scoliosis, and adult degenerative scoliosis, each of which may have more clinically significant pelvic rotation. It is also unclear how pelvic rotation affects pelvic parameters such as pelvic tilt, sacral slope, and sagittal vertical axis, though more relevant to an adult scoliosis population. As 3D software continues to be utilized, and may eventually become standard of care, comparison of the radio and patient plane is important to ensure uniformity and accuracy when treating patients and communicating amongst surgeons. Though the current study did not include postoperative information, all patients underwent surgical correction. One important factor to consider when pelvic obliquity is present, in either a rigid or flexible spine, is the presence of leg-length discrepancy. Though more common in older populations, shoe lifts can be recommended to improve ambulation and reduce disability in any patient with scoliosis. Moreover, the presence a fixed pelvic obliquity must be taken note of intraoperatively after any deformity correction to ensure the spine is straight against a neutral pelvis, or else coronal malalignment may occur. For centers without EOS technology, these results can be used to educate X-ray technicians and patients to be sure the patient gives as best effort as possible to stand straight and orthogonal in the X-ray scanner. Perhaps specific lines and techniques can be used to ensure consistency and repeat X-rays in the orthogonal plane for all patients.

Though this was intended to be a pilot study, a limitation is the small sample size of 15 patients. Similar imaging

studies have used small sample sizes (5), the results of this preliminary analysis are exploratory in nature and should be interpreted with caution. Second, all radiographic measurements were generated by EOS imaging software and not measured by individual surgeons. Moreover, no internal reliability or validity assessment was performed. One prior study correlated radiographic measurements between 2D and EOS generated 3D images and found excellent correlation between coronal measurements ( $r=0.950$ ) and thoracic kyphosis ( $r=0.893$ ) (9). A similar study found substantial interobserver and excellent intraobserver agreement on multiple radiographic measurements with 3D EOS imaging, with less than  $4^\circ$  difference found between two raters on AVR (11). In a study of severe AIS curves  $>50^\circ$ , a third study reported intraclass correlation (ICC) values among 3 raters of 0.97 using 3D AIS images. Based on the prior literature supporting the reliability and accuracy of 3D EOS imaging, no internal reliability or accuracy assessments were performed. That said, multiple prior studies have shown that 3D images produced excellent reliability and accuracy compared to 2D and CT measurements (9,11–14). Third, though our results yielded statistical significance in the sagittal and rotational planes, it is unknown if this translates to clinical significance. The expected measurement error in sagittal and coronal 2D radiographic measurements has been estimated to be  $1.8^\circ$ – $3.0^\circ$  (16,17), compared to our approximate differences  $3^\circ$ – $6^\circ$ . Thus, we caution against overextrapolation of our findings. Nonetheless, our average preoperative Cobb angle was  $51.9^\circ \pm 14.9^\circ$ , and these variations may become more pronounced with more severe curves, as prior studies have suggested (4,6).

Overall, in light of the small sample and previous studies showing the importance of pelvic rotation, it is our hope these results can add to the growing evidence that the patient's position in the scanner must be taken into account when using EOS images. If spinal alignment is examined in absence of accounting for pelvic rotation, operative plans may be designed incorrectly, with potentially postoperative coronal or sagittal malalignment requiring revision surgery. Given the potential iatrogenic complications of not accounting for a patient's rotated pelvis, we believe these results can be of use to all practicing spinal deformity surgeons.

## Conclusions

An average of  $5.1^\circ$  of pelvic rotation occurred in each AIS

patient prior to correction to the perpendicular, patient plane. Pelvic rotation (i.e., the patient's position in the X-ray scanner) impacted sagittal and rotational measurements, whereas coronal measurements were not affected. These results have implications for measurement accuracy, surgical decision-making and postoperative monitoring.

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## Footnote

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*Ethical Statement:* The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by institutional/regional/national ethics/committee/ethics board of Columbia University (No.: AAAQ8122) and individual consent for this retrospective analysis was waived.

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