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Prevalence of Sagittal Spinal Deformity Among Patients Undergoing Total Hip Arthroplasty

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ABSTRACT

Background: The important relationship between sagittal spinal alignment and total hip arthroplasty (THA) is becoming well recognized. Prior research has shown a significant relationship between sagittal spinal deformity (SSD) and THA instability. This study aims at determining the prevalence of SSD among preoperative THA patients.
Methods: A multicenter database of preoperative THA patients was analyzed. Radiographic parameters measured from standing radiographs included anterior pelvic plane tilt, spinopelvic tilt, and lumbar lordosis (LL); pelvic incidence (PI) was measured from computed tomography scans. Lumbar flatback was defined as PI-LL mismatch >10°, balanced as PI-LL of −10° to 10°, and hyperlordosis as PI-LL <−10°.
Results: A total of 1088 patients were analyzed (mean, 64 years; 48% female). And 59% (n = 644) of patients had balanced alignment, 16% (n = 174) had a PI-LL > 10°, and 4% (n = 46) had a PI-LL > 20° (severe flatback deformity). The prevalence of hyperlordosis was 25% (n = 270). Flatback patients tended to be older than balanced and hyperlordotic patients (69.5 vs 64.0 vs 60.8 years, $P < .001$). Spinopelvic tilt was more posterior in flatback compared to balanced and hyperlordotic patients (24.7° vs 15.4° vs 7.0°) as was anterior pelvic plane tilt (−7.1° vs −2.0° vs 2.5°) and PI (64.1° vs 56.8° vs 49.0°), all $P < .001$.
Conclusion: Only 59% of patients undergoing THA have normally aligned lumbar spines. Flatback SSD was observed in 16% (4% with severe flatback deformity) and there was a 25% prevalence of hyperlordosis. Lumbar flatback was associated with increasing age, posterior pelvic tilt, and larger PI. The relatively high prevalence of spinal deformity in this population reinforces the importance of considering spinopelvic alignment in THA planning and risk stratification.

The increasing incidence of hip osteoarthritis in an increasingly active aging population has led to a surge in the number of patients undergoing total hip arthroplasty (THA). As a result, there has been a focus on determining factors that predispose these patients to complications associated with THA, including hip instability and dislocation. While efforts in defining implant safe zones [1], bearing sizes and technologies, and soft tissue balance have gone some way to reducing dislocation risk, it has become clear that spinal pathology, spinopelvic malalignment in particular, plays a significant role [2–7]. As such, there have been a growing number of studies focusing on the association between sagittal spinopelvic alignment and hip stability in THA patients, particularly pelvic tilt.

Pelvic tilt can be measured in 2 ways: anterior pelvic plane tilt (APPt) or spinopelvic tilt (SPT). APPt is the angle between a line between the anterior superior iliac spines and the pubic symphysis, and the vertical; SPT is the angle formed by a line between the bicoxofemoral axis and the midpoint of the sacral endplate, and the vertical (Fig. 1). APPt is generally preferred by arthroplasty surgeons as it is measured using landmarks that can be easily identified

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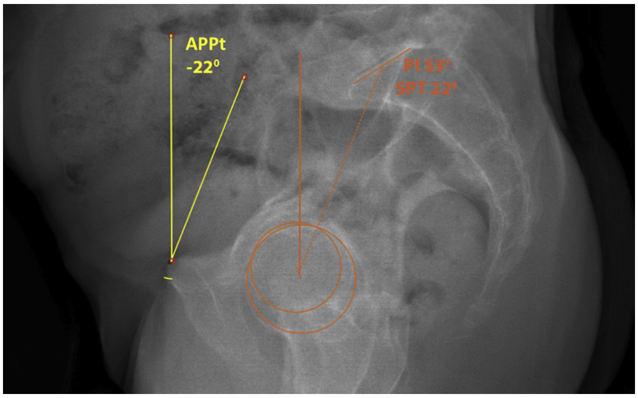

Fig. 1. Lateral radiograph illustrating the 2 measures of pelvic tilt: spinopelvic tilt (SPT—orange) and anterior pelvic plane tilt (APPt—yellow). SPT is the angle between the vertical and a line from the bicoxofemoral axis to the middle of the sacral endplate. APPt is the angle between the vertical and a line from the pubic tubercle to the anterior-superior iliac spines.

intraoperatively, whereas spine surgeons use SPT, which has greater precision [8]. Increases in SPT refer to posterior pelvic tilt (Fig. 2), and Maratt et al [9] found that functional anteversion increases by 0.74° per each degree of posterior pelvic tilt. In the spine literature, it is well established that posterior pelvic tilt is an important compensatory mechanism for patients with sagittal spinal deformity (SSD) as it functions to restore the gravity line over the pelvis [3,10–12].

Spinopelvic alignment is typically measured in terms of the mismatch (mathematical difference) between pelvic incidence and lumbar lordosis (PI minus LL or PI-LL) [13,14]. PI is a morphologic parameter, which reflects the relationship between the position of the sacrum and pelvis. Although PI increases slightly with age [15], this parameter is unique to each patient and does not vary with posture. It is measured as the angle between a line perpendicular to the sacral endplate and the line from the bicoxofemoral axis to the midpoint of the sacral endplate. LL is the Cobb angle between the superior endplate of the L1 body and the sacral endplate (Fig. 3). Ideally, patients should have an LL that matches their PI within 10° [16]. Patients who have a larger PI require more LL to maintain optimal spinopelvic balance, which is why LL alone cannot be used to effectively assess deformity of the lumbar spine. A larger mismatch between PI and LL represents greater spinopelvic malalignment and is associated with greater disability [16]. Greater PI-LL mismatch has also been shown to be a significant risk factor for THA dislocation [3].

Given the multitude of studies highlighting the strong association between sagittal spine alignment and the stability of THA, further investigation into the prevalence of sagittal spine malalignment in THA patients is warranted. Our study aims at determining the prevalence of sagittal spine deformity in preoperative THA candidates using a large multicenter database of patients.

Materials and Methods

Patient Population and Data Collection

This study is a multicenter, prospectively collected database of 1100 patients over age 18, undergoing primary THA, enrolled consecutively. Database exclusion criteria included revision THA, prior infection, or tumor. After excluding 11 patients with a history of spinal fusion, 1088 primary THA patients were included in the analysis. Appropriate institutional review board approval was obtained before the data collection process. The demographic information recorded for each patient included age and gender.

Radiographic Evaluation

All patients had preoperative standing lateral radiographs of the pelvis and lumbar spine (Fig. 1). Low-dose computed tomography (CT) scans of the pelvis were also obtained for each patient as part of the standard THA planning protocol in order to determine the native acetabular anatomy as well as for custom guide manufacturing and intraoperative navigation. Parameters measured from lateral radiographs included APPt (the angle between a line between the anterior superior iliac spines and the pubic symphysis, and the vertical), SPT (the angle between a line between the bicoxofemoral axis and the midpoint of the sacral endplate, and the vertical), sacral slope (the angle between the

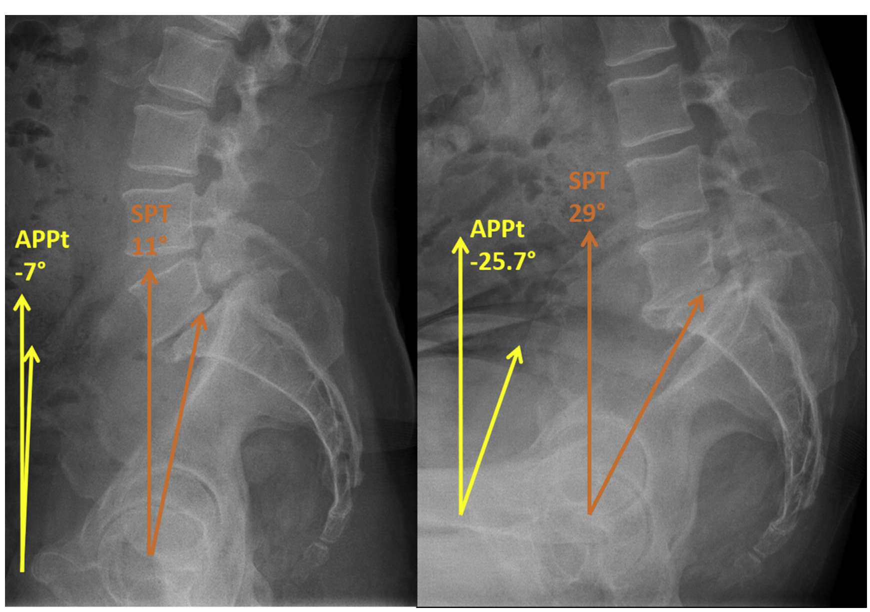

Fig. 2. Lateral radiographs demonstrating the relationship between pelvic tilt and postural change. As the patient moves from a standing (left) to a seated (right) posture, posterior pelvic tilt (pelvic retroversion) increases, which is represented by an increase in SPT and a decrease in APPt.

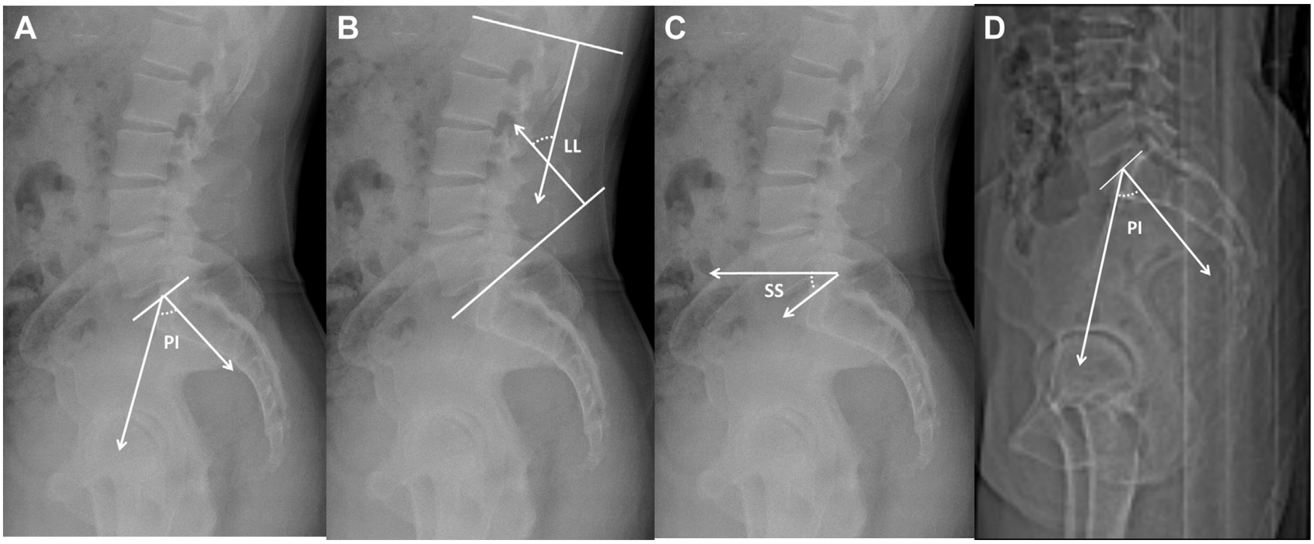

Fig. 3. Standing lateral radiograph illustrating (A) pelvic incidence (PI), (B) lumbar lordosis (LL), and (C) sacral slope (SS). (D) An image from a computed tomography scan to demonstrate how PI was measured in this study. LL is the Cobb angle between the superior endplate of L1 and the sacral endplate. PI is the angle formed between a line perpendicular to the sacral endplate and a line from the bicoxofemoral axis to the middle of the sacral endplate. SS is the angle between the plane of the sacral endplate and the horizontal.

sacral endplate and the horizontal), and LL (the angle between the upper endplate of L1 and the upper endplate of S1 vertebrae; Figs. 1 and 3). PI (the angle between a line between the bicoxofemoral axis and the midpoint of the sacral endplate, and a line perpendicular to the sacral endplate) was measured from CT scans. PI-LL mismatch (PI minus LL) was defined as the mathematical difference between PI and LL on the sagittal CT reconstruction and is a measure of sagittal lumbopelvic alignment. All radiographic measurements were performed at a central location using a dedicated and validated software (RadiAnt DICOM Viewer version 4.1.6).

SSD was defined by the difference between PI and LL. Flatback was defined if the PI-LL difference was >10°. Sagittal spinal alignment was considered balanced if the PI-LL difference was between −10° and 10°. Hyperlordosis was defined if the PI-LL difference was <−10° (Fig. 4).

Statistical Analysis

The cohort was first analyzed as a whole before patients were stratified into 3 groups based on PI-LL mismatch: balanced (−10° to +10°), flatback (>10°), and hyperlordotic (<−10°). Patients in these 3 groups were compared for baseline demographic information as well as radiographic parameters.

Relationships between continuous variables across the unstratified cohort were analyzed via bivariate Pearson correlations. After stratifying by PI-LL, continuous variables were compared across PI-LL groups using 1-way analysis of variance. Homogeneity of variance was assessed by Levene's test. Post hoc comparisons were performed via Tukey honest significant difference tests. Categorical variables were compared using Pearson χ^2 tests. All statistical analyses were performed using the Statistical

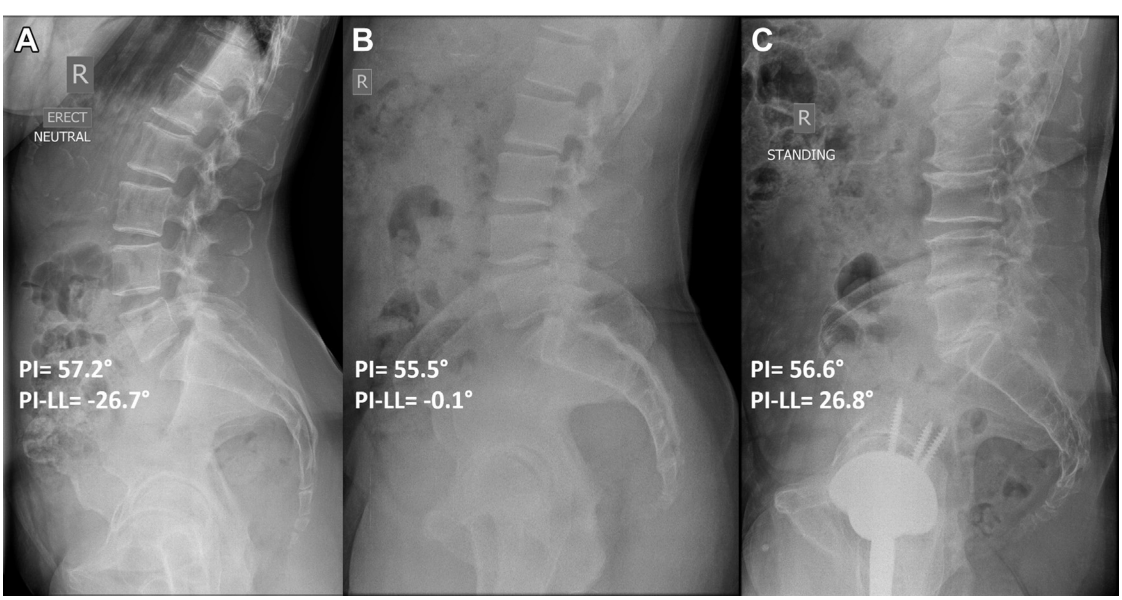

Fig. 4. Standing lateral radiographs demonstrating PI-LL mismatch in 3 patients with a similar PI. (A) Hyperlordosis (PI-LL < −10°). (B) Balanced (PI-LL = −10° to +10°). (C) Lumbar flatback (PI-LL > 10°).

Table 1
Baseline Characteristics of the Cohort, Stratified by Pelvic Incidence-Lumbar Lordosis (PI-LL) Mismatch. Age and Pelvic Incidence Are Reported as Mean ± Standard Deviation. *P* Values < .05 Represent Significant Differences Between PI-LL Groups.

	Hyperlordotic (N = 270)	Balanced (N = 644)	Flatback (N = 174)	Total (N = 1088)	*P* Value
Age (y)	60.8 ± 10.4	64.0 ± 9.9	69.5 ± 9.8	64.1 ± 10.4	<.001
Gender (% female)	50.7	48.4	47.1	48.8	.87
Pelvic incidence	49.0 ± 8.7	56.8 ± 10.5	64.1 ± 12.6	56.0 ± 11.5	<.001

Package for the Social Sciences (SPSS version 23.0, IBM Corp, Armonk, NY). The cutoff for statistical significance was set at a *P* value <.05.

Results

Patient Sample

Of the 1088 preoperative THA patients, 48.8% were female and the average age was 64.1 ± 10.4 years. The mean PI was 56.0°10.11.5°. The proportion of patients with balanced alignment (PI-LL between −10° and +10°) was 59.2% (n = 648). The prevalence of flatback deformity (PI-LL > 10°) and hyperlordosis (PI-LL < −10°) were 16.0% (n = 177) and 24.8% (n = 273), respectively. Severe flatback deformity (PI-LL > 20°) was observed in 4.2% (n = 46) of patients. Flatback patients were significantly older and had a higher PI compared to normal and hyperlordotic patients. Gender distribution did not vary significantly across PI-LL groups (Table 1).

Spinopelvic Parameters and PI-LL Mismatch

The average PI-LL mismatch was 17.6° for flatback patients, −0.9° for balanced patients, and −17.1° for hyperlordotic patients. On average, flatback patients had 19.6° less LL than hyperlordotic patients and 11.2° less than balanced patients (P < .001). Flatback deformity was also associated with less sacral slope compared to balanced and hyperlordotic patients (39.3° vs 41.5° vs 42.7°; P < .001; Table 2).

Pelvic Tilt and PI-LL Mismatch

By both measures of pelvic tilt, SPT and APPt, there was a significant association between PI-LL mismatch and posterior tilt. Posterior pelvic tilt is represented by a positive SPT and a negative APPt (Fig. 5). SPT among flatback patients was significantly higher (more posterior) compared to balanced and hyperlordotic patients (24.7° vs 15.4° vs 7.0°; P < .001). A similar, but less pronounced, relationship was also observed for APPt (−7.1° vs −2.0° vs 2.5°). Increasing PI-LL mismatch was correlated with greater posterior pelvic tilt for both measures of pelvic tilt, but the correlation was stronger for SPT compared to APPt (r = 0.722 vs r = −0.494; P < .001 for both; Table 2; Figs. 5 and 6).

Discussion

The results of this large multicenter study are one of the first to demonstrate the high prevalence of sagittal spine deformity in preoperative THA candidates. Prior studies have analyzed various spinopelvic parameters (pelvic tilt, PI, LL, and PI-LL mismatch) to demonstrate the implications of sagittal spine imbalance on the stability of THA in postoperative patients [2,3,5,7,17]. The utilization of PI-LL mismatch to classify the severity of "flatback," "hyperlordotic," and "balanced" sagittal spinal alignment is well established in spine literature [16,18]. More recently, this framework has been applied to understanding the role of pelvic tilt in assessing THA stability. DelSole et al [3] studied a group of patients with hip dislocation events following THA and determined that these patients in comparison to nondislocators had increased PI-LL mismatch as well as greater posterior pelvic tilt and global sagittal imbalance. In addition to looking at the general prevalence of SSD in preoperative THA candidates, we incorporated the PI-LL mismatch as a stratification measure. We found the prevalence of flatback deformity (PI-LL > 10°-20°) to be 16.0% and severe sagittal spine deformity (PI-LL > 20°) to be roughly 4%. Additionally, 25% of patients were classified as hyperlordotic (PI-LL < 10°). The results of this study highlight that strong consideration should be placed on implementing sagittal spinal alignment risk stratification algorithm in patients undergoing THA. Patients with a flatback deformity tended to be older, which is expected given that the degenerative changes associated with aging result in progressive kyphosis and sagittal spinal imbalance. This result points to the possibility of implementing sagittal spinal alignment screening tools specifically in older THA candidates.

The results of the association between PI-LL mismatch and spinopelvic parameters highlight important implications for prosthetic joint stability, particularly in patients with flatback deformity. These flatback patients had roughly 20° less LL than hyperlordotic patients and 8° less than balanced patients. As demonstrated by Esposito et al [19], patients with decreased LL display less posterior pelvic tilt in the sitting position and a smaller change in pelvic tilt when transitioning from standing to sitting, which can cause impingement of the femoral neck and acetabular component, predisposing these patients to dislocation. Additionally, Buckland et al [10] further demonstrated that patients with worse spinopelvic malalignment had more posterior pelvic tilt in the standing posture and as a result had more functionally anteverted acetabular components. This study further determined that change in acetabular anteversion was most closely correlated with

Table 2
Spinopelvic Alignment Stratified by Pelvic IncidenceLumbar Lordosis (PI-LL) Mismatch. Average Values of Spinopelvic Parameters Measured From Standing Lateral Radiographs. Values are Reported as Mean ± Standard Deviation. *P* Values < .05 Represent Significant Differences Between PI-LL Groups.

	Hyperlordotic (N = 270)	Balanced (N = 644)	Flatback (N = 174)	Total (N = 1088)	*P* Value
PI-LL mismatch	−17.1 ± 5.5	−0.9 ± 5.5	17.6 ± 7.0	−2.0 ± 12.3	<.001
Lumbar lordosis	66.1 ± 8.7	57.7 ± 10.3	46.5 ± 13.2	58.0 ± 12.1	<.001
Sacral slope	42.7 ± 7.8	41.5 ± 8.4	39.3 ± 9.7	41.5 ± 8.5	<.001
Spinopelvic tilt	7.0 ± 7.9	15.4 ± 6.1	24.7 ± 7.1	14.8 ± 8.7	<.001
Anterior pelvic plane tilt	2.5 ± 6.5	−2.0 ± 6.1	−7.1 ± 6.9	−1.7 ± 7.0	<.001

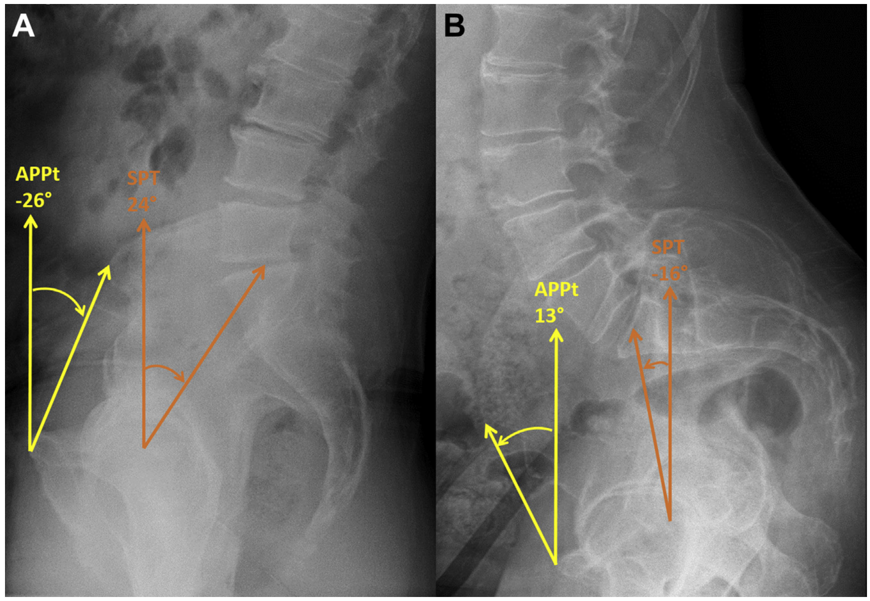

Fig. 5. Standing lateral radiographs illustrating (A) posterior pelvic tilt and (B) anterior pelvic tilt. Posterior pelvic tilt is represented by positive SPT (orange) and negative APPt (yellow).

SPT. The findings of these studies further emphasize the significance of flatback deformity among THA candidates. Specific pelvic tilt–adjusted alterations in the acetabular component orientation may provide better implant stability [4,5,20]. Given our results, consideration of spinal corrective surgery should be entertained before THA in patients with SSD rather than adjusting the acetabular component based on the sagittal spine malalignment. Buckland et al [10,21] demonstrated that acetabular anteversion was altered following sagittal realignment and this most closely correlated with changes in pelvic tilt. Furthermore, a 9.1% revision THA rate for instability occurred within 2 years after spinal realignment surgery in patients whose THAs were previously stable [2,21].

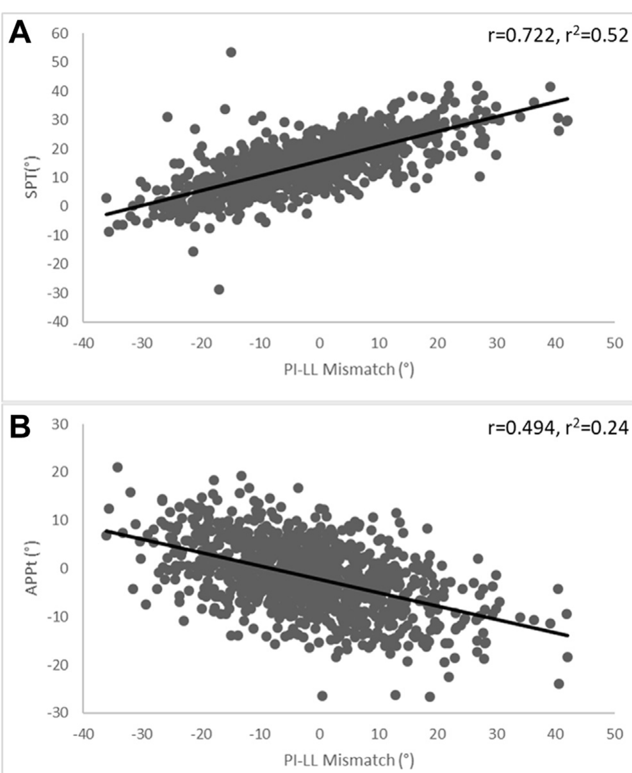

Fig. 6. Scatter plots demonstrating the linear relationship between PI-LL mismatch and (A) standing SPT and (B) standing APPt. Greater PI-LL mismatch is significantly associated with greater posterior pelvic tilt when standing. PI-LL is more strongly correlated with SPT than with APPt.

This study has some limitations that warrant discussion. The radiographic parameters measured were taken from standing lateral spine radiographs which does not provide quantification of these parameters during dynamic changes in patient position, such as in sitting and supine. Additional studies are needed to analyze whether variations in these parameters during different patient positions have clinical implications for the stability of THA. Given that this is an observational study, further investigation is required to determine the effectiveness of implementing screening lateral lumbar radiographs in all vs a select group of preoperative THA patients. Nonetheless, the aim of this study is to raise awareness of the relatively high prevalence of spinal deformity in the THA population to show how critical it is for surgeons to evaluate THA patients for sagittal spinal malalignment. Strategies such as adjusting the anteversion of the acetabular component to account for pelvic tilt and/or using additional constraint such as dual-mobility implants to reduce the dislocation risk in these patients should be considered. Additional evaluation by a spine surgeon is recommended before undergoing THA as surgical correction of the deformity can alter pelvic tilt and acetabular anteversion.

Conclusion

Spinal malalignment has been shown to increase the risk of dislocation following THA through its effects on the functional inclination and anteversion of the acetabular component. In this study, 16.0% of patients had some degree of SSD and 4.2% had severe deformity. Greater PI-LL mismatch was associated with increasing age, more posterior pelvic tilt, and a larger PI. The relatively high prevalence of spinal deformity in this population underscores the importance of assessing spinopelvic alignment when planning THA.

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