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Original Article

Orthopaedics Section

Radiographic and Clinical Association between Pelvic Incidence-lumbar Lordosis Mismatch and Disability in Chronic Low Back Pain: A Retrospective Single-centre Study

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ABSTRACT

Introduction: Pelvic Incidence- Lumbar Lordosis (PI-LL) mismatch is a key sagittal alignment parameter that may influence pain and disability in patients with Chronic Low Back Pain (CLBP). While its relevance in spinal deformity and surgical cohorts is established, its role in non surgical CLBP patient remains underexplored.

Aim: To assess the relationship between the mismatch of PI-LL and the level of functional disability in individuals diagnosed with CLBP, based on findings from standing lateral lumbosacral spine radiographs.

Materials and Methods: This retrospective study was conducted at a tertiary care teaching hospital included 120 patients with CLBP. Standing lateral lumbosacral radiographs were used to measure PI and LL, and PI-LL mismatch was calculated. Functional disability was assessed using the Oswestry Disability Index (ODI), and pain severity using the Visual Analogue Scale (VAS). Patients were divided into minimal disability (ODI ≤20%) and moderate-to-severe disability groups (ODI >20%). Correlation analysis, Receiver Operating Characteristic (ROC) curve, and multivariate regression were performed.

Results: The mean PI-LL mismatch was significantly higher in the moderate-to-severe disability group (12.9±8.0°) than in the minimal disability group (2.5±4.1°, p-value <0.001). PI-LL mismatch showed a strong positive correlation with ODI (r=0.62) and VAS (r=0.51). ROC analysis identified an optimal PI–LL mismatch cut-off of 9.1°, approximating the clinically relevant threshold of 10° for predicting moderate-to-severe disability (specificity: 89.5%, sensitivity (78%), PPV: 94.1%). In multivariate analysis, PI-LL mismatch remained an independent predictor of disability (β=0.55, p-value <0.001), along with pain severity.

Conclusion: PI-LL mismatch is an independent predictor of disability in CLBP. A mismatch of approximately >10° may identify patients at higher risk of functional impairment and guide targeted management strategies.

Keywords: Healthcare, Lumbar vertebrae, Outcome assessment, Pelvis, Posture, Radiography, Spinal curvature

INTRODUCTION

The Chronic Low Back Pain (CLBP) represents a pervasive healthcare challenge globally, contributing substantially to disability and diminished quality of life. Increasing evidence suggests that spinopelvic alignment, specifically the relationship between pelvic morphology and lumbar spine curvature is a key biomechanical factor potentially influencing patient outcomes. Among these parameters, the measurement of the difference between PI and LL, often termed the PI-LL mismatch, has emerged as a significant focus in both degenerative spine disease and spinal fusion surgery contexts [1].

The PI, initially described as a fixed anatomic parameter [2] reflects the orientation of the pelvis relative to the spine and hips, while LL describes the inward curvature of the lumbar spine. A harmonious relation between PI and LL is thought to support optimal sagittal balance and reduce mechanical stress across the lumbar spine and adjacent segments [3]. Evidence from the spinal deformity literature suggests that when LL fails to adapt to a patient's pelvic morphology, it results in sagittal imbalance and increased biomechanical stress across adjacent levels [4]; Senteler M et al., found that a PI-LL mismatch of >15° was associated with a 20-fold increase in risk of adjacent segment disease following lumbar fusion [5].

While much of the PI-LL mismatch literature has centred on patients undergoing fusion or those with spinal deformities, less is known regarding its role in non surgical patients with CLBP. One recent retrospective radiographic analysis by Harrison DE et al., comparing CLBP patients versus pain-free controls found that although pelvic morphological measures (e.g., PI) did not differ significantly between groups, the LL was reduced in the CLBP group. The correlation between pelvic morphology and LL was weaker, suggesting a mismatch between pelvic morphology and lumbar curvature in CLBP [6]. Tartara F et al., highlighted that evidence remains inconsistent, with most studies being small, retrospective, and heterogeneous in their definitions and outcomes [7].

Despite strong mechanistic plausibility, the clinical relevance of PI-LL mismatch in non surgical CLBP remains unclear. Given that many patients with CLBP undergo non operative management, understanding whether this spinopelvic mismatch is associated with worse disability could help stratify risk, tailor rehabilitation or even inform preventive strategies. This study addressed this gap by correlating radiographic PI-LL mismatch with validated disability metrics in CLBP patients. Understanding this relationship may improve biomechanical insight into CLBP and may help identify a useful radiographic marker that can guide patient-specific conservative management strategies. These findings support the importance of sagittal spinal-pelvic alignment in CLBP beyond the surgical context and thus support broader biomechanical assessment in clinical practice. This study hypothesised that increased PI-LL mismatch is associated with greater disability in patients with CLBP.

The aim was to assess the relationship between the mismatch of PI and LL and the level of functional disability in individuals diagnosed

with CLBP, based on findings from standing lateral lumbosacral spine radiographs.

Objectives:

- To quantitatively assess PI and LL using lateral standing lumbosacral spine X-rays.
- To compute the PI-LL mismatch for each subject included in the study.
- To explore the correlation between the PI-LL mismatch and disability severity, as determined by the ODI.
- To investigate whether a specific PI-LL mismatch threshold is indicative of moderate to severe disability in patients with CLBP.

MATERIALS AND METHODS

This study was conducted as a retrospective, single-centre investigation at Chettinad Hospital and Research Institute, Chennai, Tamil Nadu, India. Data were collected from January 2023 to June 2025 and analysed between November 2025 to January 2026 after ethical committee approval (IHEC-1/043/10/2025). The requirement for informed consent was waived due to the retrospective and anonymised nature of the study. A total of 120 participants with a clinical diagnosis of CLBP were included based on predefined inclusion and exclusion criteria.

Inclusion criteria: Adults aged 18-80 years with documented CLBP (>3 months), availability of standing lateral lumbosacral spine radiographs with clear visualisation of both femoral heads and the S1 endplate, as well as an ODI score recorded within three months of the radiographic exam were included in the study.

Exclusion criteria: Patients who had undergone previous spinal surgery, sustained vertebral fractures, or had radiographic evidence of spondyloptosis, tumours, infection, or inflammatory spondyloarthropathy. Inadequate radiographs-those failing to demonstrate the S1 endplate or both femoral heads- were excluded. Patients with acute neurological deficits, traumatic injuries, or severe spinal deformities (Cobb angle >20°) were excluded from the study.

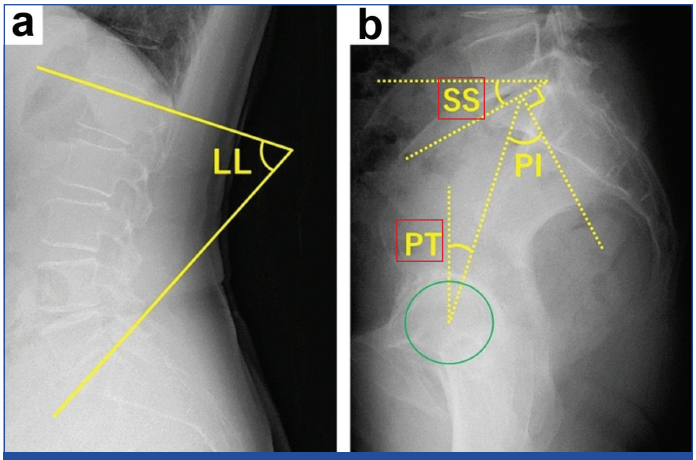
Study Procedure

The sample size was calculated using the Fisher's Z transformation, assuming a small-moderate correlation coefficient (r=0.25) [8] between PI-LL mismatch and ODI score. Using a significance level (α) of 0.05 and a power (1-β) of 0.80, the estimated sample size was 123. Considering feasibility constraints and potential data completeness, a total of 120 participants were included in the final analysis.

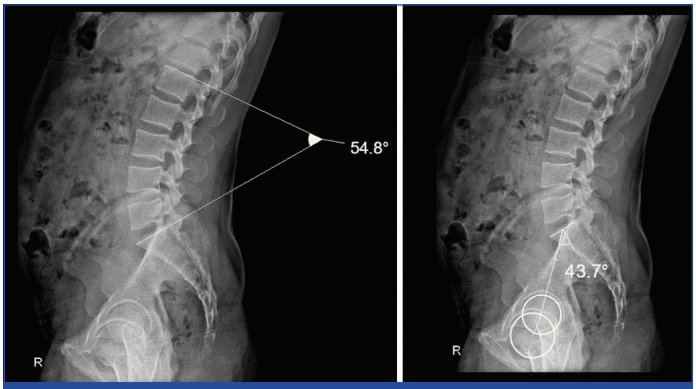
Data retrieval procedure: Eligible CLBP patients were identified from the hospital databases over the past 1.5 years, and corresponding radiographic, clinical and demographic data were retrieved from the hospital's Picture Archiving and Communication System (PACS) and outpatient records.

Radiographic analysis: Standardised lateral standing radiographs of the lumbosacral spine were used for measurement. PI was calculated as the angle between a line perpendicular to the S1 endplate at its midpoint and the line joining this point to the midpoint between the femoral head centres (bicoxofemoral axis). LL was measured using the Cobb method between the superior endplates of the L1 and S1 vertebrae [9]. The PI-LL mismatch was determined by subtracting the LL value from the PI value for each patient [10]. All measurements were performed using the digital angle measurement tool available within the PACS software [Table/Fig-1,2].

Measurement reliability: Intra- and inter-observer reliability was assessed using a randomly selected subset of 20 radiographs. Intraclass correlation coefficients demonstrated excellent reproducibility for all measurements. Intraobserver ICCs were 0.96 for PI and 0.94 for LL, while interobserver ICCs were 0.93 and 0.91, respectively. The derived PI-LL mismatch also showed excellent reliability (intraobserver ICC 0.95; interobserver ICC 0.92).



[Table/Fig-1]: Methods of radiographic measurement of spinopelvic parameters. Methods for Lumbar Lordosis (LL), Pelvic Incidence (PI), Sacral Slope (SS), Pelvic Tilt (PT) [10].



[Table/Fig-2]: Calculated Lumbar Lordosis (LL) and Pelvic incidence (PI) on PACS software.

Clinical outcome assessment: Functional disability was evaluated using the ODI Version 2.0 [11]. Patients were categorised based on ODI score as follows:

- 0-20%: Minimal disability;
- 21-40%: Moderate disability;
- 41-60%: Severe disability;
- 61-80%: Crippling back pain;
- 81-100%: Bed-bound or exaggerated symptoms.

Pain severity was additionally assessed using the VAS, ranging from 0 (no pain) to 10 (worst imaginable pain) [12], and categorised based on standardised facial expression charts.

STATISTICAL ANALYSIS

Data were analysed using Statistical Package for the Social Sciences (SPSS) version 26.0. Continuous variables were presented as mean±standard deviation for normally distributed data and median (interquartile range) for non normally distributed data, and categorical data as proportions. The Shapiro-Wilk test was applied to evaluate normality. Pearson's correlation coefficient was used for normally distributed variables, and Spearman's rank correlation was applied for non parametric data. Group comparisons between minimal and moderate-to-severe disability were performed using the independent t-test for normally distributed variables and the Mann-Whitney U test for non normally distributed variables. ROC curve analysis was performed to determine the optimal PI-LL mismatch threshold for predicting moderate-to-severe disability. A multivariate linear regression analysis was performed with ODI as the dependent variable and PI-LL mismatch as the primary predictor, adjusting for age, sex, and BMI. A p-value <0.05 was considered statistically significant.

RESULTS

The cohort was split into "Minimal Disability" (ODI ≤20%) and "moderate-severe disability" (ODI >20%) to identify differences. The group with higher disability was slightly older and had a significantly longer duration of pain. The anatomical parameter PI did not differ between groups. This finding suggests that disability is related to spinal adaptation rather than pelvic morphology. The high-disability group had a significantly smaller LL and, consequently, a much larger PI-LL mismatch. This was the central radiographic finding of the study. [Table/Fig-3] summarises the demographic, clinical, and radiographic characteristics of the study population.

Characteristic	Total cohort (N=120)	Minimal disability (ODI ≤20%, n=38)	Moderate-Severe Disability (ODI >20%, n=82)	p-value
Age (years), Mean±SD	52.4±12.8	49.1±11.5	54.0±13.2	0.045*
Sex, n (%)				
Male	65 (54.2)	24 (63.2)	41 (50.0)	0.210
Female	55 (45.8)	14 (36.8)	41 (50.0)	
BMI (kg/m²), mean±SD	26.8±4.1	25.9±3.8	27.2±4.2	0.095
Pain duration (months), mean±SD	28.5±15.2	24.1±12.0	30.6±16.1	0.025*
VAS score, mean±SD	6.5±1.8	4.9±1.5	7.2±1.6	<0.001*
Radiographic parameters, mean±SD				
Pelvic Incidence (PI) (°)	54.6±11.2	53.8±10.5	55.0±11.6	0.580
Lumbar Lordosis (LL) (°)	45.1±12.4	51.3±9.8	42.1±12.5	<0.001*
PI-LL Mismatch (°)	9.5±8.7	2.5±4.1	12.9±8.0	<0.001*

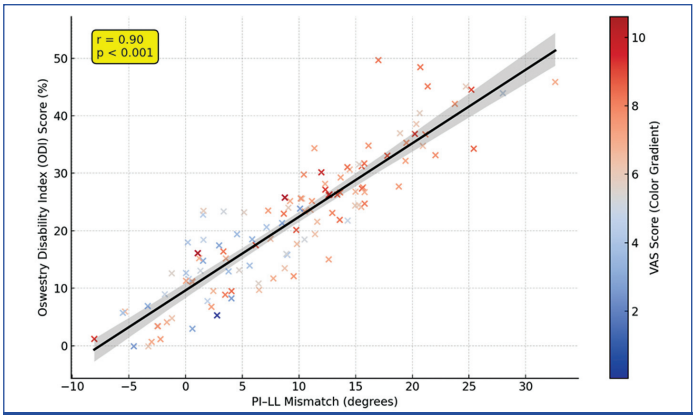
[Table/Fig-3]: Patient demographics and baseline characteristics (N=120). (p-value <0.05 considered statistically significant)

There was a strong, statistically significant positive correlation between PI-LL mismatch and both ODI and VAS scores. This means that as the mismatch increases (i.e., the lumbar spine becomes flatter relative to the pelvis), the level of disability and pain also increases. There was a strong negative correlation between LL and the clinical scores. This confirms the above: a smaller LL (hypolordosis) is associated with worse outcomes. PI alone does not correlate with disability or pain, reinforcing the idea that it's the mismatch, not the anatomy itself that is clinically important [Table/Fig-4,5].

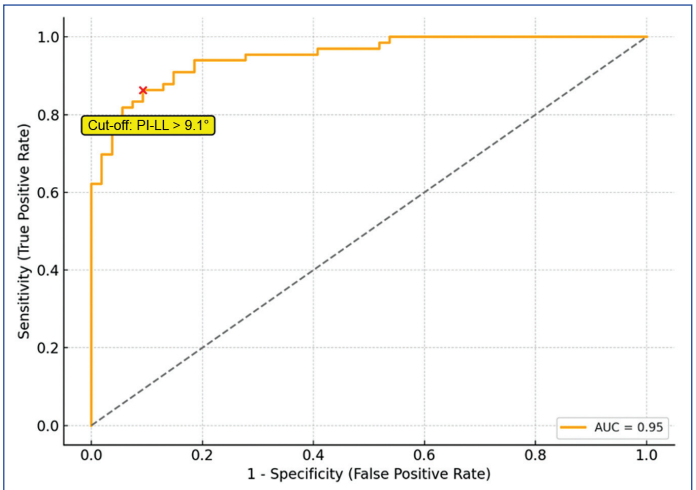
Variables	ODI score		VAS score	
	r	p-value	r	p-value
PI-LL Mismatch	0.62	<0.001*	0.51	<0.001*
Lumbar Lordosis (LL)	-0.58	<0.001*	-0.47	<0.001*
Pelvic Incidence (PI)	0.09	0.320	0.07	0.430

[Table/Fig-4]: Correlation between radiographic parameters and clinical scores.

The ROC curve was analysed to determine the ability of PI-LL mismatch to predict moderate-to-severe disability (ODI > 20%). A PI-LL mismatch cut-off value of 9.1°, which closely approximates the clinically established threshold of 10° for sagittal imbalance. Using a practical threshold of >10°, sensitivity was 78%, a specificity of 89.5% and an overall diagnostic accuracy of 81.7%. The Area Under the Curve (AUC) was 0.95, indicating excellent discriminatory ability. This threshold was clinically useful for risk stratification. It can help identify CLBP patients who are biomechanically "at-risk" and may require more targeted interventions (e.g., physiotherapy focused on restoring lordosis). The ROC curve is illustrated in [Table/Fig-6].



[Table/Fig-5]: Scatter plot demonstrating the positive correlation between PI-LL mismatch and Oswestry Disability Index (ODI) score in patients with Chronic Low Back Pain (CLBP).



[Table/Fig-6]: Receiver Operating Characteristic (ROC) curve demonstrating the performance of PI-LL mismatch in predicting moderate-to-severe disability (ODI >20%). An ROC-derived cut-off value of 9.1° demonstrated excellent discrimination (AUC=0.95), approximating the clinically used threshold of 10°.

The model explained 50.4% of the variance in ODI scores (R^2=0.504, Adjusted R^2=0.482), indicating a moderate-to-good fit. This model confirms that PI-LL mismatch is an independent predictor of ODI score (β=0.55, p-value <0.001). For every 1° increase in mismatch, the ODI score increases by 1.18 points, after controlling for age, sex, BMI, and pain level. Pain (VAS) was also, an independent predictor of disability. Age, sex, and BMI were not independent predictors in this model, suggesting that the PI-LL mismatch's effect is robust and not confounded by these demographic factors [Table/Fig-7].

Predictor variable	Unstandardised coefficient (B)	Standard error	Standardised coefficient (β)	p-value
(Constant)	5.25	4.12		0.205
PI-LL mismatch	1.18	0.18	0.55	0.001*
Age	0.15	0.09	0.12	0.098
Sex (female)	1.95	1.21	0.11	0.109
BMI	0.28	0.19	0.10	0.142
VAS score	2.02	0.45	0.32	<0.001*

[Table/Fig-7]: Multivariate linear regression with ODI score as the dependent variable.

DISCUSSION

In this retrospective single-centre study of 120 patients with CLBP, it was found that a greater PI-LL mismatch was significantly associated with worse functional disability (ODI) and greater pain (VAS). Age and pain duration were higher in the higher disability group, but PI itself did not differ significantly between groups; instead, LL was significantly lower and the resulting PI-LL mismatch significantly greater (p-value <0.001). Moreover, regression analysis revealed that the PI-LL mismatch was an independent predictor of ODI score (β=0.55, p-value <0.001), after adjustment for age, sex, BMI and pain

(VAS). ROC threshold analysis identified an optimal PI–LL mismatch cutoff of 9.1°, closely approximating the clinically relevant threshold of 10°, with high specificity (89.5%) and Positive Predictive Value (PPV) (94.1%) for identifying moderate-severe disability.

The key finding from this study was that it is not the pelvic morphology itself (PI) but rather how the lumbar spine adapts lordosis relative to that morphology (i.e., PI-LL mismatch). The lack of difference in mean PI between groups supports this interpretation: pelvic shape/parameter alone appears not to predispose to higher disability, but the failure of the lumbar spine to adapt lordosis to the pelvic template (i.e., a "mismatch"). The significantly smaller LL in the high disability group aligns with this, signifying a hypolordotic lumbar spine relative to the pelvis.

The finding-that PI-LL mismatch correlates with pain (r=0.51) and disability (r=0.62)-supports the hypothesis that sagittal imbalance manifests clinically in CLBP. This was consistent with biomechanical models indicating that a PI-LL mismatch alters load distribution across the lumbar facets and discs, potentially accelerating degenerative changes and pain generation [13].

The ROC-derived cut-off of 9.1°, approximating the clinically accepted 10° threshold for PI-LL mismatch, may be clinically useful. In surgical spine literature, a PI-LL mismatch of ~10° (±) is often used as a target parameter. For example, Schwab F et al., proposed PI-LL≤10° as ideal in deformity surgery [10]. The data suggests that even in a non fusion CLBP cohort, a similar threshold may help stratify the risk of moderate-severe disability. This finding resonates with recent studies in CLBP populations demonstrating that a PI-LL mismatch exceeding 10° is associated with greater disability, altered sagittal mechanics, and poorer spinopelvic compensation, supporting its role as a clinically relevant prognostic marker [14].

Harrison DE et al., found that LL was significantly reduced in CLBP patients compared with controls despite similar pelvic morphology [6]. Similarly, Lee SH et al., reported that PI influences LL and is associated with paraspinal muscle morphology, suggesting that both structural alignment and muscular factors contribute to sagittal imbalance and functional impairment [15]. Another recent population-based MRI/sub radiographic study found that a PI-LL mismatch >11° was associated with disc degeneration and Modic changes in the lumbar region, stating that tissue-level pathology may contribute to pain/disability [16].

Conversely, older study like Chaléat-Valayer E et al., had failed to demonstrate a robust association between spinopelvic parameters and CLBP [17]. A systematic review noted that while many studies reported hypolordosis in CLBP groups, correlation with pain/disability was inconsistent [7]. The discrepancies may stem from heterogeneous populations variable measurement protocols, and lack of stratification by disability severity. This study addresses this by stratifying by ODI and following a standardised measurement protocol with excellent reliability (ICC for PI=0.96; LL=0.94).

In the surgical domain, (Tempel ZJ et al.,) have shown that postoperative PI-LL mismatch correlates with worse functional outcomes and adjacent segment disease [4]. A recent work (Cho Y et al.,) has explored compensatory mechanisms in pelvis/hips/knees in PI-LL mismatch groups, finding altered gait/posture in mismatch cohorts [18].

The strengths of this study include evaluation of a non surgical CLBP cohort with validated clinical outcomes, high radiographic measurement reliability (ICC>0.90), identification of a clinically relevant PI-LL mismatch threshold approximating 10º, may help identify "at-risk" patients and confirmation of PI-LL mismatch as an independent independent predictor through multivariate regression analysis- emphasising its distinct biomechanical contribution, with the overall model achieving an R^2 of 0.504 and Adjusted R^2 of 0.482. Importantly, the present study focused on a non surgical population and fills a gap noted in recent literature, which has called for more studies investigating the direct clinical impact of spinopelvic alignment in conservative management pathways [3].

The findings suggest that in CLBP patients, routine evaluation of standing lateral lumbosacral radiographs for spinopelvic alignment may be warranted. Patients with a PI-LL mismatch of approximately >10° may constitute a subgroup with biomechanical imbalance contributing to disability and may potentially benefit from targeted interventions. Physical therapy programmes may incorporate sagittal balance correction (e.g., lumbar extension strengthening, postural training, hip extension flexibility, and pelvic retroversion correction). Bracing or orthotic strategies might be considered for those with fixed mismatch or hypolordosis. In refractory cases, referral for more advanced biomechanical assessment (e.g., dynamic sagittal film, alignment correction strategies) may be considered.

Limitation(s)

Despite its contributions, this study had limitations. Being retrospective, causality cannot be established; one cannot conclude that PI-LL mismatch causes increased disability; it may also be that patients with worse pain adopt a reduced LL as a protective posture. This study was conducted at a single centre with a modest sample size (n=120) and from a single geographic region; generalisability may be limited. Although LL and PI were measured, other spinopelvic parameters (pelvic tilt, sacral slope, and sagittal vertical axis) were not analysed. The final sample size (n=120) was slightly below the estimated requirement (n=123), which may have had a minimal impact on the statistical power and precision of the results. The study excluded patients with prior surgery, major deformity or neurological deficits; thus, findings may not apply to more complex CLBP populations. The threshold of >10° does not account for individual PI magnitude. Additionally, although ROC analysis identified an optimal cutoff of 9.1°, a rounded threshold of 10° was adopted for clinical interpretability and consistency with prior spinopelvic alignment literature (for example, PI-LL≈-28.5+0.44×PI) rather than a universal threshold [19]. This study did not capture dynamic or functional radiographic measures (e.g., hip compensation, knee flexion) or MRI spinal degeneration markers which might mediate the association.

Future research should include prospective studies incorporating a broader set of sagittal alignment parameters and dynamic functional assessments to better characterise the biomechanics of mismatch. Stratifying patients by PI magnitude (e.g., <50°, 50-65°, >65°) to test whether the optimal mismatch target varies by pelvic morphology, as some asymptomatic volunteer data suggest [19]. Running randomised controlled trials of targeted rehabilitation interventions (e.g., extension-based therapy, lordosis enhancement protocols) in CLBP patients with PI-LL mismatch to correct/improve the mismatch and analyse for better outcomes. Exploring advanced imaging correlations to determine whether the correlation of PI-LL mismatch improves clinical outcomes in CLBP.

CONCLUSION(S)

In summary, in this cohort of CLBP patients, a larger mismatch between PI and LL was significantly associated with greater functional disability and pain. PI by itself was not discriminatory; rather, the failure of the lumbar spine to adapt lordosis to the pelvic morphology (i.e., PI-LL mismatch) appears to drive worse outcomes. These findings align with the growing body of spinopelvic research and extend the relevance of sagittal balance beyond surgical populations into non operative CLBP settings. The ROC analysis identified a cutoff approximating 10°, supporting the clinical relevance of a PI-LL mismatch threshold >10° in identifying higher-risk patients. Given the high reliability of measurement and the

independent predictive value of mismatch, incorporation of sagittal spinopelvic radiographic assessment in CLBP evaluation may help stratify disability risk and inform targeted intervention strategies.

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Authors' contribution: SV: Conceptualisation, Methodology, Writing - original draft; KVAK: Conceptualisation, Supervision, Project administration; EP: Supervision, Writing and review and editing; CK: Investigation, Data curation; SK: Formal analysis, Validation, Visualisation; GK: Investigation and validation; SKh: Methodology, Formal analysis; SM: Data curation; Writing and review and editing.

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