

# Maintenance of radiographic correction at 2 years following lumbar pedicle subtraction osteotomy is superior with upper thoracic compared with thoracolumbar junction upper instrumented vertebra

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## Abstract

**Purpose** The goal of this study was to characterize the spino-pelvic realignment and the maintenance of that realignment by the upper-most instrumented vertebra (UIV) for adult deformity spinal (ASD) patients treated with lumbar pedicle subtraction osteotomy (PSO).

**Methods** ASD patients were divided by UIV, classified as upper thoracic (UT: T1–T6) or Thoracolumbar (TL: T9–L1). Complications were recorded and radiographic parameters included thoracic kyphosis (TK, T2–T12), lumbar lordosis (LL, L1–S1), sagittal vertical axis (SVA), pelvic tilt, and the mismatch between pelvic incidence and

LL. Patients were also classified by the Scoliosis Research Society (SRS)-Schwab modifier grades. Changes in radiographic parameters and SRS-Schwab grades were evaluated between the two groups. Additional analyses were performed on patients with pre-operative SVA  $\geq 15$  cm.

**Results** 165 patients were included (UT: 81 and TL: 84); 124 women, 41 men, with average age  $59.9 \pm 11.1$  years (range 25–81). UT had a lower percentage of patients above the radiographic thresholds for disability than TL. UT had a significantly higher percentage of patients that improved in SRS-Schwab global alignment grade than the TL group at 2 years. Within the patients with pre-operative SVA  $\geq 15$  cm, TL developed significantly increased SVA

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and had a significantly higher percentage of patients above the SVA threshold at 3 months, and 1 and 2 years than UT. **Conclusions** Patients undergoing a single-level PSO for ASD who have fixation extending to the UT region (T1–T6) are more likely to maintain sagittal spino-pelvic alignment, lower overall revision rates and revision rate for proximal junctional kyphosis than those with fixation terminating in the TL region (T9–L1).

**Keywords** PSO · Adult spinal deformity · Upper instrumented vertebra · SRS-Schwab classification · Maintenance of correction

## Introduction

Adult spinal deformity (ASD) may be associated with spino-pelvic malalignment, which has been correlated with significant pain and disability [1–7]. Increased sagittal vertical axis (SVA) is associated with poor health-related quality of life (HRQOL) [4, 7]. This concept has been well adopted in current ASD management; however, more recent studies have determined that pelvic parameters, including pelvic tilt (PT) and pelvic incidence (PI), also have a fundamental role in spinal alignment, since the pelvis serves as the intermediary between the spine and lower limbs [5, 8–10].

Of the osteotomy options to correct spinal malalignment in ASD surgery, the pedicle subtraction osteotomy (PSO) allows for substantial spino-pelvic realignment through a three-column osteotomy at a single vertebral level [11–20]. ASD procedures have increased by 275 % in 10 years [21]. However, radiographic failures and poor maintenance of correction have been reported. Kim et al. [15] investigated the long-term (>5 years) clinical and radiographic outcomes of patients who underwent lumbar PSO. The authors found a significant increase in SVA and decrease in LL from post-operative to 2-year follow-up; however, it is unclear if UIV had any effect on these changes [15]. Similarly, Rose et al. [9] studied the radiographic changes in patients undergoing lumbar PSO and also found a significant increase in 2-year SVA and decrease in 2-year LL from initial post-operative values. The effect of UIV was also unclear [9].

There exists a subset of patients that do not maintain post-operative spinal alignment and those with worse pre-operative spinal alignment are more likely to lose correction over time [6, 9, 15]. To date, there exists no study that has directly investigated the relationship between UIV and loss of spino-pelvic realignment as well as how UIV and loss of correction are related to the SRS-Schwab classification system. Therefore, the objective of this study was to characterize the spino-pelvic realignment and the maintenance of that realignment based on the UIV for ASD

patients treated with PSO. The following specific aims were addressed: to determine the (1) radiographic differences and changes based UIV over 2 years, (2) percentage of patients by UIV and age that are above the radiographic thresholds associated with disability, (3) changes in the SRS-Schwab criteria by UIV at 1 and 2 years post-operatively and (4) revision and proximal junctional kyphosis (PJK) rates.

## Methods

### Patient population

This study is a retrospective review of a multi-center ASD database. Patients were taken consecutively and drawn from the International Spine Study Group (ISSG), which is composed of 11 sites across the United States. All patients were enrolled into an Institutional Review Board-approved protocol by each site. Inclusion criteria for the ISSG database were: age  $\geq 18$  years and presence of spinal deformity, as defined by scoliosis Cobb angle  $\geq 20^\circ$ , SVA  $\geq 5$  cm, PT  $\geq 25^\circ$ , and/or thoracic kyphosis (TK)  $\geq 60^\circ$ . Exclusion criteria included spinal deformity of a neuromuscular etiology and presence of active infection or malignancy. In addition to the database inclusion criteria, patients were included in the present study if (1) they underwent a single lumbar (L1–L5) PSO, (2) fixation termination levels were between T1 and the ilium, and (3) there was a minimum of 2-year radiographic follow-up. A subanalysis was conducted in which patients were excluded that underwent revision surgery that may affect alignment over the 2-year follow-up period (NOREV). These included instrumentation failure, pseudarthrosis, and proximal junctional kyphosis (PJK). This subanalysis was conducted to differentiate the long-term radiographic outcome in a best case scenario and to isolate the effect of UIV on alignment change over 2 years.

### Data collection, radiographic assessment, and classification

Data collected included patient age, gender, body mass index (BMI), fixation levels, PSO sites, operating room time, estimated blood loss (EBL), and revisions. Full-length free-standing lateral spine radiographs (36" cassette) at baseline, 6-week, 3-month, 1- and 2 years follow-up were analyzed using validated software [22, 23] (Spineview<sup>®</sup>, ENSAM, Laboratory of Biomechanics, Paris, France). All radiographic measures were performed at a central location based on standard techniques [24] and included: thoracic kyphosis (TK, T2–T12; Cobb angle between superior endplate of T2 and inferior endplate of T12), LL (Cobb angle between superior endplate of L1 and

superior endplate of S1), SVA (C7 plumbline relative to S1), PT, and PI-LL mismatch. The PJK angle was defined as the Cobb measurement between the cranial endplate of the UIV to the cranial endplate two vertebrae above. Abnormal radiographic PJK was defined as a proximal junctional angle  $>10^\circ$  and at least  $10^\circ$  greater than the corresponding pre-operative measurement.

Patients were categorized into two groups based on the UIV. The upper thoracic (UT) region was defined as fixation terminating between T1–T6 and L3-iliac (Fig. 1a). The thoracolumbar [TL] region was defined as fixation between T9–L1 to L3-iliac (Fig. 1b).

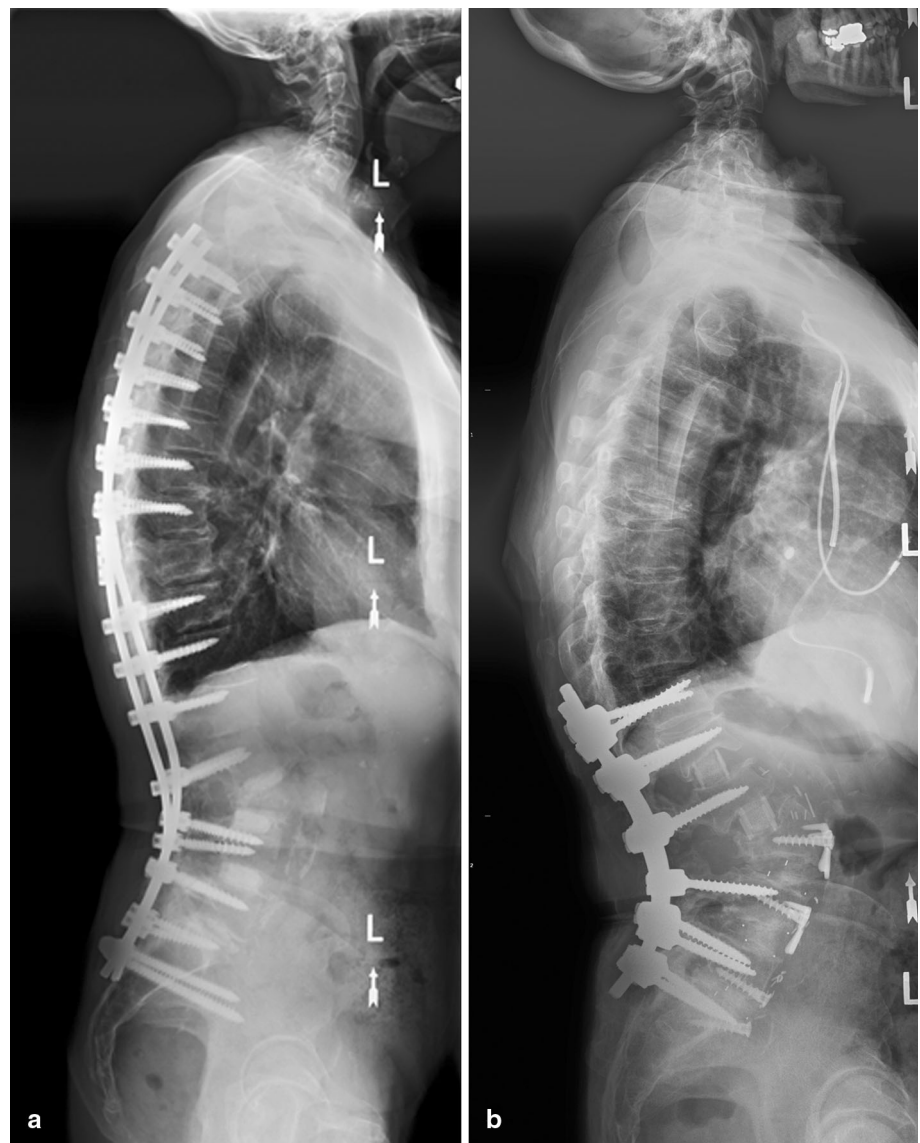
Based on the above radiographic parameters, patients were additionally stratified by the SRS-Schwab adult spinal deformity classification (Fig. 2) [25]. Patients were categorized based on the coronal classification and sagittal modifiers at base line and on the three sagittal modifiers at

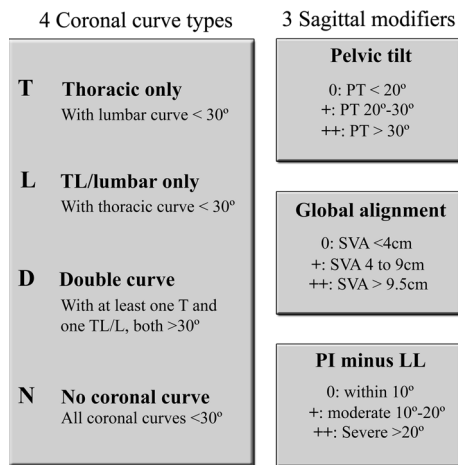
6 weeks, 3 months, 1 year, and 2 years post-operatively. Determination of the cutoff values for the SRS-Schwab classification was performed previously in the setting of a multi-center prospective analysis of 492 adults with spinal deformity [5, 26]. Furthermore, radiographic thresholds used in the current study that predict severe disability [Oswestry Disability Index (ODI)  $\geq 40$ ] were based on previous studies and included an SVA of 4.6 cm, PT of  $22^\circ$ , and PI-LL of  $11^\circ$  [5, 26, 27]. Lastly, a subgroup of patients with very high pre-operative SVA  $\geq 15$  cm (SVA15) was selected and analyzed.

#### Statistical analyses

Continuous variables were described with the mean and standard deviation. ANOVA or Kruskal–Wallis test and Student's t test or Wilcoxon rank-sum tests were used

**Fig. 1** Lateral standing 36-inch radiographs demonstrating a representative patient from each of the groups in the present study based on the upper-most instrumented vertebra (UIV). The upper thoracic (UT) group had fixation terminating between T1–T6, and the thoracolumbar (TL) group had fixation terminating between T9–L1. **a** Patient in the UT group with UIV of T3 and a pedicle subtraction osteotomy (PSO) at L3. **b** Patient in the TL group with UIV of T12 and a PSO at L3





**Fig. 2** The SRS-Schwab classification includes four coronal curve types and three sagittal modifiers of pelvic tilt (PT), sagittal vertical axis (SVA), and the difference between pelvic incidence (PI) and lumbar lordosis (LL)

where appropriate. Frequency analysis was used for categorical variables. The change in each of the SRS-Schwab classification sagittal modifiers was stratified to define three groups that included: no change in grade between baseline and the post-operative follow-up time points, deterioration by 1 or 2 grades, and improvement by 1 or 2 grades. For each modifier a comparison was made between the percentage of patients in each class as well as the change in grade between baseline and post-operative and was carried out using a  $\chi^2$  analysis. All statistical analyses were conducted using commercially available software (JMP v7.0, SAS Institute, Inc., Cary, NC) and the level of significance was set at  $p < 0.05$  for all.

## Results

### Patient population

A total of 188 patients were eligible to be included. 165 patients met inclusion criteria and were evaluated in this study. There were 124 women and 41 men, and the average age was  $59.9 \pm 11.1$  years (range 25–81). All 165 patients had complete baseline and 2-year radiographic data. 81 patients were included in the UT group (fixation termination between T1–T6) and 84 in the TL group (fixation termination between T9–L1). The PSO sites and SRS-Schwab coronal curve types for UT and TL are presented in Table 1. There were no significant differences between UT and TL for age, BMI, EBL, PSO sites or SRS-Schwab coronal curve types ( $p > 0.05$  for all, Table 1). The UT group had significantly longer OR time than the TL group (Table 1). Out of the total 165 patients, 79 (47.9 %) had a

**Table 1** Demographic and operative results for all patients

	UT	TL	<i>p</i> value
Number of patients	81	84	
Age	$60.3 \pm 11.3$	$59.6 \pm 11$	0.7011
Male:female	15:66	26:58	
BMI	$27.4 \pm 6.5$	$27.9 \pm 7.7$	0.9268
<b>OR time*</b>	<b><math>487.1 \pm 143</math></b>	<b><math>406.4 \pm 136.8</math></b>	<b>0.0042</b>
EBL	$3,260.4 \pm 2,432.3$	$2,533.9 \pm 1,532.9$	0.1221
PSO sites			
L1	2.5 %	3.6 %	0.6785
L2	22.2 %	17.9 %	0.4833
L3	50.6 %	41.7 %	0.2486
L4	21.0 %	28.6 %	0.2587
L5	3.7 %	8.3 %	0.2128
Pre-operative SRS-Schwab coronal			
Type T	6.2 %	3.6 %	0.4332
Type L	30.9 %	23.8 %	0.3028
Type D	9.9 %	6.0 %	0.3459
Type N	49.4 %	63.1 %	0.0703

*UT* upper thoracic (fixation terminating between T1–T6), *TL* thoracolumbar (fixation terminating between T9–L1), *BMI* body mass index, *EBL* estimated blood loss, *PSO* pedicle subtraction osteotomy, *Type T* patients with a thoracic major curve of greater than 30° (apical level of T9 or higher), *Type L* patients with a lumbar or thoracolumbar major curve of greater than 30° (apical level of T10 or lower), *Type D* patients with a double major curve, with each curve greater than 30°, and *Type N* patients with no coronal curve greater than 30° (i.e. no major coronal deformity), *Unknown* patients unable to be classified due to missing pre-operative anterior–posterior X-rays

\* Values marked in bold are statistically significant between UT and TL

baseline SVA  $\geq 15$  cm (UT:  $n = 44$ , TL:  $n = 35$ ) and were included in the subgroup analysis (SVA15).

43 (26.1 %) patients had at least one revision (range 1–3). 30 of those patients had a revision for mechanical reasons, which included implant failure, pseudoarthrosis, and PJK. The remaining 13 patients had revisions for neurological deficit, wound infection, and instrumentation pain. Thus, 135 patients did not have a revision for mechanical reasons (NOREV) and were analyzed separately. TL had a significantly higher proportion of patients that underwent a revision [UT: 11/43 (25.6 %), TL: 32/43 (74.4 %),  $p = 0.0003$ ]. UT had a higher rate of hardware failure (6/11, 54.5 %) than TL (11/32, 34.4 %); however, this difference was not significant ( $p = 0.2152$ ). 62 (37.6 %) patients had abnormal PJK ( $>10^\circ$  and  $>10^\circ$  from the pre-operative value) with UT having 32/62 (51.6 %) and TL having 30/62 (48.4 %),  $p = 0.8525$ . Out of the 11 patients (6.7 % of total) that had a revision for abnormal PJK, TL had a significantly higher proportion than UT [TL  $n = 9/11$  (81.8 %), UT  $n = 2/11$  (18.2 %),  $p = 0.0274$ ].

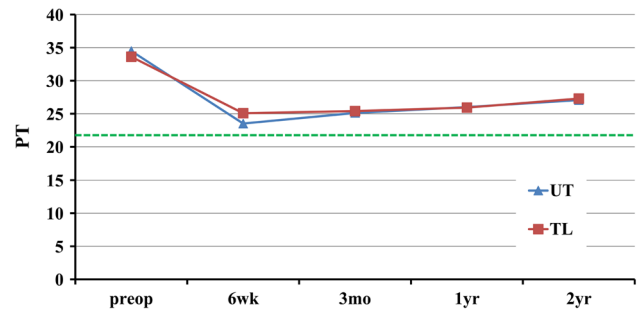
Radiographic analysis

For all patients (overall), NOREV and SVA15, both the UT and TL groups had statistically similar average pre-operative LL, PT, SVA, and PI-LL ( $p > 0.05$  for all). Overall and NOREV had significantly higher pre-operative TK in the UT group than the TL group ( $p < 0.05$ ). All groups had a significant improvement in all radiographic parameters at 6 weeks post-operatively compared with pre-operative values ( $p < 0.05$  for all). Compared to the 6-week post-operative values, the UT group had significantly increased average TK at 2 years post-operatively ( $41.3 \pm 15.5^\circ$  vs.  $49.1 \pm 14.6^\circ$ ,  $p = 0.0084$ ) and the TL group had a significant increase in SVA ( $3.9 \pm 5.3$  vs.  $6.1 \pm 5.4$  cm,  $p = 0.0331$ ). Similarly within the SVA15 group, the UT group had significantly increased average TK at 2 years post-operatively ( $37.4 \pm 15.8^\circ$  vs.  $47.8 \pm 15.4^\circ$ ,  $p = 0.0072$ ) and the TL group had a significant increase in SVA ( $5.3 \pm 5.3$  vs.  $8.1 \pm 5.1$  cm,  $p = 0.0453$ ). No other significant changes for any group were noted ( $p > 0.05$  for all).

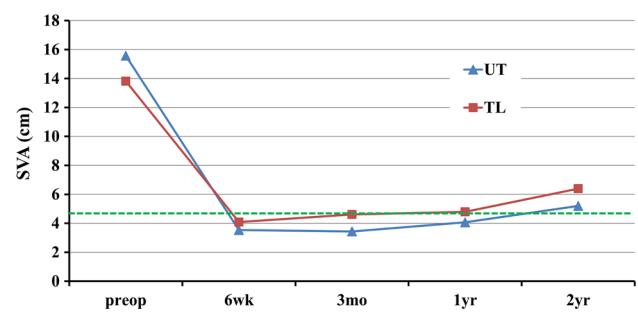
The average PT, SVA, and PI-LL for both UT and TL groups in the NOREV group are plotted in Figs. 3, 4 and 5 with their corresponding threshold values (dotted line) associated with severe disability. The SVA for NOREV with pre-operative SVA  $\geq 15$  cm is plotted in Fig. 6. Within all groups, TL had a higher percentage of patients above the thresholds for all three modifiers at all post-operative time points except for 2-year PT for all patients and NOREV (Table 2 left) and 3-month PI-LL in the NOREV group (Table 2 right). None of these percentages were statistically significant for all patients and NOREV ( $p > 0.05$  for all). However, for SVA15 and without revision (SVA15 + NOREV), there was a significantly higher percentage of patients in the TL group that were above the SVA threshold than the UT group for all post-operative time points with statistical significance being reached at 6 weeks (70.0 vs. 40.0 %,  $p = 0.0429$ ), 3 months (70.0 vs. 39.1 %,  $p = 0.0410$ ), 1 year (78.3 vs. 51.6,  $p = 0.0414$ ), and 2 years (86.2 vs. 64.1 %,  $p = 0.0358$ , Table 2 right, Fig. 6).

SRS-Schwab classification analysis

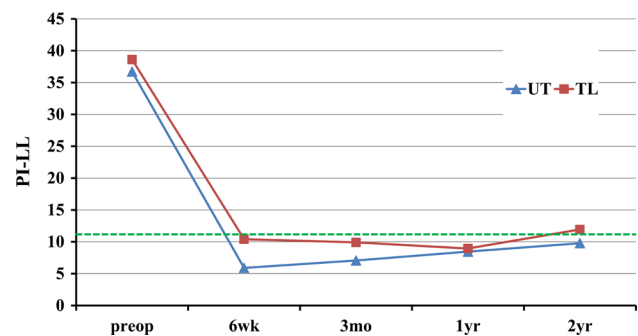
For all cohorts, the UT and TL groups were statistically similar for the pre-operative SRS-Schwab sagittal modifiers of PT, GA, and PI-LL modifiers ( $p > 0.05$  for all, Table 3). There were no significant differences in the percentage of patients in either the UT or TL group that did not have a change (none), deteriorated, or improved in the SRS-Schwab classification for the PT and PI-LL modifier for both all patients and NOREV ( $p > 0.05$  for all, Table 4). The UT group had significantly fewer patients



**Fig. 3** Average pelvic tilt (PT) trends for both UT and TL groups without revision ( $n = 135$ ). The dotted line denotes  $22^\circ$ ; the PT threshold in which severe disability occurs [Oswestry disability index (ODI)  $\geq 40$ ]. UT upper thoracic (fixation terminating between T1–T6), TL thoracolumbar (fixation terminating between T9–L1)



**Fig. 4** Average sagittal vertical axis (SVA) trends for both UT and TL groups without revision ( $n = 135$ ). The dotted line denotes 4.6 cm; the SVA threshold in which severe disability occurs [Oswestry disability index (ODI)  $\geq 40$ ]. UT upper thoracic (fixation terminating between T1–T6), TL thoracolumbar (fixation terminating between T9–L1)



**Fig. 5** Average difference between pelvic incidence and lumbar lordosis (PI-LL) trends for both UT and TL groups without revision ( $n = 135$ ). The dotted line denotes  $11^\circ$ ; the PI-LL threshold in which severe disability occurs [Oswestry disability index (ODI)  $\geq 40$ ]. UT upper thoracic (fixation terminating between T1–T6), TL thoracolumbar (fixation terminating between T9–L1)

with no change in the GA modifier (SVA) at 2 years compared with pre-operative values than did the TL group for both overall (28.8 vs. 43.2 %,  $p = 0.0085$ ) and NOREV (22.9 vs. 45.2 %,  $p = 0.0162$ , Table 4). Furthermore,

**Table 2** The distribution of patients without mechanical revision that was over the listed radiographic threshold presented as percentages of each the UT and TL groups for all patients (left) and for patients with a pre-operative sagittal vertical axis (SVA)  $\geq 15$  cm (right)

All patients without revision ( $n = 135$ )		% of group above threshold		$p$ value	
Modifier	Time	UT	TL		
PT (threshold $22^\circ$ )	Preop	88.7	90.6	$>0.05$	
	6 week	45.5	56.5		
	3 months	61.9	69.8		
	1 year	66	66.7		
	2 year	68.6	64.1		
GA (threshold 4.6 cm)	Preop	95.7	88.7	$>0.05$	
	6 week	32.6	51.1		
	3 months	31	51.2		
	1 year	45.3	54.2		
	2 year	54.9	64.1		
PI-LL (threshold $11^\circ$ )	Preop	90.1	92.2	$>0.05$	
	6 week	34.1	45.7		
	3 months	40.5	44.2		
	1 year	39.6	41.7		
	2 year	40.0	45.3		
Patients without revision and preop SVA $\geq 15$ cm ( $n = 68$ )		% of group above threshold		$p$ value	
Modifier	Time	UT	TL		
PT (threshold $22^\circ$ )	Preop	94.9	96.6	$>0.05$	
	6 week	50	70		
	3 months	58.3	80		
	1 year	61.3	73.9		
	2 year	69.2	72.4		
GA (threshold 4.6 cm)	Preop	100	100	NA	
	<b>6 week</b>	<b>40</b>	<b>70</b>		<b>0.0429*</b>
	<b>3 months</b>	<b>39.1</b>	<b>70</b>		<b>0.0410*</b>
	<b>1 year</b>	<b>51.6</b>	<b>78.3</b>		<b>0.0414*</b>
	<b>2 year</b>	<b>64.1</b>	<b>86.2</b>		<b>0.0358*</b>
PI-LL (threshold $11^\circ$ )	Preop	97.4	100	$>0.05$	
	6 week	42.3	45		
	3 months	50	45		
	1 year	48.4	52.2		
	2 year	51.3	51.7		

UT upper thoracic (fixation terminating between T1–T6), TL thoracolumbar (fixation terminating between T9–L1), PT pelvic tilt, GA global alignment (SVA), PI-LL the difference between the pelvic incidence and lumbar lordosis

\* Values marked in bold are statistically significant between UT and TL

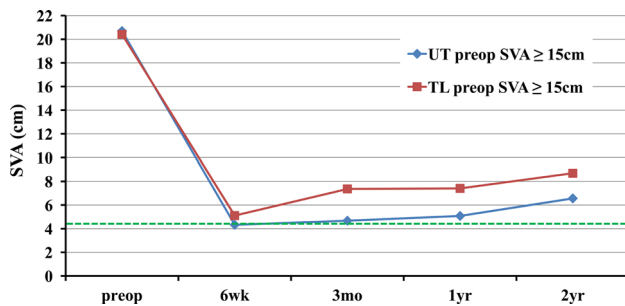
a significantly higher percentage of patients in the UT group improved in the GA (SVA) modifier for both the entire cohort (72.5 vs. 54.3 %,  $p = 0.0065$ ) and NOREV (72.9 vs. 51.6 %,  $p = 0.0115$ , Table 4). However, for SVA15 and SVA15 + NOREV, there were no significant differences in the percentages of patients in either the UT or TL group for any of the SRS-Schwab classification changes for all three modifiers ( $p > 0.05$  for all, Table 5).

## Discussion

Adult spinal deformity continues to be clinically challenging, and the surgical management remains technically demanding. Despite improved function, better overall

health status, and decreased pain following treatment with a PSO, [9, 12–20, 28] complications of these complex procedures are common including loss of correction over time [12, 15, 18, 19, 28]. The results of the present study suggest that patients undergoing a single-level PSO with the UIV in the upper thoracic region (T1–T6) and are more likely to maintain sagittal spino-pelvic alignment have lower overall revision rates, and lower revision rate for PJK than those with fixation terminating in the thoracolumbar region (T9–L1).

There are few reports specifically evaluating spino-pelvic realignment following ASD surgery with PSO. Kim et al. [15] investigated clinical and radiographic outcomes of patients who underwent lumbar PSO across 5–8 years. The authors found a significant increase in average SVA



**Fig. 6** Average sagittal vertical axis (SVA) trends for both UT and TL groups within the patient population having a pre-operative SVA  $\geq 15$  cm and without revision ( $n = 79$ ). The dotted line denotes 4.6 cm; the SVA threshold in which severe disability occurs [Oswestry disability index (ODI)  $\geq 40$ ]. UT upper thoracic (fixation terminating between T1–T6), TL thoracolumbar (fixation terminating between T9–L1)

and decrease in average LL from 8 weeks post-operative to 2-year follow-up [15]. This trend was also seen in the current study as the changes from 6 weeks post-operative to 2 years for average SVA and LL; however, this was not statistically significant for either group. Kim et al. [15] also stratified their patients by what the authors defined as sagittal imbalance corresponding to a post-operative SVA  $\geq 8$  cm at ultimate follow-up. The 8 weeks post-operative SVA of these patients was already above the threshold and significantly increased at ultimate follow-up. The patients that ended up with an SVA  $\geq 8$  cm had higher pre-operative SVA (20.3 vs 11.6 cm) than did those who maintained correction ( $< 8$  cm at final follow-up). This trend was the same for the current study and even more pronounced for the TL group. For the patients with pre-operative SVA  $\geq 15$  cm, both the UT and TL groups increased SVA, however, the TL group had a significant increase in SVA from 6 weeks post-operative to 2 years and was significantly higher than the UT group at 2 years. Furthermore, significantly more patients were above the SVA threshold of 4.6 cm in the TL group than the UT group beginning at 6 weeks post-operative.

Similarly, Rose et al. [9] studied the radiographic changes in 40 patients undergoing lumbar PSO and also found a significant increase in 2-year SVA and decrease in 2-year LL from post-operative values. The authors also stratified the patients by UIV when evaluating thoracic kyphosis (above or below T5). Those patients that received fixation  $\geq T5$  did not have any significant change in pre-operative and 2-year TK, whereas those below T5 significantly increased in TK. This trend is opposite of the current study results in which the UT group (T1–T6) had a significant increase in TK and the TL group (T9–L1) did not. This is likely due to more of the UT patients having thoracic, lumbar, and double coronal curves than the TL group. The distribution of the coronal curves in the Rose study was not reported.

**Table 3** The pre-operative distribution of SRS-Schwab sagittal modifiers presented as percentages of each the UT and TL groups for all patients (left) and for patients without revision

All patients ( $n = 165$ )		% of group		<i>p</i> value
Modifier	Grade	UT	TL	
PT	0	7.4	11.9	$>0.05$
	+	32.1	32.1	
	++	60.5	56	
GA	0	6.3	7.3	$>0.05$
	+	16.3	25.6	
	++	77.5	67.1	
PI-LL	0	11.1	8.3	$>0.05$
	+	7.4	9.5	
	++	81.5	82.1	

Patients without revision ( $n = 135$ )		% of group		<i>p</i> value
Modifier	Grade	UT	TL	
PT	0	8.5	9.4	$>0.05$
	+	29.6	32.8	
	++	62	57.8	
GA	0	4.3	9.7	$>0.05$
	+	17.1	22.6	
	++	78.6	67.7	
PI-LL	0	9.9	6.3	$>0.05$
	+	7	10.9	
	++	83.1	82.8	

The PT modifier includes “0”: patients with a PT less than 20°, “+”: patients with a PT between 20° and 30°, and “++”: patients with a PT greater than 30°. The global alignment modifier includes “0”: patients with an SVA less than 4 cm, “+”: patients with an SVA between 4.0 and 9.5 cm, and “++”: patients with an SVA greater than 9.5 cm. The PI-LL sagittal modifier includes “0”: patients with a PI-LL value less than 10°, “+”: patients with a PI-LL value between 10° and 20°, and “++”: patients with a PI-LL value greater than 20° UT upper thoracic (fixation terminating between T1–T6), TL thoracolumbar (fixation terminating between T9–L1), PT pelvic tilt, GA global alignment (SVA), PI-LL the difference between the pelvic incidence and lumbar lordosis

The strengths of the current study include the multicenter design and the complete pre-operative and 2-year follow-up of the patients assessed. These cases were contributed from multiple surgeons from 11 different sites across the United States, which allows for better generalizability of the results. Furthermore, all the radiographic measurements were performed at a single center using standardized image analysis software that minimized any potential variation in technique. The limitations include the retrospective design, and a relatively small sample size. Patients with multilevel PSOs, PSOs in the thoracic spine, or vertebral column resections were excluded. Further analysis with larger populations that include these patients

**Table 4** The 2-year post-operative distribution of either no change (none), improvement, or deterioration of the SRS-Schwab sagittal modifiers compared with pre-operative grades presented as percentages of each the UT and TL groups for the entire cohort (left) and those without revision (right)

2-year changes for all patients ( <i>n</i> = 165)		% of group		<i>p</i> value
Modifier	Change	UT	TL	
PT	None	62.5	51.2	>0.05
	Deteriorate	1.3	4.8	
	Improvement	36.3	44	
GA	<b>None</b>	<b>23.8</b>	<b>43.2</b>	<b>0.0085*</b>
	Deteriorate	3.8	2.5	0.6384
	<b>Improvement</b>	<b>72.5</b>	<b>54.3</b>	<b>0.0162*</b>
PI-LL	None	33.8	33.3	>0.05
	Deteriorate	1.3	0	
	Improvement	65	66.7	
2-year changes for patients without revision ( <i>n</i> = 135)		% of group		<i>p</i> value
Modifier	Change	UT	TL	
PT	None	61.4	53.1	>0.05
	Deteriorate	1.4	4.7	
	Improvement	37.1	42.2	
GA	<b>None</b>	<b>22.9</b>	<b>45.2</b>	<b>0.0065*</b>
	Deteriorate	4.3	3.2	0.7492
	<b>Improvement</b>	<b>72.9</b>	<b>51.6</b>	<b>0.0115*</b>
PI-LL	None	32.9	35.9	>0.05
	Deteriorate	1.4	0	
	Improvement	65.7	64.1	

*None* no change in grade between baseline and the post-operative follow-up time point, *deterioration* increase by 1 or 2 grades, *improvement* decrease by 1 or 2 grades, upper thoracic (fixation terminating between T1–T6), *TL* thoracolumbar (fixation terminating between T9–L1), *PT* pelvic tilt, *GA* global alignment (SVA), *PI-LL* the difference between the pelvic incidence and lumbar lordosis

\* Values marked in bold are statistically significant between UT and TL

**Table 5** The post-operative distribution of either no change (none), improvement, or deterioration of the SRS-Schwab sagittal modifiers compared with pre-operative grades for the population of patients with a pre-operative SVA  $\geq 15$  cm presented as percentages of each the UT and TL groups for all patients (left) and those without revision (right)

All patients with preop SVA $\geq 15$ cm ( <i>n</i> = 79)		% of group		<i>p</i> value
Modifier	Change	UT	TL	
PT	None	61.4	45.7	>0.05
	Deteriorate	0	2.9	
	Improvement	38.6	51.4	
GA	None	27.3	45.7	>0.05
	Deteriorate	0	0	
	Improvement	72.7	54.3	
PI-LL	None	31.8	28.6	>0.05
	Deteriorate	0	0	
	Improvement	68.2	71.4	
Patients with preop SVA $\geq 15$ cm and without revision ( <i>n</i> = 68)		% of group		<i>p</i> value
Modifier	Change	UT	TL	
PT	None	59	48.3	>0.05
	Deteriorate	0	3.4	
	Improvement	41	48.3	
GA	None	28.2	48.3	>0.05
	Deteriorate	0	0	
	Improvement	71.8	51.7	
PI-LL	None	33.3	31	>0.05
	Deteriorate	0	0	
	Improvement	66.7	69	

*None* no change in grade between baseline and the post-operative follow-up time point, *deterioration* increase by 1 or 2 grades, *improvement* decrease by 1 or 2 grades, upper thoracic (fixation terminating between T1–T6), *TL* thoracolumbar (fixation terminating between T9–L1), *PT* pelvic tilt, *GA* global alignment (SVA), *PI-LL* the difference between the pelvic incidence and lumbar lordosis

can offer insight into how maintenance of correction may affect osteotomy type as well as the multiple osteotomies. The choice to terminate at UT or TL was selected based on surgeon preference and their respective indications. Thus, it should be noted that the decision to terminate at UT or TL was not controlled for and another limitation of the present study. However, given the multi-center design, the population may be a represented sample of patients encountering surgeons with many different preferences. Additional limitations include the lack of information regarding osteoporotic management, use of different bone grafts, anterior column support, and staging of the procedures due to the retrospective design.

## Conclusion

Patients undergoing a single-level PSO for ASD who have fixation extending into the upper thoracic region (T1–T6) are more likely to maintain sagittal spino-pelvic alignment, specifically those not undergoing revision surgery, than those with fixation terminating in the thoracolumbar region (T9–L1). This is especially true for patients with severe pre-operative sagittal malalignment ( $SVA \geq 15$  cm) in which the patients that received fixation terminating in the upper thoracic region maintained correction longer (1 and 2 years) while those with fixation in the thoracolumbar region group lost correction earlier and this loss of correction was of greater magnitude. Furthermore, within this cohort, the overall revision rates and revision rates for PJK were lower for patients with fixation extending into the upper thoracic region (T1–T6) than in the thoracolumbar region (T9–L1).

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