Original Article

Does change in focal lordosis after spinal fusion affect clinical outcomes in degenerative spondylolisthesis?

ABSTRACT

Study Design: Retrospective cohort study.

Objective: The objective of this study is to determine the effect of focal lordosis and global alignment and proportion (GAP) scores on patient reported outcome measures (PROMs) after posterior lumbar fusion for patients with 1- or 2-level lumbar degenerative spondylolisthesis (DS).

Summary of Background Data: In patients with DS, improvements in spinopelvic parameters are believed to improve clinical outcomes. However, the effect of changing focal lordosis in patients with 1-or 2-level degenerative lumbar spondylolisthesis is unclear.

Materials and Methods: Postoperative spinopelvic parameters and perioperative focal lordosis changes were measured for 162 patients at a single academic center from January 2013 to December 2017. Patients were divided into three groups: >2° (lordotic group), between 2° and −2° (neutral group), and −2° (kyphotic group). Patients were then reclassified based on GAP scores. Recovery ratios (RR) and the number of patients achieving the minimal clinically important difference (MCID) were calculated for PROMs. Standard descriptive statistics were reported for patient demographics and outcomes data. Multiple linear regression analysis controlled for confounders. Alpha was set at $P < 0.05$.

Results: There was no significant association between change in focal lordosis and surgical complications including adjacent segment disease ($P = 0.282$), instrumentation failure ($P = 0.196$), pseudarthrosis ($P = 0.623$), or revision surgery ($P = 0.424$). In addition, the only PROM affected by change in focal lordosis was Mental Component Scores (MCS-12) (lordotic = 2.5, neutral = 8.54, and kyphotic = 5.96, $P = 0.017$) and RR for MCS-12 (lordotic = 0.02, neutral = 0.14, kyphotic 0.10, $P = 0.008$). Linear regression analysis demonstrated focal lordosis was a predictor of decreased improvement in MCS-12 ($\beta = -6.45$ [−11.03- −1.83], $P = 0.007$). GAP scores suggested patients who were correctly proportioned had worse MCID compared to moderately disproportioned and severely disproportioned patients ($P = 0.024$).

Conclusions: The change in focal lordosis not a significant predictor of change in PROMs for disability, pain, or physical function. Proportioned patients based on the GAP score had worse MCID for Oswestry Disability Index.

Level of Evidence: III

Keywords: Degenerative spondylolisthesis, lordosis, patient reported outcome measures, posterolateral fusion, transforaminal lumbar interbody fusion

Brian A. Karamian[1], Stephen DiMaria[1], Mark J. Lambrechts[1], Nicholas D. D'Antonio[1], Andrew Sawires[2], Jose A. Canseco[1], I. David Kaye[1], Barrett I. Woods[1], Mark F. Kurd[1], Jeffery A. Rihn[1], Joseph K. Lee[1], Alan S. Hilibrand[1], Christopher K. Kepler[1], Alexander R. Vaccaro[1], Gregory D. Schroeder[1]

[1]Rothman Orthopaedic Institute, Thomas Jefferson University, Philadelphia, Pennsylvania, [2]Department of Orthopedic Surgery, Lenox Hill Hospital, New York City, New York, USA

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

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INTRODUCTION

Degenerative spondylolisthesis (DS) typically follows a progressive course, evolving from disc degeneration and narrowing of the intervertebral disc space to resultant buckling of the ligamentum flavum, and ultimately instability of the affected spinal segment.[1,2] The eventual compromise of the facet joints and the supporting capsular ligaments result in either anterolisthesis or retrolisthesis

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of the motion segment, which leads to a net effect of segmental hypolordosis or kyphosis.[3,4] Although patients are often asymptomatic, DS can ultimately lead to sagittal imbalance and symptomatic spinal stenosis.[3,4] If conservative management does not improve patients pain or functional status, surgery is indicated due to its superior short and long-term outcomes compared to nonoperative modalities.[5,6]

A variety of surgical techniques ranging from decompression alone to decompression and fusion have been described for DS.[7] Posterolateral fusion (PLF), which involves placement of inter-transverse process bone graft to fuse the segment is one of the mainstays of surgical treatment for DS.[3,4] However, PLF has been increasingly replaced by transforaminal lumbar interbody fusion (TLIF).[8] Theoretically, TLIFs provide indirect decompression by distraction of the intervertebral disc space with an interbody cage, but the cage also allows placement of bone graft anteriorly to supplement the posterior fusion. While TLIFs potentially allow for improved disc space distraction, its ability to improve preoperative lordosis is questionable.[9,10]

Previous research has investigated the relationship between radiographic spinopelvic parameters and outcomes in patients with DS after 1-and 2-level TLIFs. Improvements in pelvic tilt (PT), pelvic incidence-lumbar lordosis (PI-LL) mismatch, and sagittal vertical axis improve Oswestry Disability Index (ODI) and Visual Analogue Scale Back (VAS Back) scores.[10] Furthermore, in patients undergoing posterior lumbar interbody fusion, increased postoperative PT appears correlated with worse low back pain suggesting increased pelvic retroversion and loss of LL are associated with postoperative pain.[11] The global alignment and proportion (GAP) score was devised initially for adult spinal deformity surgery patients to predict mechanical complications and revisions in patients who were not proportionally aligned.[12] Whether these scores have any predictive effect on the clinical outcomes of DS patients with spinopelvic malalignment is unclear.

Despite prior research evaluating global spinopelvic parameters in DS, the role of focal lordosis is also not yet fully elucidated. Studies investigating sagittal alignment after TLIF have demonstrated variable change in perioperative focal lordosis.[13,14] Therefore, the aim of this study is to determine the association between changes in focal lordosis and GAP scores and their effects on patient reported outcomes in patients undergoing 1-or 2-level posterolateral lumbar fusion procedures for degenerative lumbar spondylolisthesis.

MATERIALS AND METHODS

Patient selection and data collection

After review from our Institutional Review Board, our project was given exempt status (Control #19D.508). We retrospectively reviewed patients with a 1-or 2-level lumbar decompression and fusion for DS at a single, academic center between January 1, 2013 and December 31, 2017. Using a Standardized Query Language (SQL) search, patients with PLF alone or in combination with TLIF were identified using Common Procedural Terminology codes: 22612, 22630, 22633, 22840, 22842. Decision to perform PLF alone or PLF with TLIF was at the discretion of the surgeon. Any reduction in spondylolisthesis obtained after fusion was achieved indirectly since no surgeon attempts a formal reduction at our institution. All fusion were achieved with a combination of cancellous bone autograft and allograft. The exclusion criteria included <1 year follow-up, an arthrodesis procedure of >2-levels, any fusion technique other than PLF (with or without TLIF), revision surgery, or a surgical indication of infection, trauma, or malignancy.

Demographics and surgical characteristics

Patient demographics and surgical case characteristics were obtained via SQL search and manual chart review. Standing lateral radiographs of all patients were then reviewed and each patient was classified according to the Clinical and Radiographic DS Classification: type A – disc space collapse (advanced) with no evidence of kyphosis, Type B – disc space preserved (partially) with <5.0 mm of translation, Type C – disc space preserved (partially) with >5.0 mm of translation, and Type D– kyphotic alignment pattern.[15]

In addition, surgical complications including rate of revision surgery, instrumentation failure, symptomatic pseudarthrosis, and adjacent segment disease (ASD) were recorded. Pseudarthrosis was defined as nonbridging bone at the fusion level a minimum of 6 months after surgery and it required the diagnosis by computed tomography. ASD was defined as either symptomatic adjacent level listhesis or symptomatic canal stenosis, which had advanced compared to preoperative imaging.

Patient reported outcomes

Baseline and postoperative patient reported outcome measures (PROMs) were gathered at 1-year for each patient. PROMs collected included ODI, Physical and Mental Component Scores of the Short Form-12 Health Survey (PCS-12 and MCS-12, respectively), VAS Back and Leg (VAS Leg) pain scores. Recovery ratios (RR) and the percent of patients achieving the minimum clinically important

difference (MCID) were calculated to determine the extent to which patients benefitted from surgical intervention. RR is defined as Δ PROM/([“Optimal” PROM-baseline PROM]), using a score of 0 as “optimal” for ODI, VAS Back, and VAS Leg, and a score of 100 as “optimal” for PCS-12 and MCS-12. The number of patients who achieved the MCID was calculated 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, VAS Leg: 2.4 points.[16,17]

Radiographic measures

Radiographic measurements were performed on standing lateral lumbar radiographs and included focal lordosis, PI, LL, mismatch PI-LL, PT, and sacral slope (SS). Focal lordosis measurements were obtained preoperatively and 1-year postoperatively utilizing Cobb angles based on the superior endplate of the cephalad fusion level to the inferior endplate of the caudal fusion level. Patients were divided into three groups based on the change in focal lordosis (i.e., the difference between postoperative and preoperative focal lordosis measurements): lordotic group (>2° of segmental lordosis 7) segmental lordosis after surgery. A cutoff of two degrees was chosen based on previous literature demonstrating a standard error of measurement for determining LL of 1.99°.[18] Each patient then had a GAP score calculated. The GAP score is based on the inherent anatomy of each individual, as such, each parameter accounts for the patients fixed PI. The score is comprised of the following: patients age (<60 or >60), relative pelvic version (measured minus ideal SS), relative LL (measured minus ideal LL), lordosis distribution index (L4-S1 lordosis divided by L1-S1 and multiplied by 100) and relative spinopelvic alignment (measured minus ideal global tilt – since this required full length standing radiographs this measurement was not calculated or included for our analysis).[12] A score is then applied based on if a patient is appropriately proportioned (0–2), moderately disproportioned (3–6), or severely disproportioned (>7). All radiographic measurements were conducted on Sectra Workstation IDS7 18.2 (Sectra AB; Linköping, Sweden).

Statistical analysis

Standard descriptive statistics including proportions, means, and 95% confidence intervals (CI) were reported for patient demographics, follow-up, and outcomes data. Differences in demographic characteristics were compared using Pearson Chi-square test for categorical variables. For normally distributed continuous variables, a one-way ANOVA test with a Bonferroni *post hoc* test was used to compare means between groups. For nonnormally distributed outcome scores, a Kruskal-Wallis test with a Dunn *post hoc* test was used to compare means between groups. Primary analysis compared baseline, postoperative, and Δ (postoperative minus preoperative) PROM scores between the three groups. Secondary analysis included multiple linear regression analysis including surgery type, focal lordosis, age, sex, Body mass index (BMI), smoking status, duration of symptoms, and workers’ compensation status to determine independent predictors of change in PROMs. All statistical analyses were conducted using RStudio (Version 1.3.1073-1, RStudio, Inc., Boston, MA) where the threshold for statistical significance was set at $P < 0.05$.

RESULTS

Demographics and surgical complications

A total of 162 patients were included for analysis, 43 (26.5%) were allocated to the neutral lordosis group (>2° and <−2°), 58 (35.8%) to the focal kyphotic group (<−2°), and 61 (37.7%) to the focal lordosis group (>2°). There was no difference in age ($P = 0.779$), sex ($P = 0.509$), BMI ($P = 0.748$), smoking status ($P = 0.7$), duration of preoperative symptoms ($P = 0.112$), or physical therapy status ($P = 0.522$) between groups. However, there was a significant difference in worker’s compensation (WC) status between the neutral, kyphotic, and lordotic groups with 32.6%, 31.0%, and 13.1% of patients receiving WC, respectively ($P < 0.001$) [Table 1].

In the neutral group, 76.7% of patients had a stand-alone PLF, 60.3% of the kyphotic group had a stand-alone PLF, and 85.2% of the lordotic group had a stand-alone PLF with the remaining patients having both a TLIF and PLF procedure. This resulted in a significant difference in procedure types between groups ($P = 0.007$). Length of follow-up was also significantly shorter in the focal lordosis group (months, 20.9 neutral vs. 21.1 kyphotic vs. 17.4 lordotic, $P = 0.018$). No other significant surgical characteristics or surgical complications were identified between groups including rate of ASD ($P = 0.282$), instrumentation failure ($P = 0.196$), pseudarthrosis ($P = 0.623$), or revisions ($P = 0.424$) [Table 2].

After reclassifying patients based on GAP scores into proportioned ($N = 36$), moderately disproportioned ($N = 72$), and severely disproportioned ($N = 52$) alignment, younger age ($P = 0.004$) and physical therapy use ($P < 0.001$) significantly favored the proportioned GAP group [Appendix A]. There was no significant differences in surgical complications [Appendix B].

Patient reported outcomes

The mean change in focal lordosis among the three groups was −0.4°, −7.0°, and 11.1° for the neutral, kyphotic, and lordotic groups, respectively ($P < 0.001$). There was no significant difference in the focal lordosis achieved between patients receiving PLF alone or PLF with TLIF (1.18° vs. 1.56°

Table 1: Demographics of cohort based on degree of curvature

Demographics	Neutral (−2°-2°), *n* (%)	Kyphotic (<−2°), *n* (%)	Lordotic (>2°), *n* (%)	*P*[1]
Total (*n*=162)	*n*=43	*n*=58	*n*=61	
Age, mean (SD)	63.8 (11.1)	62.2 (9.28)	63.3 (12.8)	0.779
Sex				
Male	22 (51.2)	23 (39.7)	28 (45.9)	0.509
Female	21 (48.8)	35 (60.3)	33 (54.1)	
BMI, mean (SD)	30.0 (5.98)	31.2 (6.76)	31.2 (6.78)	0.748
Smoking status				
Never	27 (62.8)	33 (56.9)	37 (60.7)	0.700
Current	7 (16.3)	10 (17.2)	6 (9.84)	
Former	9 (20.9)	15 (25.9)	18 (29.5)	
Duration of preoperative symptoms (months)				
3	12 (27.9)	18 (31.0)	31 (50.8)	0.112
3-6	13 (30.2)	18 (31.0)	12 (19.7)	
6+	18 (41.9)	22 (37.9)	18 (29.5)	
Worker's compensation status				
No workers comp	27 (62.8)	37 (63.8)	36 (59.0)	<0.001*
Workers comp	14 (32.6)	18 (31.0)	8 (13.1)	
Retired	2 (4.65)	3 (5.17)	17 (27.9)	
Physical therapy group				
No	15 (34.9)	18 (31.0)	25 (41.0)	0.522
Yes	28 (65.1)	40 (69.0)	36 (59.0)	

*Statistical significance ($P<0.05$), [1]Baseline demographics were compared between groups with Pearson's Chi-square, one-way ANOVA, or Kruskal-Wallis H-test. SD - Standard deviation, BMI - Body mass index

Table 2: Surgical characteristics and outcomes based on degree of curvature

Surgical characteristics and outcomes	Neutral (−2°-2°), *n* (%)	Kyphotic (<−2°), *n* (%)	Lordotic (>2°), *n* (%)	*P*[1]
Total (*n*=162)	*n*=43	*n*=58	*n*=61	
Surgery				
PLF	33 (76.7)	35 (60.3)	52 (85.2)	0.007*
PLF + TLIF	10 (23.3)	23 (39.7)	9 (14.8)	
CARDS classification				
A	11 (25.6)	17 (29.3)	18 (29.5)	0.139
B	9 (20.9)	12 (20.7)	9 (14.8)	
C	18 (41.9)	21 (36.2)	33 (54.1)	
D	5 (11.6)	8 (13.8)	1 (1.64)	
Follow up (months), mean (SD)	20.9 (12.9)	21.1 (10.1)	17.4 (11.1)	0.018*
Adjacent segment disease				
No	30 (69.8)	48 (82.8)	45 (73.8)	0.282
Yes	13 (30.2)	10 (17.2)	16 (26.2)	
Instrumentation failure				
No	43 (100)	56 (96.6)	61 (100)	0.196
Yes	0	2 (3.45)	0	
Pseudoarthrosis				
No	43 (100)	57 (98.3)	61 (100)	0.623
Yes	0	1 (1.72)	0	
Revisions				
No	40 (93.0)	57 (98.3)	57 (93.4)	0.424
Yes	3 (6.98)	1 (1.72)	4 (6.56)	

*Statistical significance ($P<0.05$), [1]Surgical characteristics were compared between groups with Pearson's Chi-Square, One-way ANOVA, Kruskal-Wallis H-tests, or Fisher's exact tests. SD - Standard deviation, PLF - Posterolateral fusion, TLIF - Transforaminal lumbar interbody fusion, CARDS - Clinical and Radiographic Degenerative Spondylolisthesis

respectively, $P = 0.707$). Although there were significant differences between groups when evaluating the MCS-12 baseline (44.2 neutral vs. 48.2 kyphotic vs. 50.2 lordotic, $P = 0.014$), MCS-12 Δ (8.54 neutral vs. 5.96 kyphotic vs. 2.50 lordotic, $P = 0.017$) and MCS-12 RR (0.14 neutral vs. 0.10 lordotic vs. 0.02 kyphotic, $P = 0.008$), there were no

significant differences in the postoperative MCS-12 or MCID between groups. Additionally, there were no significant differences among the three groups when evaluating the remaining PROMs (ODI, PCS-12, VAS Back, VAS Leg). All clinical outcome scores are presented in Table 3.

Multiple linear regression analysis demonstrated the lordotic group to be a significant negative predictor of MCS-12 improvement (β-coefficient = −6.47, 95% CI [−11.00 - −1.95], P = 0.006), while having a PLF procedure alone predicted improvement in MCS-12 scores (β-coefficient = 4.38, 95% CI [0.34–8.42], P = 0.036). WC (β-coefficient = −2.13, 95% CI [−4.11 - −0.16], P = 0.037) and symptom duration of 3–6 months (β-coefficient = −1.81, 95% CI [−1.72 - −0.016], P = 0.043) were found to be a significant negative predictors of VAS Leg score improvement. Additionally, focal lordosis and procedure type (PLF alone vs. PLF with TLIF) were not found to be a significant predictor of outcome scores for any of the other outcome measures [Table 4].

After reclassifying patients based on GAP scores, only MCID for ODI was found to be significantly different (P = 0.024) [Table 5]. Examination of the GAP score components including relative LL [Appendix C], relative pelvic version [Appendix D], and lordosis distribution index [Appendix E], revealed only the preoperative PCS-12 was significant for relative pelvic

Table 3: Patient reported outcome measurements based on focal lordosis

PROM	Neutral (−2°-2°)	Kyphotic (<−2°)	Lordotic (>2°)	P[1]
Total (n=162)	n=43	n=58	n=61	
ODI pre	44.5 (15.5)	44.7 (17.8)	45.0 (17.9)	0.989
ODI post	18.1 (16.4)	24.5 (20.2)	20.2 (17.4)	0.411
ODI Δ	−24.54 (18.4)	−19.94 (17.7)	−24.46 (19.5)	0.373
ODI RR	0.57 (0.36)	0.48 (0.42)	0.54 (0.41)	0.532
ODI MCID				
No	6 (16.2)	11 (21.2)	7 (13.0)	0.526
Yes	31 (83.8)	41 (78.8)	47 (87.0)	
PCS-12 pre	31.1 (7.38)	30.0 (8.21)	32.0 (9.38)	0.428
PCS-12 post	40.5 (10.7)	38.7 (11.4)	42.6 (10.8)	0.186
PCS-12 Δ	8.82 (10.6)	8.76 (10.00)	10.2 (11.1)	0.739
PCS-12 RR	0.12 (0.15)	0.12 (0.14)	0.14 (0.17)	0.717
PCS-12 MCID				
No	19 (50.0)	26 (50.0)	25 (45.5)	0.868
Yes	19 (50.0)	26 (50.0)	30 (54.5)	
MCS-12 pre	44.2 (11.6)	48.2 (10.3)	50.2 (11.3)	0.014*
MCS-12 post	52.5 (8.50)	54.5 (8.73)	53.4 (9.21)	0.366
MCS-12 Δ	8.54 (9.22)	5.96 (9.91)	2.50 (10.9)	0.017*
MCS-12 RR	0.14 (0.15)	0.10 (0.17)	0.02 (0.21)	0.008*
MCS-12 MCID				
No	20 (52.6)	36 (69.2)	41 (74.5)	0.079
Yes	18 (47.4)	16 (30.8)	14 (25.5)	
VAS back pre	6.36 (2.77)	6.58 (2.67)	5.60 (3.05)	0.213
VAS back post	2.88 (2.73)	3.11 (2.74)	2.94 (2.74)	0.936
VAS back Δ	−3.37 (3.74)	−3.48 (3.25)	−2.34 (3.34)	0.130
VAS back RR	0.58 (0.52)	0.58 (0.41)	0.42 (0.81)	0.587
VAS back MCID				
No	8 (27.6)	16 (39.0)	25 (48.1)	0.193
Yes	21 (72.4)	25 (61.0)	27 (51.9)	
VAS leg pre	6.78 (3.01)	6.50 (2.56)	6.05 (3.01)	0.371
VAS leg post	2.66 (3.08)	3.34 (3.27)	2.47 (2.63)	0.337
VAS leg Δ	−4.33 (4.30)	−3.28 (3.89)	−3.34 (3.55)	0.275
VAS leg RR	0.59 (0.68)	0.56 (0.47)	0.52 (0.75)	0.613
VAS back MCID				
No	8 (27.6)	16 (39.0)	25 (48.1)	0.193
Yes	21 (72.4)	25 (61.0)	27 (51.9)	

*Statistical significance (P<0.05). PROMs reported as: Mean (SD), PROMs - ODI, PCS-12, MCS-12, VAS, VAS Back, VAS Leg. Δ PROM - Postoperative score at 1 year - preoperative score [1]Independent samples t-test or Mann-Whitney U-test. RR - Recovery ratio, MCID - Minimally clinically important difference, ODI - Oswestry disability index, PCS-12 - Short-form-12 physical component score, MCS-12 - Mental component score, VAS - Visual analogue score, VAS back - VAS back pain, VAS leg - VAS leg pain, PROMs - Patient reported outcome measurements, SD - Standard deviation

Table 4: Multiple linear regression analysis for Δ patient reported outcome measurements

Variable	Δ ODI score		Δ PCS-12		Δ MCS-12		Δ VAS back		Δ VAS leg	
	β coefficient (95% CI)	*P*	β coefficient (95% CI)	*P*	β coefficient (95% CI)	*P*	β coefficient (95% CI)	*P*	β coefficient (95% CI)	*P*
Surgery type										
PLF + TLIF	Reference		Reference		Reference		Reference		Reference	
PLF	1.81 (−5.67-9.28)	0.636	−1.42 (−5.61-2.78)	0.509	4.38 (0.34-8.42)	0.036*	0.36 (−1.18-1.91)	0.646	0.90 (−0.80-2.59)	0.303
Focal lordosis										
Neutral	Reference		Reference		Reference		Reference		Reference	
Kyphotic (<−2°)	4.67 (−3.41-12.75)	0.259	−0.56 (−5.12-3.99)	0.809	−3.83 (−8.22-0.55)	0.089	−0.20 (−1.91-1.51)	0.819	0.87 (−1.03-2.77)	0.370
Lordotic (>2°)	−1.42 (−9.64-6.81)	0.736	1.97 (−2.73-6.66)	0.414	−6.47 (−11.00-−1.95)	0.006*	0.71 (−0.98-2.390)	0.414	0.22 (−1.67-2.11)	0.820
Age	0.14 (−0.15-0.44)	0.339	−0.10 (−0.27-0.08)	0.267	−0.04 (−0.20-0.13)	0.684	0.02 (−0.04-0.09)	0.504	0.06 (−0.01-0.13)	0.089
Sex	−2.94 (−9.21-3.32)	0.359	1.35 (−2.19-4.90)	0.455	2.53 (−0.88-5.94)	0.148	0.52 (−0.77-1.810)	0.433	0.52 (−0.90-1.95)	0.472
BMI	0.36 (−0.15-0.85)	0.168	−0.17 (−0.45-0.12)	0.259	−0.10 (−0.38-0.18)	0.478	0.04 (−0.06-0.14)	0.433	0.06 (−0.05-0.17)	0.311
Smoking status										
Never	Reference		Reference		Reference		Reference		Reference	
Current	5.76 (−3.51-14.67)	0.231	−2.65 (−7.80-2.49)	0.314	−1.56 (−6.52-3.39)	0.538	1.58 (−0.25-3.40)	0.094	1.20 (−0.81-3.20)	0.246
Former	−6.06 (−13.43-1.30)	0.109	4.20 (−0.06-8.46)	0.056	0.13 (−3.98-4.24)	0.951	0.37 (−1.16-1.89)	0.638	−0.24 (−1.92-1.44)	0.779
Duration of symptoms (months)										
<3	Reference		Reference		Reference		Reference		Reference	
3-6	−0.61 (−8.46-7.25)	0.880	2.22 9−2.38-6.81)	0.346	−2.92 (−7.34-1.51)	0.199	−1.01 (−2.62-0.59)	0.218	−1.81 (−3.59-−0.04)	0.048*
>6	3.85 (−4.54-12.24)	0.370	−2.12 (−6.92-2.68)	0.389	−2.69 (−7.32-1.93)	0.256	−0.04 (−1.79-1.71)	0.963	0.20 (−1.72-2.13)	0.835
Workers comp										
No	Reference		Reference		Reference		Reference		Reference	
Yes	−1.72 (−10.16-6.73)	0.690	2.33 (−2.46-7.12)	0.341	−0.04 (−4.65-4.57)	0.987	−0.98 (−2.78-0.82)	0.288	−2.13 (−4.11-−0.16)	0.037*
Retired	10.57 (0.08-21.06)	0.050	−4.21 (−10.05-1.63)	0.160	−0.76 (−6.38-4.860	0.792	0.18 (−1.83-2.18)	0.862	0.44 (−1.76-2.65)	0.693

*Statistical significance ($P<0.05$), Δ PROM - Postoperative score at 1 year - preoperative score, Multivariate analysis - Regression model, reported as: β coefficient (95% CI), *P* value, Regression models for neutral, kyphotic, and lordotic cohort. PROMs - ODI, PCS-12, MCS-12, VAS, VAS Back, VAS Leg. ODI - Oswestry Disability Index, PCS-12 - Shortform-12 physical component score, MCS-12 - Mental component score, VAS - Visual analogue Score, VAS Back - VAS back pain, VAS Leg - VAS leg pain, PLF - Posterolateral fusion, TLIF - Transforaminal lumbar interbody fusion, CI - Confidence interval, BMI - Body mass index

Table 5: Global alignment and proportion score (0-2: Proportioned, 3-6: Mod disproportioned, >7: Severely disproportioned)

	Proportioned, *n* (%)	Moderately disproportioned, *n* (%)	Severely disproportioned, *n* (%)	*P*[1]
Total (*n*=162)	*n*=38	*n*=72	*n*=52	
ODI				
Preoperative	42.2 (18.2)	46.7 (16.1)	44.1 (17.7)	0.412
Postoperative 1 year	23.1 (19.9)	21.5 (18.6)	19.4 (16.7)	0.820
Δ 1 year	−17.56 (18.0)	−24.41 (19.0)	−24.77 (18.0)	0.153
RR	0.45 (0.44)	0.54 (0.37)	0.57 (0.41)	0.480
MCID				
No	11 (31.4)	9 (13.6)	4 (9.52)	0.024*
Yes	24 (68.6)	57 (86.4)	38 (90.5)	
PCS-12				
Preoperative	32.3 (9.85)	30.2 (7.85)	31.2 (8.20)	0.616
Postoperative 1 year	40.7 (11.6)	40.3 (11.3)	41.0 (10.6)	0.953
Δ 1 year	7.49 (11.3)	9.70 (10.9)	10.1 (9.36)	0.501
RR	0.10 (0.18)	0.14 (0.15)	0.14 (0.13)	0.683
MCID				
No	20 (58.8)	31 (47.0)	19 (42.2)	0.329
Yes	14 (41.2)	35 (53.0)	26 (57.8)	
MCS-12				
Preoperative	49.0 (9.43)	48.8 (11.2)	45.8 (12.2)	0.303
Postoperative 1 year	54.4 (8.00)	53.8 (8.45)	52.7 (10.00)	0.883
Δ 1 year	4.95 (10.0)	4.70 (10.2)	6.52 (10.8)	0.644
RR	0.08 (0.18)	0.07 (0.18)	0.10 (0.20)	0.741
MCID				
No	24 (70.6)	46 (69.7)	27 (60.0)	0.494
Yes	10 (29.4)	20 (30.3)	18 (40.0)	
VAS back				
Preoperative	6.29 (2.89)	6.16 (2.64)	6.03 (3.16)	0.937
Postoperative 1 year	3.65 (2.74)	2.63 (2.55)	2.99 (2.90)	0.226
Δ 1 year	−2.21 (3.40)	−3.26 (2.77)	−3.04 (4.20)	0.272
RR	0.49 (0.46)	0.55 (0.45)	0.46 (0.91)	0.688
MCID				
No	15 (51.7)	21 (38.2)	14 (35.9)	0.372
Yes	14 (48.3)	34 (61.8)	25 (64.1)	
VAS leg				
Preoperative	6.39 (2.61)	6.70 (2.84)	6.01 (3.06)	0.361
Postoperative 1 year	3.59 (3.16)	2.44 (2.87)	2.79 (2.96)	0.242
Δ 1 year	−2.85 (2.95)	−4.14 (3.93)	−3.23 (4.25)	0.174
RR	0.52 (0.48)	0.64 (0.53)	0.45 (0.87)	0.495
MCID				
No	15 (51.7)	16 (29.6)	14 (36.8)	0.139
Yes	14 (48.3)	38 (70.4)	24 (63.2)	

*Statistical significance ($P<0.05$), [1]Surgical characteristics were compared between groups with Pearson's Chi-Square, One-way ANOVA, Kruskal-Wallis H-tests, or Fisher's exact tests, ODI - Oswestry disability index, PCS-12 - Short-form 12 physical component score, MCS-12 - Mental component score, VAS - Visual analogue score, VAS back - VAS for back pain, VAS leg - VAS leg pain, PROMS - Patient reported outcome measurements, RR - Recovery ratio, MCID - Minimally clinically important difference

version ($P = 0.025$) and 1-year postoperative VAS Back was significant for the lordosis distribution group ($P = 0.033$).

DISCUSSION

Previous literature suggests clinical outcomes improve with restoration of spinopelvic parameters after surgery in patients with lumbar DS.[19] The aim of this study was to determine the association between changes in focal lordosis (primary objective) and GAP scores (secondary objective) on patient reported outcomes in patients with 1-or 2-level DS who received fusion surgery. We found that increases in focal lordosis correlated with worse MCS-12 outcomes, while GAP scores demonstrated worse MCID for ODI, but they otherwise were not associated with significant changes in PROMs.

Although analysis of MCS-12 outcomes demonstrated significant differences in preoperative scores ($P = 0.014$), Δ scores ($P = 0.017$), and the RR ($P = 0.008$), no significant differences were seen in postoperative MCS-12 scores or in the

MCID. The reduced improvement of postoperative MCS-12 in the focal lordosis group can be attributed to their significantly higher baseline functional scores, ultimately resulting in similar postoperative mental health component scores compared to the neutral and kyphotic focal lordosis groups. Although lordosis was a significant negative predictor of MCS-12 scores on multivariate analysis, no significant clinical differences were achieved based upon previously established MCID values.[16]

Few studies have specifically evaluated the impact of focal lordosis on outcomes after fusion surgery.[20] Our study represents the largest cohort evaluating focal lordosis in the setting of lumbar fusion for DS, with the next largest cohort consisting of 73 patients.[21] In that study they evaluated if *in situ* fusion or spondylolisthesis reduction prior to fusion improved focal lordosis. Although patients who received a reduction had significantly improved focal lordosis postoperatively ($P = 0.003$), there was no significant improvement in clinical outcomes at any time point.[21] Similarly, in our study the degree of focal lordosis did not have a significant association with changes in PROMs. In a systematic review investigating the effect of restoring LL on PROMs in single-level DS, the authors concluded that correction of focal lordosis for single-level lumbar DS did not affect PROMs.[22] Similar results were found in a study examining 2-level lumbar DS, which found correction of focal lordosis and LL had no impact on the postoperative Japanese Orthopaedic Association score.[23] One likely explanation for this finding is that the sagittal malalignment produced from a 1-or 2-level DS is relatively small compared to the normal amount of lordosis present in the lower lumbar spine.[24] Additionally, distraction of the disc space during interbody fusion has been shown to result in an indirect partial reduction in focal lordosis.[13] As a result, patients are no longer required to retrovert their pelvis to compensate. This allows for improvement in clinical outcomes without significant changes in focal lordosis.

Previous studies examining patient outcomes based on surgical techniques of PLF versus PLF with TLIF have failed to identify significant differences in clinical outcomes or radiographic fusion rates.[20,25] In the present study, more PLF procedures resulted in a position of greater focal lordosis compared to combined PLF and TLIF procedures. This finding is similar to previous literature, which failed to identify a significant increase in focal lordosis after TLIF.[14] One explanation involves the morphological changes in the spine secondary to degeneration and the listhetic process, which can limit and modify the ability to correct deformity.[26,27] Additionally, surgical techniques including suboptimal cage positioning, inadequate facetectomy, and lack of compression through the posterior instrumentation can also contribute to the lack of postoperative lordosis.[28]

The GAP score was designed for adult deformity surgery and it has not been validated for DS, however, it accounts for a patient's fixed PI, which ultimately affects their SS and PT.[12] It, therefore, may be useful tool to predict which patients have a well-proportioned LL and pelvic alignment postoperatively. Theoretically, patients with proportioned alignments, including correction of the spondylolisthesis into ideally proportioned lordosis and pelvic version, should have better outcomes. However, our exploratory study suggests GAPs do not affect short-term patient-reported outcomes or surgical complications. Patients in the proportioned groups were significantly younger than the moderately and severely disproportioned groups, but previous studies have not indicated age alone is a predictor of PROMs.[29,30] Therefore, longer-term studies are indicated to determine if patients with disproportioned alignments have worse PROMs or increased complications including ASD.

When evaluating patients by surgical complications, there was no significant difference in rate of revisions, pseudarthrosis, instrumentation failure or ASD based on focal lordosis or GAP groupings. A review of the literature by Park *et al*. identified the incidence of ASD ranges from 5% to 18.5% between 4 and 10 years follow up.[31] Our follow-up was significantly shorter with patients averaging <2-year follow-up, but our rate of ASD ranged from 17.2% to 30.2%. Surprisingly, there were higher rates of ASD in the lordotic (26.2%) and neutral (30.2%) groups, although this was not significant. As expected, there were also lower rates of ASD in the proportioned GAP group compared to the disproportioned groups, but this also did not reach significance. Previous literature has demonstrated focal kyphosis is likely a contributor to ASD due to increased stress on the supraadjacent intervertebral disc.[32] Longer clinical follow-up may improve our understanding of the interaction between acute changes in focal kyphosis and proportioned versus disproportionate alignment and its effect on ASD in patients with DS.

The retrospective nature of the study is inherently subject to limitations including selection and indication biases. This study incorporates PROMs as a primary endpoint, making it susceptible to recall bias. The three focal lordosis groups differed in surgery type and follow-up time. Nonetheless, several studies have shown that PLF alone, or in combination with TLIF, provides excellent outcomes with little to no difference in clinical satisfaction or radiographic fusion rates.[27,28,33] Surgical techniques could have varied by surgeon, contributing to a heterogenous population within each group. However, this makes the study more generalizable given the multitude of surgical techniques currently in practice throughout the world. Additionally, this study

evaluates short-term patient reported outcomes. Greater duration of patient follow-up may elicit changes in outcomes that were not evident in our study. Finally, radiographic parameters were measured on dedicated standing lateral lumbar radiographs. Full-length standing spine imaging would have allowed us to measure global spine alignment and would have given us completed GAP scores to see if focal lordosis correction or the complete GAP score affected patient reported outcomes. However, this was not within the scope of this manuscript as full-length standing radiographs were not available for these patients postoperatively.

CONCLUSIONS

Our study suggests changes in focal lordosis and GAP scores after lumbar fusion in patients with 1-and 2-level DS does not significantly affect 1-year clinical outcomes. This study is an exploratory study on the effect of postoperative sagittal alignment in patients undergoing 1-and 2-level fusion for spondylolisthesis and it suggests long-term data and further studies on GAP scores and the lordosis distribution index are indicated to elucidate drivers of improved patient outcomes and surgical complications including ASD.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Jacobsen S, Sonne-Holm S, Rovsing H, Monrad H, Gebuhr P. Degenerative lumbar spondylolisthesis: An epidemiological perspective: The copenhagen osteoarthritis study. Spine (Phila Pa 1976) 2007;32:120-5.
2. Kushchayev SV, Glushko T, Jarraya M, Schuleri KH, Preul MC, Brooks ML, *et al.* ABCs of the degenerative spine. Insights Imaging 2018;9:253-74.
3. Rosenberg N. Degenerative spondylolisthesis. Predisposing factors. JBJS 1975;57:467-74.
4. Sengupta DK, Herkowitz HN. Degenerative spondylolisthesis: Review of current trends and controversies. Spine (Phila Pa 1976) 2005;30:S71-81.
5. Weinstein JN, Lurie JD, Tosteson TD, Zhao W, Blood EA, Tosteson AN, *et al.* Surgical compared with nonoperative treatment for lumbar degenerative spondylolisthesis. four-year results in the Spine Patient Outcomes Research Trial (SPORT) randomized and observational cohorts. J Bone Joint Surg Am 2009;91:1295-304.
6. Lurie JD, Tosteson TD, Tosteson A, Abdu WA, Zhao W, Morgan TS, *et al.* Long-term outcomes of lumbar spinal stenosis: Eight-year results of the Spine Patient Outcomes Research Trial (SPORT). Spine (Phila Pa 1976) 2015;40:63-76
7. Ghogawala Z, Dziura J, Butler WE, Dai F, Terrin N, Magge SN, *et al.* Laminectomy plus fusion versus laminectomy alone for lumbar spondylolisthesis. N Engl J Med 2016;374:1424-34.
8. Kepler CK, Vaccaro AR, Hilibrand AS, Anderson DG, Rihn JA, Albert TJ, *et al.* National trends in the use of fusion techniques to treat degenerative spondylolisthesis. Spine (Phila Pa 1976) 2014;39:1584-9.
9. Rosenberg WS, Mummaneni PV. Transforaminal lumbar interbody fusion: Technique, complications, and early results. Neurosurgery 2001;48:569-74.
10. Cheng X, Zhang F, Zhang K, Sun X, Zhao C, Li H, *et al.* Effect of single-level transforaminal lumbar interbody fusion on segmental and overall lumbar lordosis in patients with lumbar degenerative disease. World Neurosurg 2018;109:e244-51.
11. Kim MK, Lee SH, Kim ES, Eoh W, Chung SS, Lee CS. The impact of sagittal balance on clinical results after posterior interbody fusion for patients with degenerative spondylolisthesis: A pilot study. BMC Musculoskelet Disord 2011;12:69.
12. Yilgor C, Sogunmez N, Boissiere L, Yavuz Y, Obeid I, Kleinstück F, *et al.* Global alignment and proportion (GAP) score: Development and validation of a new method of analyzing spinopelvic alignment to predict mechanical complications after adult spinal deformity surgery. J Bone Joint Surg Am 2017;99:1661-72.
13. Sears W. Posterior lumbar interbody fusion for degenerative spondylolisthesis: Restoration of sagittal balance using insert-and-rotate interbody spacers. Spine J 2005;5:170-9.
14. Champagne PO, Walsh C, Diabira J, Plante MÉ, Wang Z, Boubez G, *et al.* Sagittal balance correction following lumbar interbody fusion: A comparison of the three approaches. Asian Spine J 2019;13:450-8.
15. Kepler CK, Hilibrand AS, Sayadipour A, Koerner JD, Rihn JA, Radcliff KE, *et al.* Clinical and radiographic degenerative spondylolisthesis (CARDS) classification. Spine J 2015;15:1804-11.
16. Parker SL, Mendenhall SK, Shau D, Adogwa O, Cheng JS, Anderson WN, *et al.* Determination of minimum clinically important difference in pain, disability, and quality of life after extension of fusion for adjacent-segment disease. J Neurosurg Spine 2012;16:61-7.
17. Parker SL, Adogwa O, Paul AR, Anderson WN, Aaronson O, Cheng JS, *et al.* Utility of minimum clinically important difference in assessing pain, disability, and health state after transforaminal lumbar interbody fusion for degenerative lumbar spondylolisthesis. J Neurosurg Spine 2011;14:598-604.
18. Hicks GE, George SZ, Nevitt MA, Cauley JA, Vogt MT. Measurement of lumbar lordosis: Inter-rater reliability, minimum detectable change and longitudinal variation. J Spinal Disord Tech 2006;19:501-6.
19. Kong LD, Zhang YZ, Wang F, Kong FL, Ding WY, Shen Y. Radiographic restoration of sagittal spinopelvic alignment after posterior lumbar interbody fusion in degenerative spondylolisthesis. Clin Spine Surg 2016;29:E87-92.
20. Challier V, Boissiere L, Obeid I, Vital JM, Castelain JE, Bénard A, *et al.* One-level lumbar degenerative spondylolisthesis and posterior approach: Is transforaminal lateral interbody fusion mandatory?: A randomized controlled trial with 2-year follow-up. Spine (Phila Pa 1976) 2017;42:531-9.
21. Lian XF, Hou TS, Xu JG, Zeng BF, Zhao J, Liu XK, *et al.* Posterior lumbar interbody fusion for aged patients with degenerative spondylolisthesis: Is intentional surgical reduction essential? Spine J 2013;13:1183-9.
22. Rhee C, Visintini S, Dunning CE, Oxner WM, Glennie RA. Does restoration of focal lumbar lordosis for single level degenerative spondylolisthesis result in better patient-reported clinical outcomes? A systematic literature review. J Clin Neurosci 2017;44:95-100.
23. Takahashi Y, Okuda S, Nagamoto Y, Matsumoto T, Sugiura T, Iwasaki M. Effect of segmental lordosis on the clinical outcomes of 2-level posterior lumbar interbody fusion for 2-level degenerative lumbar spondylolisthesis. J Neurosurg Spine 2001;31:670-5.
24. Tay KS, Bassi A, Yeo W, Yue WM. Intraoperative reduction does not result in better outcomes in low-grade lumbar spondylolisthesis with neurogenic symptoms after minimally invasive transforaminal lumbar interbody fusion-a 5-year follow-up study. Spine J 2016;16:182-90.

25. Levin JM, Tanenbaum JE, Steinmetz MP, Mroz TE, Overley SC. Posterolateral Fusion (PLF) versus Transforaminal Lumbar Interbody Fusion (TLIF) for spondylolisthesis: A systematic review and meta-analysis. Spine J 2018;18:1088-98.
26. Carreon LY, Glassman SD, Kantamneni NR, Mugavin MO, Djurasovic M. Clinical outcomes after posterolateral lumbar fusion in workers' compensation patients: A case-control study. Spine (Phila Pa 1976) 2010;35:1812-7.
27. Nguyen TH, Randolph DC, Talmage J, Succop P, Travis R. Long-term outcomes of lumbar fusion among workers' compensation subjects: A historical cohort study. Spine (Phila Pa 1976) 2011;36:320-31.
28. Landham PR, Don AS, Robertson PA. Do position and size matter? An analysis of cage and placement variables for optimum lordosis in PLIF reconstruction. Eur Spine J 2017;26:2843-50.
29. Claus CF, Tong D, Lytle E, Bahoura M, Garmo L, Li C, *et al.* Age as a predictor for complications and patient-reported outcomes in multilevel transforaminal lumbar interbody fusions: Analyses from the Michigan Spine Surgery Improvement Collaborative (MSSIC). Spine (Phila Pa 1976) 2021;46:356-65.
30. Ibrahim JM, Singh P, Beckerman D, Hu SS, Tay B, Deviren V, *et al.* Outcomes and quality of life improvement after multilevel spinal fusion in elderly patients. Global Spine J 2020;10:153-9.
31. Park P, Garton HJ, Gala VC, Hoff JT, McGillicuddy JE. Adjacent segment disease after lumbar or lumbosacral fusion: Review of the literature. Spine (Phila Pa 1976) 2004;29:1938-44.
32. Tsuang FY, Tsai JC, Lai DM. Effect of lordosis on adjacent levels after lumbar interbody fusion, before and after removal of the spinal fixator: A finite element analysis. BMC Musculoskelet Disord 2019;20:470.
33. Rihn JA, Hilibrand AS, Radcliff K, Kurd M, Lurie J, Blood E, *et al*. Duration of symptoms resulting from lumbar disc herniation: Effect on treatment outcomes: analysis of the Spine Patient Outcomes Research Trial (SPORT). J Bone Joint Surg 2011;93:1906-14.

Appendix A: Demographics of cohort based on degree of curvature

Demographics	Proportioned, *n* (%)	Moderately disproportioned, *n* (%)	Severely disproportioned, *n* (%)	*P*[1]
Total (*n*=162)	*n*=38	*n*=72	*n*=52	
Age, mean (SD)	57.9 (12.1)	64.3 (10.2)	65.0 (10.7)	0.004*
Sex				
Male	13 (34.2)	36 (50.0)	24 (46.2)	0.281
Female	25 (65.8)	36 (50.0)	28 (53.8)	
BMI, mean (SD)	31.7 (5.32)	31.1 (6.16)	29.9 (7.79)	0.122
Smoking status				
Never	25 (65.8)	41 (56.9)	31 (59.6)	0.273
Current	8 (21.1)	9 (12.5)	6 (11.5)	
Former	5 (13.2)	22 (30.6)	15 (28.8)	
Duration of preoperative symptoms (months)				
3	16 (42.1)	29 (40.3)	16 (30.8)	0.567
3-6	7 (18.4)	19 (26.4)	17 (32.7)	
6+	15 (39.5)	24 (33.3)	19 (36.5)	
Worker's compensation status				
No workers comp	22 (57.9)	49 (68.1)	29 (55.8)	0.299
Workers comp	11 (28.9)	17 (23.6)	12 (23.1)	
Retired	5 (13.2)	6 (8.33)	11 (21.2)	
Physical therapy group				
No	23 (60.5)	28 (38.9)	7 (13.5)	<0.001*
Yes	15 (39.5)	44 (61.1)	45 (86.5)	

*Statistical significance ($P<0.05$), [1]Baseline demographics were compared between groups with Pearson's Chi-Square, One-way ANOVA, or Kruskal-Wallis H-test. SD - Standard deviation, BMI - Body mass index

Appendix B: Surgical characteristics and outcomes based on degree of curvature

Surgical characteristics and outcomes	Proportioned	Moderately disproportioned	Severely disproportioned	*P*[1]
Total (*n*=162)	*n*=38	*n*=72	*n*=52	
Surgery				
PLF	28 (73.7)	55 (76.4)	37 (71.2)	0.805
PLF + TLIF	10 (26.3)	17 (23.6)	15 (28.8)	
Cards classification				
A	10 (26.3)	20 (27.8)	16 (30.8)	0.170
B	13 (34.2)	11 (15.3)	6 (11.5)	
C	14 (36.8)	33 (45.8)	25 (48.1)	
D	1 (2.63)	8 (11.1)	5 (9.62)	
Follow up (months), mean (SD)	17.4 (10.7)	21.2 (11.0)	19.2 (12.1)	0.257
Adjacent segment disease				
No	31 (81.6)	52 (72.2)	40 (76.9)	0.540
Yes	7 (18.4)	20 (27.8)	12 (23.1)	
Instrumentation failure				
No	36 (94.7)	72 (100)	52 (100)	0.054
Yes	2 (5.26)	0	0	
Pseudoarthrosis				
No	37 (97.4)	72 (100)	52 (100)	0.235
Yes	1 (2.63)	0	0	
Revisions				
No	37 (97.4)	69 (95.8)	48 (92.3)	0.582
Yes	1 (2.63)	3 (4.17)	4 (7.69)	

[1]Surgical characteristics were compared between groups with Pearson's Chi-Square, One-way ANOVA, Kruskal-Wallis H-tests, or Fisher's exact tests. PLF - Posterolateral fusion, TLIF - Transforaminal lumbar interbody fusion, SD - Standard deviation

Appendix C: Global alignment and proportion score parameter: Relative lumbar lordosis

	Relative lumbar lordosis not aligned, *n* (%)	Relative lumbar lordosis aligned, *n* (%)	*P*[1]
Total (*n*=162)	*n*=118	*n*=44	
ODI			
Preoperative	45.4 (16.8)	43.4 (18.0)	0.530
Postoperative 1 year	21.0 (18.0)	21.9 (19.4)	0.918
Δ 1 year	−24.07 (18.8)	−19.55 (17.7)	0.185
RR	0.54 (0.40)	0.50 (0.39)	0.563
Percentage MCID			
No	14 (13.5)	10 (25.6)	0.138
Yes	90 (86.5)	29 (74.4)	
PCS-12			
Preoperative	31.1 (8.28)	30.8 (9.00)	0.655
Postoperative 1 year	41.0 (11.2)	39.7 (10.8)	0.502
Δ 1 year	9.74 (10.5)	8.17 (10.6)	0.430
RR	0.14 (0.15)	0.11 (0.16)	0.492
Percentage MCID			
No	48 (45.3)	22 (56.4)	0.317
Yes	58 (54.7)	17 (43.6)	
MCS-12			
Preoperative	47.7 (11.8)	48.2 (9.64)	0.989
Postoperative 1 year	53.4 (8.93)	54.0 (8.65)	0.823
Δ 1 year	5.37 (10.2)	5.18 (10.9)	0.924
RR	0.08 (0.18)	0.08 (0.20)	0.982
Percentage MCID			
No	72 (67.9)	25 (64.1)	0.814
Yes	34 (32.1)	14 (35.9)	
VAS back			
Preoperative	6.05 (2.94)	6.41 (2.64)	0.560
Postoperative 1 year	2.91 (2.70)	3.18 (2.81)	0.692
Δ 1 year	−2.98 (3.55)	−2.83 (3.07)	0.630
RR	0.51 (0.68)	0.50 (0.48)	0.530
Percentage MCID			
No	36 (39.6)	14 (43.8)	0.837
Yes	55 (60.4)	18 (56.2)	
VAS leg			
Preoperative	6.25 (3.00)	6.81 (2.42)	0.458
Postoperative 1 year	2.75 (2.94)	3.03 (3.12)	0.592
Δ 1 year	−3.49 (4.06)	−3.71 (3.18)	0.986
RR	0.54 (0.71)	0.58 (0.46)	0.583
Percentage MCID			
No	32 (36.0)	13 (40.6)	0.798
Yes	57 (64.0)	19 (59.4)	

PROMS reported as: Mean (SD), [1]Independent samples *t*-test or Mann-Whitney U-test. Percentage MCID - Percent of patients who achieved the MCID at follow-up. PROMS: ODI, PCS-12, MCS-12, VAS, VAS back, VAS leg. MCID - Minimally clinically important difference, PROMS - Patient reported outcome measurements, RR - Recovery ratio, SD - Standard deviation, ODI - Oswestry disability index, PCS-12 - Short-form 12 physical component score, MCS-12 - Mental component score, VAS - Visual analogue score, VAS back - VAS back pain, VAS leg - VAS leg pain

Appendix D: Global alignment and proportion score parameter: Relative pelvic version

	Relative pelvic version not aligned, *n* (%)	Relative pelvic version aligned, *n* (%)	*P*[1]
Total (*n*=162)	*n*=100	*n*=62	
ODI			
Preoperative	45.8 (16.2)	43.3 (18.4)	0.403
Postoperative 1 year	20.8 (18.6)	21.9 (18.0)	0.639
Δ 1 year	−24.62 (17.1)	−20.07 (20.5)	0.171
RR	0.56 (0.38)	0.47 (0.43)	0.250
Percentage MCID			
No	10 (11.5)	14 (25.0)	0.060
Yes	77 (88.5)	42 (75.0)	
PCS-12			
Preoperative	29.7 (7.81)	33.2 (9.04)	0.025*
Postoperative 1 year	40.3 (11.1)	41.2 (11.0)	0.620
Δ 1 year	10.6 (9.57)	7.28 (11.7)	0.083
RR	0.15 (0.14)	0.10 (0.18)	0.118
Percentage MCID			
No	39 (43.3)	31 (56.4)	0.176
Yes	51 (56.7)	24 (43.6)	
MCS-12			
Preoperative	47.0 (11.5)	49.3 (10.7)	0.197
Postoperative 1 year	53.4 (9.57)	53.9 (7.51)	0.998
Δ 1 year	6.11 (10.9)	4.04 (9.29)	0.226
RR	0.09 (0.19)	0.06 (0.17)	0.271
Percentage MCID			
No	57 (63.3)	40 (72.7)	0.325
Yes	33 (36.7)	15 (27.3)	
VAS back			
Preoperative	6.34 (2.77)	5.84 (2.99)	0.306
Postoperative 1 year	2.92 (2.88)	3.10 (2.45)	0.354
Δ 1 year	−3.19 (3.58)	−2.48 (3.09)	0.138
RR	0.50 (0.72)	0.53 (0.42)	0.534
Percentage MCID			
No	28 (35.0)	22 (51.2)	0.122
Yes	52 (65.0)	21 (48.8)	
VAS leg			
Preoperative	6.64 (2.71)	6.01 (3.07)	0.196
Postoperative 1 year	2.79 (3.04)	2.89 (2.91)	0.802
Δ 1 year	−3.74 (3.91)	−3.18 (3.71)	0.320
RR	0.52 (0.73)	0.60 (0.44)	0.928
Percentage MCID			
No	26 (32.9)	19 (45.2)	0.255
Yes	53 (67.1)	23 (54.8)	

*Statistical significance ($P<0.05$). PROMS reported as: Mean (SD), [1]Independent samples *t*-test or Mann-Whitney U-test. Percentage MCID - Percent of patients who achieved the MCID at follow-up. PROMS: ODI, PCS-12, MCS-12, VAS, VAS back, VAS leg. MCID - Minimally clinically important difference, PROMS - Patient reported outcome measurements, RR - Recovery ratio, SD - Standard deviation, ODI - Oswestry disability index, PCS-12 - Short-form 12 physical component score, MCS-12 - Mental component score, VAS - Visual Analog Score, VAS back - VAS back pain, VAS leg - VAS leg pain

Appendix E: Global alignment and proportion score parameter: Lordosis distribution index

	Lordosis distribution index not aligned, *n* (%)	Lordosis distribution index aligned, *n* (%)	*P*[1]
Total (*n*=162)	*n*=78	*n*=84	
ODI			
Preoperative	43.5 (19.1)	45.9 (15.1)	0.395
Postoperative 1 year	19.1 (17.2)	23.1 (19.2)	0.235
Δ 1 year	−23.27 (18.9)	−22.47 (18.4)	0.798
RR	0.55 (0.42)	0.50 (0.38)	0.304
Percentage MCID			
No	8 (12.1)	16 (20.8)	0.247
Yes	58 (87.9)	61 (79.2)	
PCS-12			
Preoperative	31.8 (8.22)	30.3 (8.66)	0.125
Postoperative 1 year	41.3 (10.6)	40.0 (11.5)	0.478
Δ 1 year	9.70 (10.2)	8.97 (10.9)	0.677
RR	0.14 (0.15)	0.12 (0.16)	0.798
Percentage MCID			
No	33 (47.1)	37 (49.3)	0.922
Yes	37 (52.9)	38 (50.7)	
MCS-12			
Preoperative	46.8 (11.5)	48.9 (10.9)	0.221
Postoperative 1 year	53.5 (8.76)	53.7 (8.95)	0.862
Δ 1 year	6.23 (10.8)	4.48 (9.90)	0.311
RR	0.09 (0.20)	0.07 (0.17)	0.446
Percentage MCID			
No	42 (60.0)	55 (73.3)	0.126
Yes	28 (40.0)	20 (26.7)	
VAS back			
Preoperative	6.35 (2.98)	5.96 (2.75)	0.231
Postoperative 1 year	2.72 (2.73)	3.22 (2.71)	0.195
Δ 1 year	−3.47 (3.69)	−2.47 (3.12)	0.033*
RR	0.53 (0.77)	0.49 (0.48)	0.180
Percentage MCID			
No	18 (31.0)	32 (49.2)	0.062
Yes	40 (69.0)	33 (50.8)	
VAS leg			
Preoperative	6.23 (3.02)	6.56 (2.70)	0.524
Postoperative 1 year	2.47 (2.93)	3.14 (3.01)	0.095
Δ 1 year	−3.61 (4.30)	−3.50 (3.43)	0.521
RR	0.54 (0.76)	0.55 (0.53)	0.299
Percentage MCID			
No	19 (33.9)	26 (40.0)	0.617
Yes	37 (66.1)	39 (60.0)	

*Statistical significance ($P<0.05$). PROMS reported as: Mean (SD), [1]Independent samples *t*-test or Mann-Whitney U-test. Percentage MCID - Percent of patients who achieved the MCID at follow-up. PROMS: ODI, PCS-12, MCS-12, VAS, VAS back, VAS leg. MCID - Minimally clinically important difference, PROMS - Patient reported outcome measurements, RR - Recovery ratio, SD - Standard deviation, ODI - Oswestry disability index, PCS-12 - Short-form 12 physical component score, MCS-12 - Mental component score, VAS - Visual analogue score, VAS back - VAS back pain, VAS leg - VAS leg pain