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ASSOCIATION BETWEEN SPINOPELVIC PARAMETERS AND PATIENT-REPORTED OUTCOMES AFTER LUMBAR FUSION: A PROSPECTIVE COHORT STUDY

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ABSTRACT
Objectives: To determine whether postoperative spinopelvic parameters are associated with patient-reported disability and pain after instrumented lumbar fusion for degenerative lumbar disease, with postoperative PI–LL mismatch analysed primarily as a continuous exposure and secondarily using a prespecified 10° threshold.
Methods: Adults undergoing one to three level instrumented lumbar fusion will be assessed with standardized standing radiographs including the pelvis before surgery and at the prespecified postoperative assessment. Pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), lumbar lordosis (LL), and PI–LL mismatch will be measured independently by two observers. The primary clinical outcome will be postoperative Oswestry Disability Index (ODI). Secondary outcomes will include postoperative back- and leg-pain VAS and change from baseline. Multivariable regression will assess whether postoperative PI–LL remains associated with postoperative ODI after adjustment for clinically relevant baseline factors.
Results: Of 100 patients assessed, 8 were excluded (3 prior spine surgery, 2 deformity >30° Cobb angle, 2 incomplete radiographs, and 1 declined consent), leaving 92 enrolled and operated. Six patients were lost to follow-up, leaving 86 patients for the final analysis. The mean PI–LL mismatch improved from 16.8° ± 6.3° preoperatively to 7.5° ± 4.1° postoperatively ($P<0.001$). Lumbar lordosis increased from 38.6° ± 9.1° to 47.9° ± 7.4° ($P<0.001$), pelvic tilt decreased from 27.6° ± 6.0° to 19.8° ± 5.2° ($P<0.001$) and sacral slope increased from 27.1° ± 6.8° to 34.6° ± 5.9° ($P<0.001$). ODI improved from 52.3% ± 10.4% to 22.6% ± 9.8% (mean change 29.7 percentage points, $P<0.001$). Back-pain VAS improved from 7.2 ± 1.3 to 2.4 ± 1.1 and leg-pain VAS from 6.5 ± 1.6 to 1.9 ± 1.2 (both $P<0.001$). The postoperative PI–LL correlation coefficients of 0.65 with ODI and 0.58 with VAS, both $P<0.001$. In the threshold analysis, 55 patients were reported in the ≤10° group and 31 in the >10° group; postoperative ODI, back-pain VAS, leg-pain VAS, and satisfaction were all reported as better in the ≤10° group. Multivariable analysis reported postoperative PI–LL mismatch ($\beta=0.62$, 95% CI 0.41–0.83, $P<0.001$) and pelvic tilt ($\beta=0.28$, 95% CI 0.05–0.51, $P=0.018$) as independent predictors of postoperative ODI.
Conclusions: In the cohort, postoperative improvement in lumbar lordosis and reduction in PI–LL mismatch were accompanied by improvement in ODI,pain scores and residual PI–LL mismatch was positively associated with postoperative disability. Pre-operative radiographic planning using pelvic parameters may help optimise the choice of fusion levels and lordosis restoration, reducing the risk of mechanical complications and unsatisfactory outcomes.

KEYWORDS: spinopelvic parameters; pelvic incidence; lumbar lordosis; PI–LL mismatch; lumbar fusion; Oswestry Disability Index; patient-reported outcomes; Sustainable Development Goals(SDG 3:Good health and well-being).

1. INTRODUCTION

Sagittal spinopelvic alignment is an important component of contemporary planning and outcome assessment in lumbar fusion surgery. Pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), and lumbar lordosis (LL) describe the relationship between pelvic morphology and spinal alignment. These parameters are interrelated, and PI is a morphologic parameter that remains essentially constant after skeletal maturity, whereas PT, SS, and LL vary with posture and spinal alignment.[1–4]

PI is defined by the angle between a line perpendicular to the sacral endplate at its midpoint and a line connecting that point to the centre of the bicoxofemoral axis. PT describes pelvic orientation relative to the vertical, and SS describes sacral orientation relative to the horizontal; therefore, PI = PT + SS.[1–4] PI–LL mismatch has subsequently been used as a summary measure of sagittal congruence. Much of the influential evidence relating PI–LL mismatch to disability originated in adult spinal deformity populations. Schwab et al. demonstrated associations between radiographic sagittal parameters and disability in a prospective multicentre cohort, while other studies established the relationship between positive sagittal alignment and health status.[5–7] However, the applicability of adult-deformity alignment thresholds to patients undergoing limited lumbar fusion for degenerative disease remains uncertain. Studies specifically addressing short-segment degenerative fusion have produced conflicting results. Aoki et al. reported worse postoperative pain-related outcomes among patient s with postoperative PI–LL mismatch ≥11° after one- or two-level TLIF.[8] In contrast, Divi et al., in a larger cohort of 306 patients undergoing one- or two-level lumbar fusion, found no significant difference in patient-reported outcomes between patients with and without postoperative PI–LL mismatch and concluded that the commonly used threshold did not consistently predict outcomes.[9] More recent prospective data have likewise suggested that changes in individual lordosis, rather than attainment of a universal alignment target, may be more closely related to early pain improvement.[10]

These findings suggest that the clinically relevant question is not simply whether a patient crosses an arbitrary PI–LL threshold, but whether postoperative sagittal alignment is associated with patient-reported recovery after accounting for baseline disability and other clinical factors. The present study therefore evaluates postoperative spinopelvic parameters as continuous variables, while retaining the 10° PI–LL threshold as a secondary, clinically interpretable analysis. The primary objective was to determine whether postoperative PI–LL mismatch is associated with postoperative ODI in adults undergoing one- to three-level instrumented lumbar fusion for degenerative lumbar disease. Secondary objectives were to evaluate associations between PT, SS, LL and postoperative ODI/VAS, and to compare outcomes according to postoperative PI–LL mismatch ≤10° versus >10°.

2. MATERIALS AND METHODS

2.1 Study Design and Setting

This was a single-center, prospective observational cohort study caried out in the Department of Orthopaedics at Saveetha Institute of Medical and Technical sciences, Chennai, Tamil Nadu, tertiary referral orthopedic center in India over a period of 3 years (January 2021 to June 2024), with a minimum follow-up of 24 months. The study was approved by the Institutional Ethics Committee of Saveetha Institute of Medical and Technical Sciences (IEC/2021/047).Written informed consent was obtained from all participants. The study was conducted in accordance with the Declaration of Helsinki (2013).

2.2 Participants

Consecutive eligible adults undergoing elective instrumented lumbar fusion were considered for inclusion. Age 18 years or older, Elective one- to three-level instrumented posterior lumbar fusion for degenerative disc disease, degenerative or isthmic spondylolisthesis, or lumbar canal stenosis with instability,availability of standardized standing radiographs including the pelvis and femoral heads before surgery and at the prespecified postoperative time point,availability of baseline and postoperative ODI and VAS assessments,ability to stand unsupported for radiographic acquisition and willingness to provide informed consent. Exclusion criteria were: Previous lumbar surgery at the index level or adjacent levels, if this was part of the prespecified protocol,structural coronal or sagittal deformity exceeding the prespecified threshold or an indication for long-segment adult spinal deformity reconstruction. Active spinal infection, malignancy, neuromuscular disease substantially affecting posture or gait, or metabolic bone disease expected to affect fusion or alignment and radiographs that did not permit reliable identification of the required landmarks.

2.3 Sample Size

A total of 100 patients were assessed. The final analyzed cohort was 86 after exclusions and loss to follow-up.

2.4 Radiographic Assessment

Standing full-spine lateral radiographs were obtained using 36-inch long-cassette radiography. Patients were positioned in a standardized upright posture with hips and knees extended and the arms flexed with the hands resting on the clavicles or in a clenched-fist position.The measurements were performed on PACS software by two independent observers, with a third measurement in case of disagreement >5°. PI: angle between the perpendicular to the sacral endplate at its midpoint and the line joining that point to the centre of the bicoxofemoral axis.PT: angle between the vertical and the line connecting the bicoxofemoral axis to the midpoint of the sacral endplate.SS: angle between the superior sacral endplate and the horizontal.LL: Cobb angle between the superior endplates of L1 and S1, measured in the standing lateral radiograph.PI–LL mismatch: PI minus LL.Two observers independently measured the radiographic parameters, with a third measurement reported when disagreement exceeded 5°.

2.5 Patient-Reported Outcomes

The primary clinical outcome was postoperative ODI, reported on a 0–100% scale, with higher scores indicating greater disability. Secondary outcomes were VAS scores for back pain and leg pain on a 0–10 scale.

2.6 Surgical Technique

The patients underwent standard posterior decompression with instrumented fusion using pedicle screw–rod constructs, with or without interbody cage placement (TLIF/PLIF). The number of fused levels, use of interbody cages, and intraoperative lordosis-restoration technique were recorded.

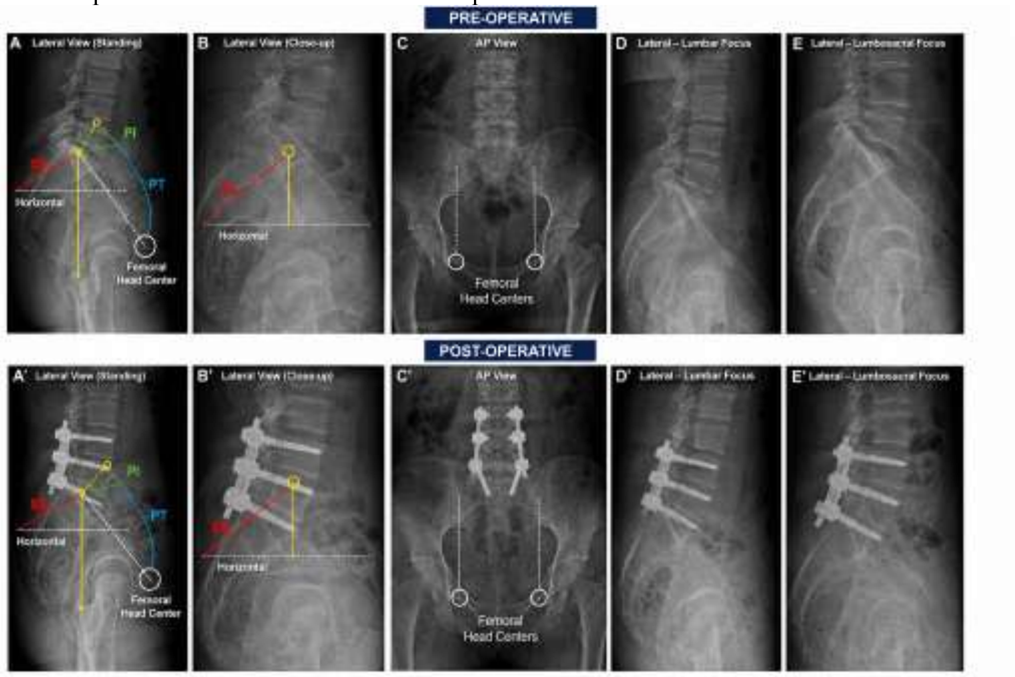

Figure 1. Representative postoperative radiographs demonstrating instrumented lumbar fusion constructs.

2.7 Outcomes and Statistical Analysis

The primary exposure was postoperative PI–LL mismatch analysed as a continuous variable. The principal secondary exposure was a prespecified postoperative PI–LL threshold of ≤10° versus >10°. The primary outcome was postoperative ODI. Secondary outcomes were postoperative VAS back pain and VAS leg pain and, where prespecified, change from baseline.Continuous variables will be assessed for distribution using graphical methods and an appropriate normality assessment. Normally distributed variables will be summarized as mean ± standard deviation and non-normally distributed variables as median (interquartile range). Categorical variables will be summarized as counts and percentages.Preoperative and postoperative radiographic parameters and patient-reported outcomes will be compared using paired t tests or Wilcoxon signed-rank tests as appropriate. Associations between continuous radiographic parameters and postoperative outcomes will be examined using Pearson or Spearman correlation coefficients according to distribution.The primary multivariable analysis includes postoperative ODI as the dependent variable and included postoperative PI–LL mismatch, pelvic tilt, age, BMI, and number of levels fused.

3. RESULTS

3.1 Participant Flow and Baseline Characteristics

Of 100 patients assessed, 8 were excluded (3 prior spine surgery, 2 deformity >30° Cobb angle, 2 incomplete radiographs, and 1 declined consent), leaving 92 enrolled/operated. Six were lost to follow-up, leaving 86 patients in the final analysis.

Table 1. Baseline demographic and clinical characteristics of the analyzed cohort.

Variable	Value
Patients assessed	100
Age, years	52.4 ± 11.3
Sex, n (%)	46 male (46%); 54 female (54%)
BMI, kg/m²	26.8 ± 3.9
Degenerative disc disease, n (%)	38 (38%)
Spondylolisthesis, n (%)	34 (34%)
Lumbar canal stenosis, n (%)	28 (28%)
Levels fused: 1, 2, 3, n (%)	52 (52%); 33 (33%); 15 (15%)
Follow-up duration(months)	14.2 ± 3.6

Missing primary outcome data, n (%)	6/92 enrolled/operated lost to follow-up;

3.2 Preoperative and Postoperative Radiographic Parameters

Table 2. Preoperative and postoperative spinopelvic radiographic parameters.

Parameter	Preoperative	Postoperative	Mean change	P value
PI, degrees	55.4 ± 8.2	55.4 ± 8.2	0.0	0.98
LL, degrees	38.6 ± 9.1	47.9 ± 7.4	+9.3	<0.001
PI–LL, degrees	16.8 ± 6.3	7.5 ± 4.1	−9.3	<0.001
PT, degrees	27.6 ± 6.0	19.8 ± 5.2	−7.8	<0.001
SS, degrees	27.1 ± 6.8	34.6 ± 5.9	+7.5	<0.001

3.3 Patient-Reported Outcomes

Table 3. Patient-reported outcomes at baseline and final follow-up.

Outcome	Baseline	Final follow-up	Mean change	P value
ODI	52.3 ± 10.4	22.6 ± 9.8	−29.7	<0.001
VAS back pain	7.2 ± 1.3	2.4 ± 1.1	−4.8	<0.001
VAS leg pain	6.5 ± 1.6	1.9 ± 1.2	−4.6	<0.001

3.4 Association between Spinopelvic Parameters and Outcomes

Table 4. Associations between postoperative spinopelvic parameters and patient outcomes.

Radiographic parameter	Correlation with postoperative ODI(r)	p-value	Correlation with postoperative VAS(p)	p-value
PI–LL mismatch	0.65	<0.001	0.58	<0.001
Pelvic tilt (PT)	0.52	<0.001	0.47	<0.001
Sacral slope (SS)	-0.38	0.002	-0.33	0.008
Lumbar lordosis(LL)	-0.45	<0.001	-0.40	<0.001

3.5 Secondary Threshold Analysis

Patients were secondarily categorized according to postoperative PI–LL mismatch ≤10° versus >10°.

Table 5. Patient-reported outcomes according to postoperative PI–LL mismatch threshold.

Outcome	PI–LL ≤10° (n=55)	PI–LL >10° (n=31)	Between-group difference	P value
n	55	31	17.8 ± 6.4	<0.001
Postoperative ODI	17.8 ± 6.4	31.5 ± 8.9	1.9 ± 0.8	<0.001
VAS back pain	1.9 ± 0.8	3.4 ± 1.0	1.5 ± 0.7	<0.001
VAS leg pain	1.5 ± 0.7	2.7 ± 1.0	47 (85.5%)	<0.001

3.6 Multivariable Analysis

Table 6. Multivariable linear regression for postoperative ODI.

Predictor	Unstandardized β	95% CI	P value
Postoperative PI–LL, per 1°	0.62	0.41 to 0.83	<0.001
Pelvic tilt, per 1°	0.28	0.05 to 0.51	0.018
Age, per year	0.09	−0.04 to 0.22	0.17
BMI, per kg/m²	0.14	−0.02 to 0.30	0.09
Number of levels fused	0.11	−0.06 to 0.28	0.21

3.7 Measurement Reliability and Complications

Interobserver reliability was reported as ICC=0.91 for PI, 0.88 for PT, 0.89 for SS, and 0.85 for LL with 9 complications (9%): proximal junctional kyphosis (n=3), radiographic adjacent-segment degeneration (n=4), and asymptomatic screw loosening (n=2). The complication rates were numerically higher in the >10° mismatch group.

4. DISCUSSION

This prospective cohort study examined whether postoperative spinopelvic alignment is associated with patient-reported outcomes after one- to three-level lumbar fusion for degenerative disease. Aoki et al. reported worse residual symptoms in patients with postoperative PI–LL mismatch after short-segment TLIF, whereas Divi et al. found no clinically important difference in PROMs according to postoperative PI–LL mismatch in a substantially larger short-segment fusion cohort.[8],[9] A recent prospective cohort similarly reported that early pain improvement was associated with change in LL rather than with absolute postoperative alignment targets.[10]

The present study demonstrates an independent association between postoperative PI–LL and ODI after adjustment for baseline ODI and relevant clinical factors that residual sagittal incongruence has measurable clinical relevance in this population

Alignment targets developed in adult deformity populations may not be directly transferable to patients undergoing limited lumbar fusion, who generally have less global deformity and different mechanisms of disability.[5–7] Radiographic measurement methodology is another important consideration. Spinopelvic parameters are sensitive to patient positioning and landmark identification, and published studies demonstrate good-to-excellent reliability when standardized techniques are used, but measurement variability remains clinically relevant.[11–13] The present study therefore strengthens its methodology by using standardized standing imaging, independent observers, and formal reliability assessment.Contemporary evidence is not uniform regarding the relationship between PI–LL mismatch and early adjacent-segment reoperation.[15]

4.1 LIMITATIONS

Single-centre observational design limits causal inference and generalizability.Heterogeneity in degenerative diagnoses and number of fused levels may introduce confounding; diagnosis and fusion extent should therefore be addressed in the statistical model and, where feasible, sensitivity analyses.Unmeasured factors such as psychosocial status, baseline sagittal balance beyond the measured parameters, muscle quality, hip pathology, and surgical technique may influence patient-reported outcomes.

5. CONCLUSION

Spinopelvic parameters, particularly PI–LL mismatch, correlate meaningfully with functional outcome after lumbar fusion for degenerative lumbar spine disease. Restoration of lordosis appropriate to the patient's native pelvic incidence rather than decompression and fixation alone appears to be an important determinant of postoperative Oswestry Disability Index and pain scores. Incorporation of standing full-spine radiographic assessment (EOS or long-cassette) into routine pre-operative planning for lumbar fusion, even for short-segment degenerative indications, may help surgeons identify patients at risk of suboptimal alignment and guide construct planning to optimise functional recovery. Larger multicentric studies with longer-term follow-up are warranted to validate specific threshold values in diverse populations and to determine their impact on late mechanical complications such as adjacent segment disease and proximal junctional kyphosis

Conflict of interest

The authors declare no conflict of interest.

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