Original Article

How does spinopelvic alignment influence short-term clinical outcomes after lumbar fusion in patients with single-level degenerative spondylolisthesis?

ABSTRACT

Context: Studies on adult spinal deformity have shown spinopelvic malalignment results in worse outcomes. However, it is unclear if this relationship exists in patients with single-level degenerative spondylolisthesis (DS) receiving short-segment fusions.

Aims: To determine if spinopelvic alignment affects patient-reported outcome measures (PROMs) after posterior lumbar decompression and fusion (PLDF) with or without a transforaminal lumbar interbody fusion in patients with L4-5 DS.

Settings and Design: A retrospective cohort analysis was conducted on patients who underwent PLDF for L4-5 DS at a single tertiary referral academic medical center.

Materials and Methods: Patients were divided into groups based on preoperative cutoff values of 20° for pelvic tilt (PT) and 11° for pelvic incidence-lumbar lordosis mismatch (PI-LL) with subsequent reclassification based on correction to <20° PT or 11° PI-LL. Radiographic outcomes and PROMs were compared between the groups.

Statistical Analysis Used: Multiple linear regression analyses were performed to determine whether radiographic cutoff values served as the independent predictors of change in PROMs. Statistical significance was set at $P < 0.05$.

Results: A total of 188 patients with completed PROMs were included for the analysis. Preoperative PT >20° was associated with significantly greater reduction in PI-LL (−2.41° vs. 1.21°, $P = 0.004$) and increase in sacral slope (SS) (1.06° vs. −1.86°, $P = 0.005$) compared to patients with preoperative PT <20°. On univariate analysis, no significant differences were observed between any groups with regard to PROMs. Preoperative sagittal alignment measures and postoperative correction were not found to be independent predictors of improvement in clinical outcomes.

Conclusion: A preoperative PT >20° is associated with improved PI-LL reduction and an increase in SS. However, no differences in clinical outcomes were found 1 year postoperatively for patients with preoperative PT >20° and PI-LL ≥11° compared to patients below this threshold.

Keywords: Degenerative spondylolisthesis, lumbar lordosis, patient-reported outcome measures, pelvic tilt, sacral slope, spinopelvic alignment

Stephen DiMaria, Brian A. Karamian, Mark J. Lambrechts, Arun P. Kanhere, John J. Mangan, Winston W. Yen[1], Arlene Maheu, Mahir A. Qureshi, Jose A. Canseco, David I. Kaye, Barrett I. Woods, Mark F. Kurd, Kris E. Radcliff, Alan S. Hilibrand, Christopher K. Kepler, Alexander R. Vaccaro, Gregory D. Schroeder

Department of Orthopaedic Surgery, Rothman Institute, Thomas Jefferson University, Philadelphia, PA, [1]Touro College of Osteopathic Medicine, Brooklyn, NY, USA

Address for correspondence: Dr. Mark J. Lambrechts, Rothman Orthopaedic Institute at Thomas Jefferson University, Department of Orthopaedics, 925 Chestnut St., 5th Floor, Philadelphia, PA 19107, USA.
E-mail: mark.lambrechts@rothmanortho.com

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INTRODUCTION

Degenerative spondylolisthesis (DS) is an acquired condition characterized by the slippage of one vertebral body over another due spondylotic changes, without associated defects in the vertebral ring.[1] Lumbar DS occurs most commonly at

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the L4-L5 level, comprising 73%–88.5% of cases.[2,3] Lumbar DS has been associated with spinal stenosis, sagittal imbalance, kyphosis, and disc space collapse, all of which can result in symptoms of low back pain, neurogenic claudication, or radicular pain.[4] Previous studies have identified predisposing factors for the development of DS to include sagittal orientation of the facet joints, increased pedicle-facet angle, as well as generalized joint laxity.[5]

There is growing evidence supporting the importance of the interdependent relationship between the adjacent spine and pelvis and the development of DS.[6-8] Imbalances in pelvic incidence-lumbar lordosis (PI-LL) and/or pelvic tilt (PT) are believed to contribute to DS and have been associated with L4 anterior slip.[9,10] Furthermore, in patients matched based on pelvic incidence, those with lumbar DS had an anterior translation of the C7 plumb line, loss of lumbar lordosis (LL), and a decrease in sacral slope (SS).[11] Although the relationship between spinopelvic parameters and postoperative outcomes has been established in adult spinal deformity, few studies have investigated the association between preoperative spinopelvic measures and postoperative outcomes in patients with lumbar DS.[12,13]

Surgical treatment for DS has been found to substantially decrease pain and improve functional outcomes when compared to nonoperative management.[14-19] In a multi-center randomized controlled trial, it has been shown that surgical treatment for DS with associated spinal stenosis leads to substantially greater pain relief and improvement in physical function at 4 years follow-up.[14] No previous investigations have focused on the effects of preoperative spinopelvic alignment on clinical outcomes after surgery for DS. Extrapolated from adult spinal deformity literature, it has been hypothesized that PI-LL ≥11° or a PT >20° may lead to worse outcomes in short segment fusion for patients with DS.[20-22] Thus, the primary goal of our study was to determine whether a baseline PI-LL ≥11° or a PT >20° is associated with worse clinical or radiographic outcomes in patients undergoing posterior lumbar fusion to address DS at L4-L5. In addition, we compared the outcomes of patients whose sagittal alignments were and were not completely corrected according to the aforementioned values, and examined if procedure type had a significant impact on clinical outcomes.

MATERIALS AND METHODS

Study design

After obtaining approval from the Institutional Review Board, a retrospective cohort analysis was performed using a Structured Query Language search on patients with single-level L4-L5 degenerative lumbar spondylolisthesis who underwent posterior lumbar decompression and instrumented fusion (PLDF), with or without transforaminal lumbar interbody fusion (TLIF), at a single academic medical center between January 1, 2013 and December 31, 2017. Patients who underwent decompression surgery without fusion, surgical intervention to address infectious etiologies, traumatic injury, malignant tumors, or prior instrumented fusion of the involved segments were excluded from the analysis. In addition, patients with <1 year of clinical or radiologic follow-up, fusion with an anterior lumbar interbody fusion technique, or fusions greater than two levels were excluded.

Data collection

Demographic information obtained for the study included age, sex, body mass index (BMI), smoking status (never, current, and former smoker), symptom duration prior to surgery (<3 months, 3–6 months, 6 months–2 years, or >2 years), months until final follow-up, and workers compensation status (no, yes, and retired). Preoperative and 1-year postoperative patient-reported outcome measures (PROMs) were collected for each patient through Oswestry Disability Index (ODI), the Short Form-12 (SF-12) Physical Component Score (PCS-12) and Mental Component Score (MCS-12), and the Visual Analog Scale (VAS) Back (VAS Back) and Leg (VAS Leg) pain scores. In addition, preoperative and 1-year postoperative radiographic measures were collected on standing, lateral X-rays including L4-S1 lordosis, LL, PI-LL mismatch, PT, SS, and L1 axis-S1 distance (LASD).[23,24]

Statistical analysis

Baseline demographics were compared between PT and PI-LL groups above and below their respective cutoff values (PT >20°, PI-LL ≥11°) using Pearson's Chi-square analysis or Fisher's exact test (categorical variables) and independent samples *t*-test or MannWhitney *U*-test (continuous variables). The groups were compared for the differences in baseline, postoperative, and delta (postoperative minus preoperative) radiographic measures and PROMs. Two measures were used to determine the extent to which patient's benefitted from surgical intervention: (1) recovery ratios (RR) - defined as (Delta PROM/["Optimal" PROM minus baseline PROM]), using 100 as "optimal" for PCS-12 and MCS-12, and 0 as "optimal" for ODI, VAS Back and VAS Leg;[25] and (2) the percentage of patients that achieved the minimum clinically important difference (%MCID) at final clinical follow-up, based on the following MCID thresholds for meaningful improvement: ODI - 6.8 points, PCS-12-8.8 points, MCS-12-9.3 points, VAS Back – 2.1 points, and VAS Leg – 2.4 points.[26,27] Controlling for demographic and surgical characteristics, multiple linear regression analysis was performed to determine whether the predefined preoperative PT or PI-LL cutoff scores were predictors for change in PROMs during the study period. Primary analysis was performed in the overall cohort for both PT and PI-LL cutoff groups. Subsequent analysis was performed on subgroups stratified by surgery type (PLDF with and without TLIF) and correction to optimal spinopelvic parameters (PT <20° or PI-LL <11°). Correction of the spinopelvic parameters was defined as patients with preoperative PT >20° or PI-LL >11° with subsequent correction postoperatively to PT <20° or PI-LL <11°. Patients with a PT or PI-LL maintained above these thresholds were labeled uncorrected. All statistical analyses were performed using RStudio (Version 1.3.1073-1, RStudio, Inc., Boston, MA) in which the threshold for statistical significance was set at $P < 0.05$.

RESULTS

Demographics

A total of 188 patients were included in the final analysis. The average age of the cohort was 62.3 years, with 80 (42.6%) males and 108 (57.4%) females and an average BMI of 30.8. There were 113 (60.1%) never smokers, 23 (12.2%) current smokers, and 52 (27.7%) former smokers with a mean follow-up time of 22.7 months. A total of 71 (37.8%) patients experienced symptoms for <3 months, 56 (29.8%) patients experienced symptoms for 3–6 months, and 61 (32.4%) patients experienced symptoms for >6 months before surgery. A total of 111 (59.0%) patients received no workers compensation, 51 (27.1%) patients received workers compensation, and 26 (13.8%) patients retired prior to surgery.

When dividing the cohort based on PT, 64 (34%) patients had a PT <20° while 124 (66%) patients had PT >20°. When classifying patients by PI-LL mismatch, 126 (67%) patients had a PI-LL mismatch <11°, while 62 (33%) patients had a PI-LL mismatch >11°. There were no differences in age, sex, BMI, smoking, length of follow-up, or workers compensation status between groups above or below each respective parameter. There was a significant difference in symptom duration with a higher proportion of patients having longer symptom duration (3–6 and >6 months) in PT >20° and PI-LL ≥11° groups (P = 0.001 and 0.010, respectively). Demographic information and surgical characteristics are summarized in Table 1.

Patient reported outcome measures

Patients in both cohorts demonstrated significant improvement in all PROMs at 1 year ($P < 0.001$ for all) [Table 2]. When comparing outcomes between groups partitioned by PT and PI-LL thresholds, there were no significant differences with respect to preoperative, postoperative, and delta scores [Table 2], recovery ratios, or %MCID between groups [Table 3]. Multiple linear regression analysis demonstrated that PT >20° was a significant predictor of increased improvement in PCS-12 scores for patients who underwent PLDF (β = 4.17 [0.05–0.83], P = 0.0496) and PI-LL ≥11° was a significant predictor of decreased improvement in PCS-12 for those who received PLDF with TLIF (β = −7.43 [−14.54–−0.31], P = 0.048) [Table 4]. No other factors were significant predictors of change in outcomes after surgery. When comparing outcomes based on spinopelvic alignment correction to PT <20° and PI-LL <11°, there were no significant differences with respect to recovery ratios or %MCID [Appendix A] for patients who were and were not completely corrected.

Radiographic outcome measures

Radiographic outcome measures for all groups are summarized in Table 5. By definition, average PT was greater in the PT >20° group compared to the PT <20°, which was maintained postoperatively (17.3° vs. 26.1°, $P < 0.001$) as this group also exhibited a decreased delta PT (3.34 vs. −1.46, $P < 0.001$). Preoperative, postoperative, and delta PI-LL values were all greater in the PT >20° group ($P < 0.001$, $P < 0.001$, and $P = 0.004$, respectively). Preoperative and postoperative L4-S1 lordosis was significantly less in the PT >20° group ($P < 0.001$ and $P = 0.018$, respectively); however, no difference was found in delta values. Delta SS ($P = 0.005$) and preoperative and postoperative LASD ($P < 0.001$ for both) were all found to significantly differ between PT groups.

Similarly, by definition, the average PI-LL was greater in the PI-LL ≥11° group than the PI-LL <11°, which also carried through postoperatively (0.15° vs. 17.4°, $P < 0.001$) as this group exhibited a decreased delta (0.28° vs. −4.14°, $P = 0.004$). Significant differences were observed in preoperative and postoperative L4-S1 lordosis ($P < 0.001$ for both), preoperative and postoperative PT ($P < 0.001$ for both), preoperative and postoperative LL ($P < 0.001$ for both), preoperative and postoperative SS ($P = 0.047$ and $P = 0.044$, respectively), and preoperative and postoperative LASD ($P < 0.001$ for both). However, differences in delta values for these parameters were not found to be significant [Table 5].

DISCUSSION

Although the treatment of degenerative spine diseases remains under debate, it is well established that spinopelvic parameters significantly influence clinical outcomes after

Table 1: Demographics of cohort

Patient demographics	PT cutoff: 20° (n=188)			PI-LL cutoff: 11° (n=188)		
	PT <20° (n=64), n (%)	PT ≥20° (n=124), n (%)	P^a	PI-LL <11° (n=126), n (%)	PI-LL ≥11° (n=62), n (%)	P^a
Age, mean (SD)	61.2 (10.1)	62.9 (10.3)	0.268	61.8 (10.5)	63.4 (9.66)	0.290
Sex						
Male	32 (50.0)	48 (38.7)	0.184	56 (44.4)	24 (38.7)	0.555
Female	32 (50.0)	76 (61.3)		70 (55.6)	38 (61.3)	
BMI, mean (SD)	31.4 (5.64)	30.5 (6.74)	0.342	31.0 (5.97)	30.4 (7.20)	0.609
Smoking						
Never	37 (57.8)	76 (61.3)	0.715	75 (59.5)	38 (61.3)	0.918
Current	7 (10.9)	16 (12.9)		15 (11.9)	8 (12.9)	
Former	20 (31.2)	32 (25.8)		36 (28.6)	16 (25.8)	
Months follow-up, mean (SD)	22.1 (12.0)	23.0 (12.3)	0.627	21.6 (11.6)	24.7 (13.1)	0.121
Symptom duration (months)						
<3	36 (56.2)	35 (28.2)	0.001*	56 (44.4)	15 (24.2)	0.010*
3-6	14 (21.9)	42 (33.9)		30 (23.8)	26 (41.9)	
>6	14 (21.9)	47 (37.9)		40 (31.7)	21 (33.9)	
Workers compensation received?						
No	40 (62.5)	71 (57.3)	0.786	71 (56.3)	40 (64.5)	0.540
Yes	16 (25.0)	35 (28.2)		37 (29.4)	14 (22.6)	
Retired	8 (12.5)	18 (14.5)		18 (14.3)	8 (12.9)	

*Statistical significance, [a]Baseline demographics were compared between groups with Pearson's Chi-square, Fisher's exact, Independent samples *t*-test, Mann-Whitney *U*, One-way ANOVA, or Kruskal-Wallis *H*-test. PI-LL - Pelvic incidence-lumbar lordosis, PT - Pelvic tilt, SD - Standard deviation

Table 2: Patient-reported outcomes for cohort

PROM	PT cutoff: 20° (n=188)				PI-LL cutoff: 11° (n=188)		
	Overall (n=188)	PT <20° (n=64)	PT ≥20° (n=124)	P^a	PI-LL <11° (n=126)	PI-LL ≥11° (n=62)	P^a
ODI							
Pre	46.1 (17.7)	45.3 (16.0)	46.5 (18.6)	0.657	44.5 (17.6)	49.4 (17.8)	0.099
Post	22.4 (20.3)	25.1 (19.4)	20.9 (20.7)	0.199	21.6 (19.6)	24.1 (21.8)	0.468
Delta	−23.73 (20.3)	−20.21 (18.1)	−25.62 (21.2)	0.087	−22.98 (19.7)	−25.33 (21.6)	0.501
P^b	-	<0.001*	<0.001*	-	<0.001*	<0.001*	–
PCS-12							
Pre	30.9 (8.18)	31.4 (7.80)	30.6 (8.39)	0.536	31.2 (8.39)	30.3 (7.75)	0.495
Post	39.7 (11.2)	38.9 (11.0)	40.1 (11.3)	0.500	40.2 (11.4)	38.7 (10.9)	0.403
Delta	8.79 (11.1)	7.48 (10.5)	9.47 (11.3)	0.250	9.00 (11.1)	8.38 (11.2)	0.730
P^b	-	<0.001*	<0.001*	-	<0.001*	<0.001*	–
MCS-12							
Pre	47.4 (11.2)	46.3 (10.2)	48.0 (11.7)	0.324	47.6 (10.7)	47.0 (12.3)	0.735
Post	52.3 (9.90)	51.4 (8.90)	52.7 (10.4)	0.381	51.7 (9.77)	53.5 (10.2)	0.263
Delta	4.84 (11.0)	5.10 (8.70)	4.71 (12.1)	0.806	4.06 (10.7)	6.48 (11.6)	0.187
P^b	-	<0.001*	<0.001*	-	<0.001*	<0.001*	
VAS back							
Pre	6.03 (2.92)	6.35 (2.67)	5.85 (3.05)	0.294	5.93 (2.88)	6.26 (3.04)	0.535
Post	3.11 (2.97)	3.49 (2.78)	2.91 (3.06)	0.239	3.01 (2.75)	3.35 (3.45)	0.556
Delta	−2.91 (3.71)	−2.82 (3.36)	−2.96 (3.90)	0.806	−2.89 (3.40)	−2.95 (4.43)	0.937
P^b	-	<0.001*	<0.001*	-	<0.001*	<0.001*	–
VAS leg							
Pre	6.54 (2.76)	6.70 (2.68)	6.46 (2.81)	0.592	6.49 (2.79)	6.67 (2.72)	0.709
Post	2.99 (3.11)	3.37 (3.03)	2.78 (3.16)	0.263	2.93 (3.05)	3.15 (3.31)	0.703
Delta	−3.55 (4.01)	−3.33 (3.87)	−3.67 (4.09)	0.620	−3.56 (3.98)	−3.53 (4.10)	0.964
P^b	-	<0.001*	<0.001*	-	<0.001*	<0.001*	–

*Statistical significance ($P<0.05$), [a]Independent samples *t*-test or Mann-Whitney *U*-test comparing preoperative and postoperative values, [b]Paired-sample *t*-test or Wilcoxon rank sum test comparing preoperative and postoperative values. SF - Short form, PCS-12 - Physical component of SF-12, MCS-12 - Mental component of SF-12, ODI - Oswestry Disability Index, VAS: Visual Analog Scale, VAS back - VAS back pain, VAS leg - VAS leg pain, PT - Pelvic tilt, PI-LL - Pelvic incidence-lumbar lordosis, PROM - Patient-reported outcome measures

Table 3: Recovery ratios and minimal clinically important difference at 1-year follow-up

PROM	PT <20° (*n*=64)	PT ≥20° (*n*=124)	P^a	PI-LL <11° (*n*=126)	PI-LL ≥11° (*n*=62)	*P*
ODI						
RR	0.57 (0.39)	0.44 (0.54)	0.379	0.51 (0.45)	0.44 (0.57)	0.693
MCID (%)	85.7	83.3	1.000	81.5	88.2	0.689
PCS-12						
RR	0.16 (0.15)	0.08 (0.16)	0.112	0.13 (0.16)	0.06 (0.15)	0.124
MCID (%)	46.7	40.6	0.941	48.3	33.3	0.482
MCS-12						
RR	0.16 (0.13)	0.09 (0.21)	0.166	0.12 (0.18)	0.09 (0.21)	0.612
MCID (%)	40.0	31.2	0.795	37.9	27.8	0.707
VAS back						
RR	0.40 (0.64)	0.54 (0.44)	0.468	0.44 (0.57)	0.60 (0.38)	0.294
MCID (%)	57.1	53.6	1.000	55.6	53.3	1.000
VAS leg						
RR	0.62 (0.36)	0.51 (0.57)	0.424	0.55 (0.54)	0.54 (0.47)	0.932
MCID (%)	50.0	57.1	0.913	51.9	60.0	0.853

[a]Independent-samples *t*-test for RR and Pearson Chi-squared test for MCID. SF - Short form, PCS-12 - Physical component of SF-12, MCS-12 - Mental component of SF-12, ODI - Oswestry Disability Index, VAS - Visual analog scale, VAS back - VAS back pain, VAS leg - VAS leg pain, RR - Recovery ratio, MCID - Minimal clinically important difference, PROM - Patient reported outcome measures, PT - Pelvic tilt, PI-LL - Pelvic incidence-lumbar lordosis

Table 4: Linear regression by pelvic tilt and pelvic incidence-lumbar lordosis with procedure type

Variable	Full cohort (*n*=188)		PLF cohort (*n*=138)		PLF + TLIF cohort (*n*=50)	
	PT ≥20° or PI-LL ≥11°	*P*	PT ≥20° or PI-LL ≥11°	*P*	PT ≥20° or PI-LL ≥11°	*P*
Delta ODI						
PT	−5.17 (−12.06-1.73)	0.144	−7.36 (−15.23-0.52)	0.070	0.51 (−15.59-16.61)	0.951
PI-LL	−0.49 (−7.46-6.47)	0.890	−0.17 (−8.36-8.03)	0.968	3.86 (−13.32-21.03)	0.663
Delta PCS-12						
PT	1.94 (−1.58-5.46)	0.282	4.17 (0.05-0.83)	0.0496*	−6.67 (−13.53-0.18)	0.065
PI-LL	−0.76 (−4.26-2.74)	0.671	0.78 (−3.51-5.07)	0.722	−7.43 (−14.54-(−0.31))	0.048*
Delta MCS-12						
PT	−0.74 (−4.41-2.93)	0.694	0.64 (−3.55-4.83)	0.765	−5.13 (−13.67-3.42)	0.247
PI-LL	2.08 (−1.54-5.70)	0.262	3.39 (−0.86-7.64)	0.12	−3.84 (−12.85-5.17)	0.409
Delta VAS back						
PT	0.04 (−1.29-1.37)	0.95	−0.09 (−1.54-1.37)	0.904	0.07 (−3.38-3.52)	0.969
PI-LL	0.30 (−1.07-1.66)	0.671	−0.27 (−1.81-1.26)	0.729	2.53 (−1.17-6.23)	0.19
Delta VAS leg						
PT	−0.20 (−1.60-1.21)	0.784	−0.08 (−1.67-1.51)	0.921	−1.67 (−4.63-1.29)	0.278
PI-LL	0.52 (−0.91-1.95)	0.478	0.70 (−0.97-2.36)	0.413	−0.39 (−3.72-2.93)	0.819

*Statistical significance ($P<0.05$). Linear regression models for overall cohort, PLF only, and PLF and TLIF. PT <20° served as the reference group for PT 20° and PI-LL ≤11° served as the reference group for PI-LL ≥11°. PROMs: ODI - Oswestry Disability Index, PCS-12 - Physical component score-12, MCS-12 - Mental component score-12, VAS - Visual analogue scale, VAS back - VAS back pain, VAS leg - VAS leg pain, PT - Pelvic tilt, PI-LL - Pelvic incidence-lumbar lordosis, PLF - Posterolateral instrumented fusion, TLIF - Transforaminal lumbar interbody fusion, PROM - Patient-reported outcome measures

intervention.[11,13,28,29] DS is a heterogeneous condition with a wide range of radiographic parameters, which has prompted increased emphasis on defining radiographic criteria for patients requiring surgery.[4,30] Prior literature has suggested ideal alignment is achieved with reduction of the sagittal vertical axis below 5 cm, optimization of PI-LL mismatch between 9° and 11°, and PT <20°.[21,31] While it has been established that spinal alignment is important for postoperative outcomes in adult spinal deformity and isthmic spondylolisthesis,[32-34] few studies have looked at DS limited to the L4–L5 level.[29] The purpose of this study was to investigate the association between preoperative PT of >20° or PI-LL ≥11° cutoff values and radiographic and patient-reported outcomes after PLDF, with and without TLIF, in patients with L4-5 DS. In addition, outcomes were compared for patients whose sagittal alignments were and were not completely corrected based on the aforementioned cutoff values.

Prior literature evaluating the outcomes of patients with spinopelvic malalignment after surgery in the setting of DS is equivocal. A systematic literature review evaluating studies investigating spinopelvic alignment in the setting of DS revealed strong evidence from prospective trials that

Table 5: Radiographic measures of cohort

	Overall (n=188)	PT cutoff: 20° (n=188)			PI-LL cutoff: 11° (n=188)		
		PT <20° (n=64)	PT ≥20° (n=124)	P^a	PI-LL <11° (n=126)	PI-LL ≥11° (n=62)	P^a
L4-S1 lordosis							
Pre	28.5 (10.5)	32.1 (8.66)	26.7 (10.9)	<0.001*	31.8 (9.09)	22.0 (10.1)	<0.001*
Post	28.1 (18.1)	33.6 (26.2)	25.3 (11.0)	0.018*	31.6 (20.2)	21.1 (9.53)	<0.001*
Delta	−0.37 (16.6)	1.59 (26.1)	−1.38 (8.07)	0.377	−0.12 (19.2)	−0.89 (9.39)	0.712
LL°							
Pre	51.2 (13.3)	53.0 (11.4)	50.2 (14.2)	0.152	55.8 (10.8)	41.8 (13.2)	<0.001*
Post	52.3 (13.4)	53.0 (12.8)	52.0 (13.7)	0.620	56.1 (11.3)	44.7 (14.0)	<0.001*
Delta	1.25 (8.82)	0.27 (7.84)	1.75 (9.28)	0.250	0.45 (7.05)	2.87 (11.5)	0.132
PI-LL°							
Pre	7.02 (13.2)	−2.23 (8.93)	11.8 (12.6)	<0.001*	−0.13 (8.20)	21.6 (8.84)	<0.001*
Post	5.85 (12.0)	−1.02 (9.72)	9.39 (11.6)	<0.001*	0.15 (8.59)	17.4 (9.45)	<0.001*
Delta	−1.18 (8.76)	1.21 (7.24)	−2.41 (9.23)	0.004*	0.28 (7.26)	−4.14 (10.7)	0.004*
PT°							
Pre	22.9 (8.90)	13.9 (4.69)	27.5 (6.76)	<0.001*	19.5 (7.71)	29.8 (7.03)	<0.001*
Post	23.1 (8.05)	17.3 (6.31)	26.1 (7.17)	<0.001*	20.0 (6.42)	29.4 (7.36)	<0.001*
Delta	0.17 (6.73)	3.34 (4.92)	−1.46 (6.97)	<0.001*	0.48 (6.22)	−0.44 (7.69)	0.415
SS°							
Pre	35.0 (10.1)	36.7 (8.66)	34.2 (10.7)	0.092	36.2 (9.14)	32.8 (11.6)	0.047*
Post	35.1 (9.93)	34.8 (8.83)	35.3 (10.5)	0.745	36.2 (9.37)	32.9 (10.7)	0.044*
Delta	0.07 (7.48)	−1.86 (6.02)	1.06 (7.97)	0.005*	0.03 (7.61)	0.15 (7.26)	0.920
LASD°							
Pre	26.7 (19.5)	19.7 (16.2)	30.3 (20.2)	<0.001*	21.6 (15.7)	37.1 (22.3)	<0.001*
Post	28.7 (19.8)	21.4 (13.1)	32.5 (21.6)	<0.001*	24.6 (16.5)	37.0 (23.4)	<0.001*
Delta	1.99 (15.1)	1.65 (14.2)	2.17 (15.6)	0.818	3.01 (14.4)	−0.09 (16.3)	0.205

*Statistical significance (P<0.05), [a]Independent samples t-test or Mann-Whitney U-test, Radiographic parameters reported as: Mean (SD). Radiographic parameters: LL - Lumbar lordosis, PI-LL - Pelvic incidence-LL, PT - Pelvic tilt, SS - Sacral slope, L4-S1 lordosis - Anterior disc height, posterior disk height, LASD - L1 axis-S1 distance, SD - Standard deviation

increased PI is an independent predictor in the development of DS.[35] However, no studies investigating the relationship between spinopelvic parameters and patient outcomes in patients with DS were included in the review.[13] A previous pilot study has demonstrated that improved postoperative PT resulted in reduced VAS and ODI scores for patients undergoing posterior lumbar interbody fusion (PLIF) for 1 or 2-level DS.[13] Other studies have found that spinopelvic parameters do not correlate with outcomes after surgery for patients with DS.[11] In a retrospective study of 84 patients investigating postoperative sagittal spinopelvic parameters and PROMs following PLDF and PLIF for DS, greater postoperative PI and LL were found to only weakly correlate with higher SF-36 scores ($r = 0.252$, $P = 0.022$ for PI and $r = 0.282$, $P = 0.010$ for LL).[12] PT was not found to correlate with PROMs, but the study's cohort had an average PT >20°. Furthermore, a retrospective analysis investigating outcomes in a cohort of predominantly DS patients, undergoing 1 or 2 level TLIF, found having a postoperative PI-LL mismatch was not associated with a change in ODI, MCS-12, PCS-12, VAS Back, and VAS Leg scores.[36]

In the current study, patients with preoperative measurements PI-LL ≥11° and PT >20° had similar PROMs, recovery ratios, and %MCID comparisons at 1-year postlumbar fusion surgery when compared to patients without a spinopelvic mismatch and with normal PT. In addition, all patients in both cohorts showed significant improvement in all PROMs. Patients corrected to optimal parameters also had similar clinical outcomes when compared to patients who had persistent postoperative suboptimal alignment. Although linear regression in our study suggested that PLDF in patients with PT >20° leads to greater improvement in PCS-12 and TLIF in patients with PI-LL ≥11° leads to worse PCS-12 scores, these findings were likely the result of selection biases. Indications to perform a TLIF were at the discretion of the surgeon and ultimately patients with more severe degenerative disease were more likely to receive PLDF with TLIF versus PLDF alone. Although the impact of spinopelvic alignment on clinical outcomes after surgery in patients with DS remains debated in the literature, our study is one of the first to examine the effects of preoperative alignment on postoperative outcomes and is among the largest sample sizes available specifically focusing on patients with single-level DS. Unlike the adult deformity literature, our exploratory study on single-level DS suggests short-term clinical outcomes may not be affected by preoperative spinopelvic alignment and correction of spinopelvic malalignment after short-segment fusions. However, adjacent segment disease and long-term outcomes may continue to be influenced by poor spinopelvic alignment and long-term studies evaluating PROMs and adjacent segment disease is indicated in this population.

It is important to consider that patients with DS present with widely variable radiographic measures and the effect of sagittal alignment on clinical outcomes may not be equivalent for all patients.[4] In addition, patients with sagittal plane deformities often have associated spine disease that may confound pain and function, such as spinal stenosis, disc degeneration, pseudarthrosis, and sacro-iliac joint arthrosis.[37] Completely isolating the clinical impact as measured by one or more radiographic parameters is difficult and leads to some degree of variability in the relationship between these radiographic factors and clinical outcomes.[37]

Although 1-year postoperative clinical outcomes do not appear to be dictated by postoperative PI-LL mismatch, it is worth noting that patients in our cohort with preoperative PT >20° undergoing a PLDF had improved postoperative PI-LL mismatch. This can likely be attributed to an indirect reduction from on table positioning. Previous literature indicates that LL improves by almost 9° when placing the patient on a Jackson spinal table compared to standing radiographs, which likely accounts for the improvement in PI-LL mismatch found in our study.[38]

This study is not without limitations. The retrospective nature is inherently subject to selection bias. The study was limited to standing lateral radiographs as full-length standing films were not available for patients. Therefore, we were unable to assess overall sagittal alignment parameters which may serve as a potential confounder of outcomes. As mentioned above, patients with sagittal plane deformities may have associated spinal disease that are unaccounted for in this analysis. Additionally, this study is limited to 1-year follow-up. It is possible that patients with worse spinopelvic measures may experience worsening symptoms with longer follow-up and have a higher incidence of adjacent segment disease. Finally, the cohorts differed in duration of symptoms which was controlled for in regression analysis.

CONCLUSION

Our study suggests that patients with preoperative PT >20° is associated with a significantly greater reduction in PI-LL mismatch and an increase in SS due to on table patient positioning. PT >20° and PI-LL ≥11° had similar clinical outcomes at 1 year postoperatively for patients with L4-5 DS undergoing PLDF, with or without TLIF, when compared to patients below the aforementioned threshold values, respectively. Further, the correction of PT and PI-LL to optimal values did not affect 1-year PROMs. Our exploratory study suggests that PROMs may not be improved in this population at 1 year. However, additional high-quality studies are indicated to improve our understanding of the effect of continued spinopelvic malalignment and its implications on PROMs and the progression of adjacent segment disease at the long-term follow-up.

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Conflicts of interest
There are no conflicts of interest.

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Appendix A: Recovery ratios, minimal clinically important differences, and delta values of corrected and uncorrected alignments

Variable	Corrected PI-LL (*n*=19)	Uncorrected PI-LL (*n*=43)	*P*	Corrected PT (*n*=22)	Uncorrected PT (*n*=102)	*P*
ODI						
RR	0.52 (0.34-0.83)	0.66 (0.24-0.88)	0.775	0.52 (0.10-0.75)	0.71 (0.38-0.90)	0.098
MCID (%)	13 (86.7)	32 (84.2)	1.000	15 (71.4)	76 (87.4)	0.095
Delta	−26.0 (−46.0-−19.0)	−24.0 (−36.0-−11.67)	0.358	−19.18 (17.9)	−27.17 (21.7)	0.087
PCS-12						
RR	0.06 (0.16)	0.14 (0.16)	0.075	0.15 (0.00-0.19)	0.14 (0.01-0.28)	0.324
MCID (%)	5 (27.8)	21 (53.8)	0.121	11 (52.4)	53 (55.8)	0.967
Delta	4.47 (10.8)	10.2 (11.0)	0.074	6.74 (11.3)	10.1 (11.3)	0.230
MCS-12						
RR	0.10 (0.15)	0.10 (0.21)	0.999	0.06 (0.02-0.16)	0.08 (−0.08-0.24)	0.900
MCID (%)	5 (27.8)	17 (43.6)	0.397	4 (19.0)	34 (35.8)	0.222
Delta	3.88 (0.00-9.22)	56.0 (49.90-60.7)	0.959	3.95 (9.96)	4.88 (12.6)	0.717
VAS back						
RR	0.66 (0.20-0.90)	0.91 (0.33-1.00)	0.205	0.63 (0.08-0.88)	0.77 (0.30-1.00)	0.189
MCID (%)	8 (66.7)	19 (57.6)	0.735	10 (52.6)	49 (60.5)	0.713
Delta	−4.47 (−6.21-−1.49)	−3.0 (−5.89-−1.00)	0.397	−4.70 (−6.27-−0.30)	−3.18 (−5.76-−0.63)	0.819
VAS leg						
RR	0.80 (0.22-1.00)	0.86 (0.28-1.00)	0.864	0.64 (0.15-1.00)	0.90 (0.38-1.00)	0.270
MCID (%)	8 (66.7)	21 (63.6)	1.000	9 (50.0)	55 (67.9)	0.244
Delta	−5.06 (−7.48-−1.78)	−4.01 (−6.63-0.39)	0.293	−2.62 (−6.27-−0.63)	−4.38 (−7.00-−1.11)	0.514

PCS-12 - Physical component of-12, MCS-12 - Mental component of-12, ODI - Oswestry disability index, VAS - Visual analog scale, VAS back - VAS back pain, VAS leg - VAS leg pain, RR - Recovery ratio, MCID - Minimal clinically important difference, PT - Pelvic tilt, PI-LL - Pelvic incidence-lumbar lordosis