RESEARCH ARTICLE

Pelvico-Sacro-L1 Angle: An Index for Rapid Evaluation of Spinopelvic Sagittal Balance

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Abstract

Objectives: This study aimed to evaluate the Pelvico-Sacro-L1 angle (PSLA) as a direct parameter for assessing PI-LL mismatch as a key determinant of sagittal balance.

Methods: In this retrospective study, adult patients scheduled for total hip arthroplasty (THA) underwent spinopelvic lateral radiography. The pelvic sagittal line angle (PSLA) was defined as the angle between a line drawn from the center of the femoral head to the center of the superior endplate of S1 and the superior endplate of L1. The deviation from 90° was termed the modified PSLA, proposed as an alternative to the pelvic incidence–lumbar lordosis (PI–LL) mismatch. Two independent orthopaedic surgeons measured the spinopelvic parameters and repeated the assessments four weeks later to evaluate intraobserver reliability.

Results: A total of 92 patients (average age: 57.4 ± 9.9 years, 50 females) were included. The Bland–Altman plot indicated no significant systematic difference between the two measurement sets, suggesting good agreement between methods. The intraclass correlation coefficient (ICC) for PSLA in both inter- and intraobserver reliability was greater than 0.9, indicating excellent agreement.

Conclusion: The PSLA demonstrated a strong agreement with the PI-LL mismatch, confirming the reliability of this approach, which provides a more straightforward and easily interpretable measurement.

Level of evidence: II

Keywords: Lumbar lordosis, Pelvic incidence, Sagittal balance, Spinopelvic, Total hip arthroplasty

Introduction

Proper alignment of the spine, pelvis, and lower extremities in the sagittal plane is essential for maintaining a stable and biomechanically efficient posture, sustaining a forward gaze, and enabling efficient ambulation.[1,2] Sagittal imbalance may induce adaptive changes in the pelvis, hip, and knee joints through compensatory mechanisms aimed at preserving a horizontal gaze while minimizing energy expenditure.[3,4] In addition, this condition in adult spinal deformity has received increasing attention due to its association with reduced health-related quality of life and increased disability.[5,6]

Spinal imbalance is known to affect the functional positioning of the acetabulum and increase the risk of complications following total joint arthroplasty (TJA), including hip dislocation, restricted knee mobility, chronic pain, and impaired gait.[2,7] The pelvis plays a pivotal role in regulating sagittal alignment of the vertebral column, forming an integral component of the spinopelvic complex, which comprises the spine, pelvis, and hip joint.[8] The dynamic interaction between the hip and spine—particularly in the sagittal plane—has attracted considerable attention due to its influence on posture and the resulting alterations in pelvic orientation.[9-11] These changes can directly affect acetabular cup orientation, which is critical for joint mechanics, as malorientation may increase the risk of impingement, accelerated wear, pain, and instability.[12-14] Notably, an increased sagittal vertical

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axis (SVA) and pelvic incidence–lumbar lordosis (PI–LL) mismatch have been strongly associated with poorer patient-reported outcomes.[15,16] Consequently, there is growing emphasis on evaluating spinopelvic parameters, such as PI–LL mismatch and sagittal spinal alignment, to optimize implant positioning during TJA and reduce the risk of related complications.

Multiple studies have examined strategies for restoring lumbar lordosis (LL) concerning pelvic incidence (PI), yet the optimal degree of LL restoration remains uncertain.[17,18] This uncertainty may be attributable to the lack of a direct radiographic parameter for assessing LL restoration. Furthermore, the PI–LL mismatch is an indirect measure, as it requires the assessment of two distinct parameters. The primary objective of this study was to evaluate the Pelvico–Sacro–L1 angle, a direct radiographic parameter, for its ability to reflect the radiological and geometric alignment of the PI–LL mismatch concerning sagittal balance and imbalance.

Materials and Methods

In this retrospective observational study, patients who underwent total hip arthroplasty (THA) were identified from the Joint Reconstruction Research Center hip registry. Eligible participants were between 18 and 85 years of age. Exclusion criteria included radiographic evidence of hip dysplasia, spinal deformities, or a prior history of surgery involving the spine or hip. Demographic data, including age and sex, were recorded. The study was approved by the Institutional Review Board of the Orthopedic Department at Tehran University of Medical Sciences (IR.TUMS.MEDICINE.REC.1400.1442). Written informed consent was obtained from all participants at the time of admission, permitting the documentation of their data in the registry and its use in research, with strict preservation of anonymity.

Radiographic Evaluation

All included patients underwent spinopelvic lateral radiography as part of their preoperative assessment for total hip arthroplasty (THA). In patients with suspected adult spinal deformity, full-length standing posteroanterior and lateral radiographs were also obtained during the preoperative evaluation. Spinopelvic parameters—including pelvic incidence (PI), lumbar lordosis (LL), pelvic incidence–lumbar lordosis mismatch (PI–LL), sacral slope (SS), pelvic tilt (PT), and the Pelvico–Sacro–L1 angle (PSLA) as a novel index—were measured independently by two orthopedic surgeons [Figure 1]. All measurements were documented in a Microsoft Excel database.

Measurement Parameters

Pelvic incidence (PI): The PI angle is defined by the intersection of a line drawn from the center of the femoral head to the center of the superior endplate of S1 and a second line perpendicular to the S1 endplate.[19]

Lumbar Lordosis (LL): LL is the angle between the superior endplates of L1 and S1.[20]

Pelvic Incidence–Lumbar Lordosis Mismatch (PI-LL): The PI-LL angle represents the degree of imbalance and stiffness of the spinopelvic alignment.[21]

Sacral Slope (SS): SS is defined as the angle between the horizontal plane and the sacral endplate.[19]

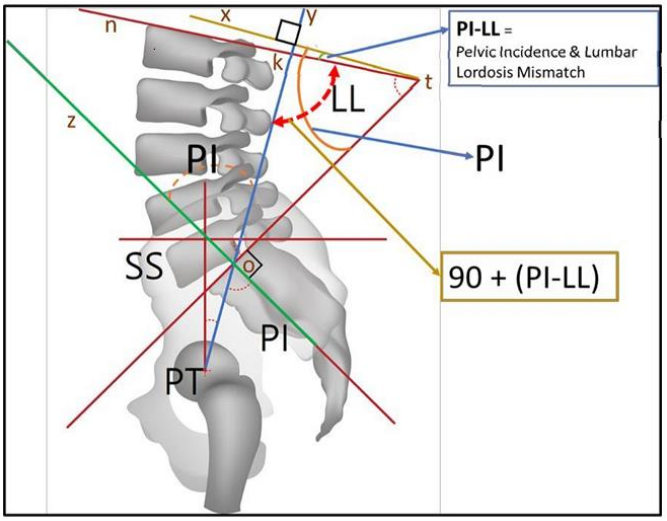

Figure 1. Pelvico-Sacro-L1 angle. The difference in this angle with 90 degrees will be equal to Pelvic Incidence and Lumbar Lordosis Mismatch

Pelvic Tilt (PT): PT is the angle formed by a vertical line passing through the center of the femoral heads and the line passing through the midpoint of the sacral endplate.[22]

Pelvico-Sacro-L1 Angle (PSLA): The PSLA is defined as the angle between a line drawn from the center of the femoral head to the center of the superior endplate of S1 and the superior endplate of L1 [Figures 2 and 3]. The deviation of this angle from 90°—referred to as the modified PSLA—is proposed as an alternative to the pelvic incidence–lumbar lordosis (PI–LL) mismatch.

Reassessment of Radiographs

After a four-week interval—considered sufficient to minimize recall bias—the same two surgeons re-evaluated the complete set of spine radiographs, presented in a different order. The assessments were performed in the same manner as the initial evaluation, without access to the original response sheets. All measurements were recorded anew in a Microsoft Excel database and matched to the corresponding patient identifiers.

The initial set of measurements was used to assess interobserver variability, whereas the comparison between the first and second measurements by each observer was used to evaluate intraobserver variability.

Statistical analysis

Quantitative variables are presented as mean ± standard deviation (SD), and categorical variables as frequency and percentage. The Kolmogorov–Smirnov test was used to assess the normality of data distribution. Associations between categorical variables were analyzed using the chi-square test or Fisher's exact test, as appropriate. Comparisons of quantitative variables were performed using the independent-samples t-test or the Mann–Whitney U test. Reliability was evaluated using the intraclass correlation coefficient (ICC) with a two-way mixed-effects model. ICC

values ≥0.90 were interpreted as excellent agreement, 0.70–0.90 as good, 0.50–0.70 as moderate, and ≤0.50 as poor.[23] Statistical significance was set at P ≤ 0.05. A Bland–Altman plot was also generated for the new index.

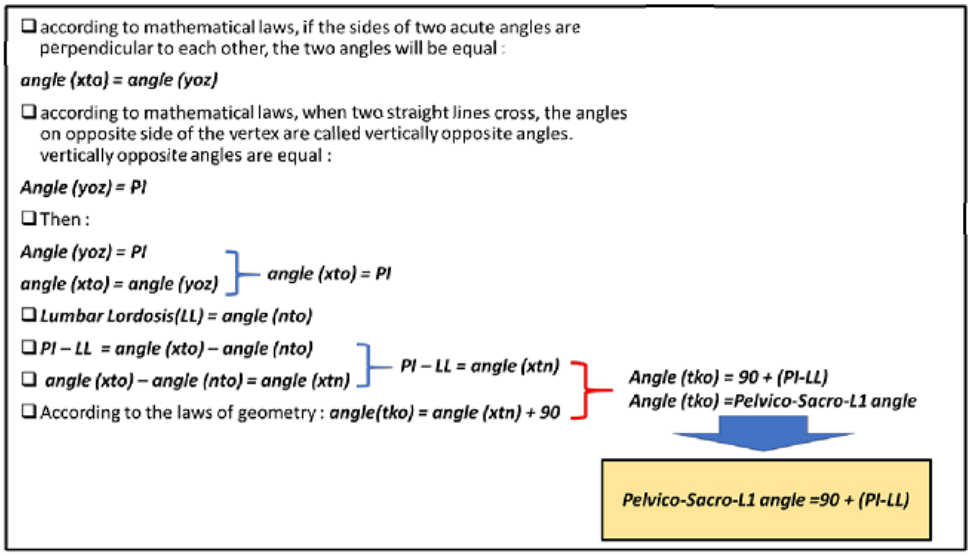

Figure 2. Demonstrating the equivalence of the Pelvico-Sacro-L1 angle with Pelvic Incidence and Lumbar Lordosis mismatch

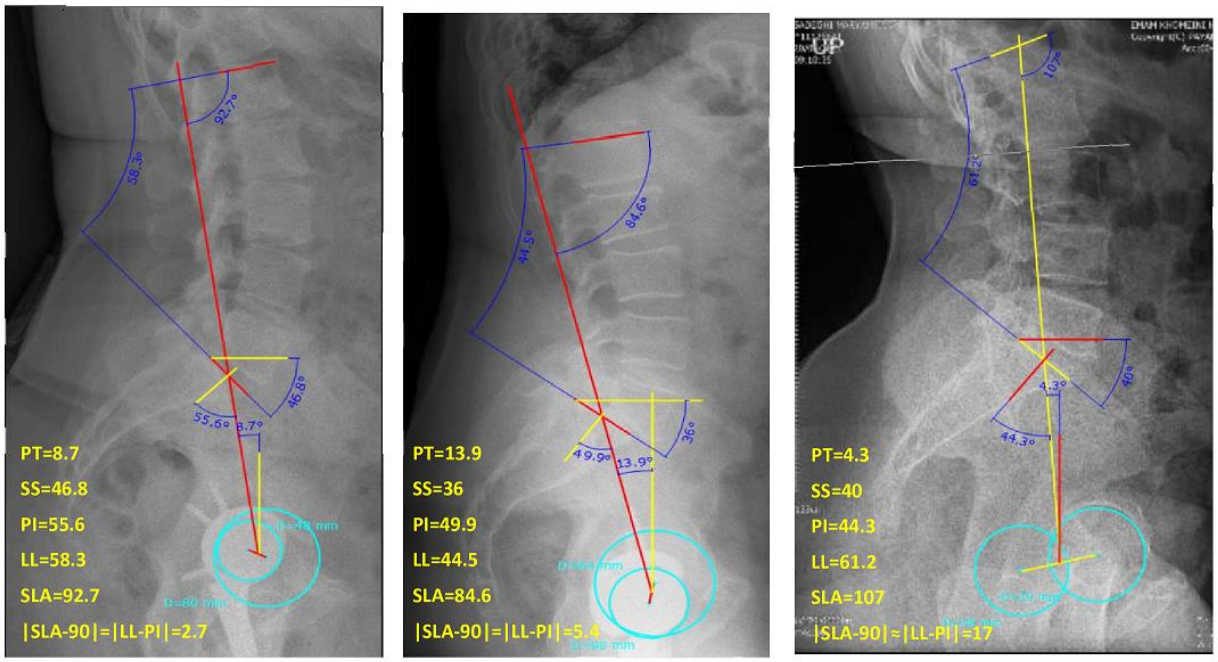

Figure 3. Measurement of spinopelvic angles, including Pelvic Tilt (PT), Pelvic Incidence (PI), Sacral Slope (SS), Lumbar Lordosis (LL), and Pelvico-Sacro-L1 Angles, on preoperative X-rays

Results

Of the 100 participants initially enrolled, eight were excluded due to insufficient imaging, leaving a final sample of 92 patients (mean age, 57.4 ± 9.9 years), of whom 50 were female. All participants underwent standing spinopelvic lateral radiography.

Table 1 presents the measurements of PI–LL and modified PSLA by the two observers, along with a comparison of these measurements [Table 1]. No significant difference was found between the PI–LL and modified PSLA values measured by the same observer. The Bland–Altman plot further revealed a mean difference

close to zero, suggesting no significant systematic bias between the two sets of measurements and indicating good agreement between the two methods [Figure 4].

Inter-observer Reliability

Interobserver reliability, which assessed the consistency between the measurements of the two observers, was high. At Time 1, the intraclass correlation coefficient (ICC) was 0.922 for the previous technique and improved to 0.954 for the new technique. At Time 2, further improvement was observed, with the ICC increasing to 0.945 in the prior technique and 0.980 for the new technique.

Intra-observer Reliability

Intraobserver reliability was assessed by calculating the intraclass correlation coefficients (ICCs) for each observer's measurements at two separate time points. The results demonstrated high reliability for both observers using both the traditional and new measurement techniques. Specifically, Observer 1 showed an ICC of 0.951 for the previous technique, improving to 0.961 with the new technique. Similarly, Observer 2 exhibited an ICC of 0.978 in the prior technique, with a slight decrease to 0.973 for the new technique. These findings suggest that both observers were able to reliably reproduce their measurements over time with both methods, with the latest technique showing comparable or slightly improved reliability.

Table 1. Comparison between existing parameter and new index as measured by observer using spinopelvic lateral X-rays

Observer	Parameter		
	|PI-LL|	|90°-SLA|	P-value [a]
Orthopedic surgeon #1	15.95 ± 13.92	15.93 ± 13.92	0.982
Orthopedic surgeon #2	15.94 ± 13.91	15.93 ± 13.92	0.988
P value [b]	0.994	0.999	

PI-LL, Pelvic Incidence–Lumbar Lordosis Mismatch; SLA, Sacral-L1 Angle

[a] Mann–Whitney U test, Comparison of PI-LL with new index within each reviewer

[b] Mann–Whitney U test, Comparison of each parameter between reviewers

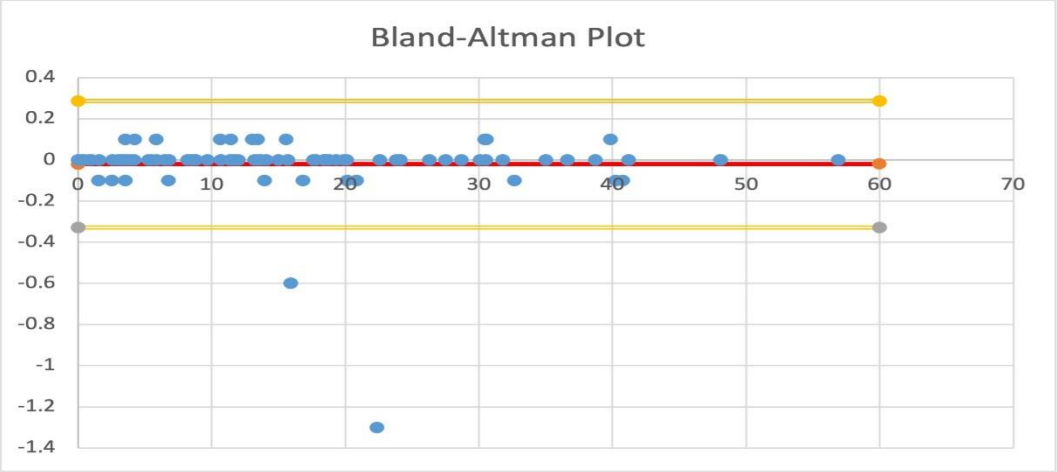

Figure 4. Bland-Altman plot showing no significant systematic difference between the two measurement sets and indicating good agreement between the methods

Discussion

Spinopelvic movement is a complex phenomenon that both spine and hip replacement surgeons have traditionally overlooked. However, its significance is gaining increasing attention, as the rising prevalence of osteoarthritis and spinal disorders is expected to lead to a higher volume of total hip arthroplasty (THA) and spinal correction procedures. An essential component of evaluating spinopelvic sagittal balance is the radiographic measurement of the pelvic incidence–lumbar lordosis (PI–LL) mismatch.[24-26] In this study, we explored the use of the Pelvico–Sacro–L1 angle (PSLA) as an alternative to the PI–LL measurement. Our findings indicate that the modified PSLA yields values closely aligned with those of PI–LL, in terms of both mean and standard deviation, within the studied population. Furthermore, Bland–Altman analysis and the calculation of the intraclass correlation coefficient (ICC) for both interobserver and intraobserver assessments demonstrate a

high level of agreement between the modified PSLA and PI–LL, confirming the reliability of this alternative measurement approach.

Before performing total hip arthroplasty (THA), surgeons evaluate spinopelvic mobility and sagittal balance in their patients. Despite the high success rate of THA, complications can still occur, with dislocation being one of the most serious. A critical factor in preventing dislocations is understanding their underlying causes, one of which is restricted spinopelvic mobility or spinal imbalance, particularly in cases of late THA dislocations. Therefore, preoperative radiographic assessment is essential, especially for patients who may have limited spinopelvic mobility. This includes individuals with a history of lumbosacral fusion, kyphotic posture, severe spinal degenerative disease, hip flexion contractures, or previous THA dislocation and revision surgery.[27,28]

Research has shown that a difference of 10° between pelvic incidence (PI) and lumbar lordosis (LL) is optimal for maintaining sagittal balance. When the difference between PI and LL is within 10° (|PI–LL| ≤ 10°), the angles are considered well-matched. However, a mismatch occurs when PI and LL differ by more than 10°, potentially leading to disharmonious sagittal alignment [Figures 5 and 6].[29] Achieving spinopelvic harmony is crucial for optimizing energy efficiency and maintaining proper posture. Correcting the PI–LL mismatch to less than 10° has been associated with improved clinical outcomes in patients with adult spinal deformity, flat-back syndrome, and those undergoing short-segment transforaminal lumbar interbody fusion.[16] In degenerative lumbar spine disease, patients with a PI–LL mismatch of 10° or greater face a higher risk of adjacent segment disease compared to those with a smaller mismatch.[29] Furthermore, in patients with high pelvic tilt or significant PI–LL mismatch, a more substantial correction is required during lumbar pedicle subtraction osteotomy. Additionally, a kyphotic spine with a PI–LL mismatch exceeding 10° often compensates by increasing posterior pelvic tilt, which can lead to greater acetabular anteversion while standing and the potential for posterior impingement.[30]

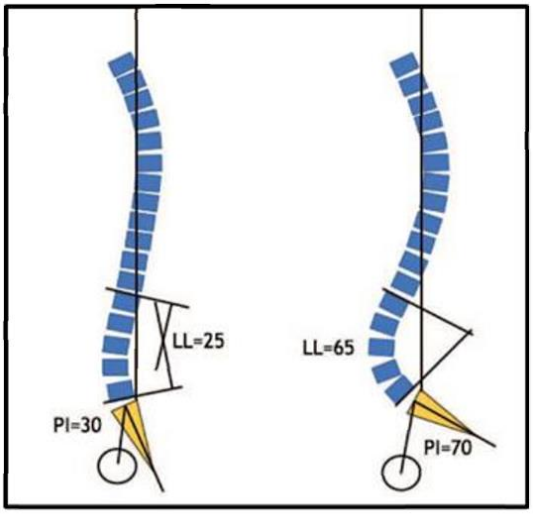

Figure 5. Examples illustrating matches between Pelvic Incidence (PI) and Lumbar Lordosis (LL)

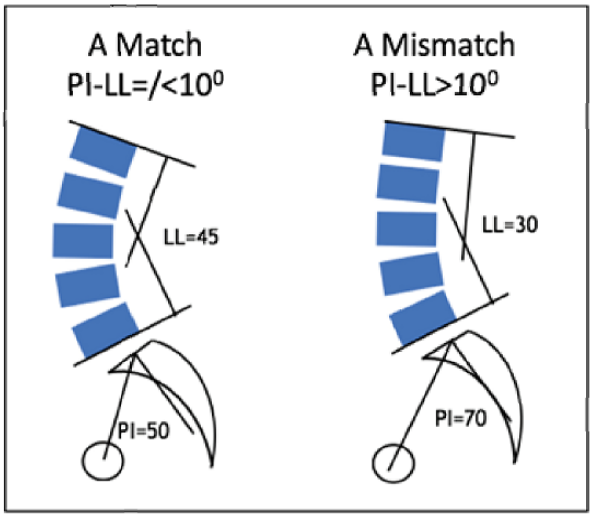

Figure 6. Representative drawings showing a match (left) and mismatch (right) between Pelvic Incidence (PI) and Lumbar Lordosis (LL)

To compute the difference between pelvic incidence (PI) and lumbar lordosis (LL), it is necessary to determine both angles. Instead of using the traditional method, we calculated the PI–LL difference using an alternative angle, referred to as the Pelvico–Sacro–L1 angle (PSLA). This angle is formed by the intersection of a line connecting the center of the femoral head to the midpoint of the superior endplate of the sacrum, and a line parallel to the upper surface of the first lumbar vertebra. As demonstrated in Figures 1 and 2, we used geometric principles to prove that the PSLA is equal to 90° plus the PI–LL difference. By measuring the deviation of the PSLA from 90°, the PI–LL mismatch can be identified. This alternative approach allows for a quicker and simpler determination of spinopelvic sagittal balance in both hips and knees, particularly before total hip and knee replacement surgery, without the need to directly measure sacral slope (SS), pelvic tilt (PT), PI, and LL angles.

Yamada et al. emphasized the importance of addressing postoperative pelvic incidence–lumbar lordosis (PI–LL) mismatch but noted that 23% of patients achieved satisfactory sagittal vertical axis alignment and clinical outcomes despite insufficient postoperative lumbar

lordosis.[31] Inami et al. proposed that the ideal postoperative PI–LL mismatch is not a fixed value but varies according to individual PI. This suggests that the optimal degree of lumbar lordosis correction relative to PI remains unclear.[18] However, future research could clarify the appropriate PI–LL mismatch by exploring the Pelvico–Sacro–L1 angle (PSLA), which provides a more straightforward and interpretable measure.

This study has several limitations. First, due to its retrospective design, variations in imaging techniques may have influenced the measurements of spinopelvic parameters. Additionally, the study was conducted at a single center, which may limit the generalizability of the findings to other populations or clinical settings.

Conclusion

Based on the results, the PSLA demonstrated strong agreement with the PI-LL mismatch, confirming the reliability of this approach. The difference between the PSLA and the 90-degree angle (modified PSLA) presented a promising alternative to the PI-LL mismatch, particularly in pre-operative planning. This approach provided a more straightforward and easily interpretable measurement.

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