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.

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 (β = −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

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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.\[^{8,9}\] However, PLF has been increasingly replaced by transforaminal lumbar interbody fusion (TLIF).\[^{10}\] 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
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).

### Radiographic measures

Radiographic measurements were performed on standing lateral lumbar radiographs and included focal lordosis, PL, 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°. 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). 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°).
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 \( \Delta \) (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

| Table 1: Demographics of cohort based on degree of curvature |
|-------------------------------------------------------------|
| Demographics                                               | Neutral (\(-2°<-2°\)) | Kyphotic (\(<-2°\)) | Lordotic (\(>2°\)) | \( P \) |
|-------------------------------------------------------------|-------------------------|---------------------|---------------------|--------|
| 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 (\( P < 0.05 \)). 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 (\(-2°<-2°\)) | Kyphotic (\(<-2°\)) | Lordotic (\(>2°\)) | \( P \) |
|-------------------------------------------------------------|-------------------------|---------------------|---------------------|--------|
| 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 (\( P < 0.05 \)). 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
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 ($\beta$-coefficient = −6.47, 95% CI [−11.00 − −1.95], $P = 0.006$), while having a PLF procedure alone predicted improvement in MCS-12 scores ($\beta$-coefficient = 4.38, 95% CI [0.34–8.42], $P = 0.036$). WC ($\beta$-coefficient = −2.13, 95% CI [−4.11 − −0.16], $P = 0.037$) and symptom duration of 3–6 months ($\beta$-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°) | $P$ |
|------|------------------|-----------------|----------------|-----|
| 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. 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 | 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 | 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 | 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 | Reference | Reference | Reference | Reference | Reference |
| 3-6                            | -0.61 (-8.46-7.25) | 0.880  | 2.229 (-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 | 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.
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

| Table 5: Global alignment and proportion score (0-2: Proportioned, 3-6: Mod disproportioned, >7: Severely disproportioned) | Proportioned, $n$ (%) | Moderately disproportioned, $n$ (%) | Severely disproportioned, $n$ (%) | $P$ |
|---|---|---|---|---|
| Total ($n=162$) | | | | |
| 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 (9.5) | 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 | 14 (48.3) | 34 (53.0) | 25 (57.8) | |
| 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 ($P < 0.05$), **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.
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 \textit{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 liesthetic 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.\(^{15}\) It, therefore, may be useful 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 \textit{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.

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Appendix A: Demographics of cohort based on degree of curvature

| Demographics                      | Proportioned, n (%) | Moderately disproportioned, n (%) | Severely disproportioned, n (%) | P*   |
|-----------------------------------|---------------------|----------------------------------|---------------------------------|------|
| Total (n=162)                     | n=38                | n=72                             | n=52                            | 0.004* |
| Age, mean (SD)                    | 57.9 (12.1)         | 64.3 (10.2)                      | 65.0 (10.7)                     |      |
| 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), *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*   |
|--------------------------------------|--------------|----------------------------|--------------------------|------|
| 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)                 |      |

*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* |
|--------------------------|-------------------------------------------|----------------------------------------|----|
| Total (n = 162)          | n = 118                                   | n = 44                                  |    |
| ODI                      |                                           |                                        |    |
| Preoperative             | 45.4 (16.8)                               | 43.4 (18.0)                             | 0.530 |
| Postoperative 1 year     | 21.0 (19.0)                               | 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          | Yes                                       | 14 (13.5)                               | 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)                              | −2.63 (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) |

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

|                          | Relative pelvic version not aligned, n (%) | Relative pelvic version aligned, n (%) | P* |
|--------------------------|-------------------------------------------|----------------------------------------|----|
| 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)                             | 0.428 |
| 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). 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

PROMS reported as: Mean (SD). 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 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), 1Independent 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