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Original Research

The Correlation Between Pelvic Motion and Lumbar Motion in Patients Presenting With a Lumbar Spinal Pathology: Implications for Assessing Dislocation Risk in Total Hip Arthroplasty

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Background: Arthroplasty surgeons use the change in sacral slope (ΔSS) from sitting to standing as a measure of spinal motion. The relationship between ΔSS and the change in lumbar lordosis (ΔLL), an established spinal motion measure, has not been well studied. This study aims to determine the correlation between ΔSS and ΔLL.

Methods: Consecutive patients presenting to a spine clinic from 2020 to 2021 at a single institution were retrospectively studied. Standing and sitting lateral radiographs were measured for SS and LL. Patients were divided using ΔSS and ΔLL into stiff (0°-9°), normal (10°-30°), or hypermobile (>30°) category. Patients with a ΔSS-determined normal or hypermobile spine but a ΔLL-determined stiff spine were compared to the rest of the cohort.

Results: Overall, 100 patients were included. Of these patients, 47% had the same classification when looking at ΔSS and ΔLL, whereas 53% had conflicting classifications. Twenty percent of patients had a ΔSS-determined normal or hypermobile spine but ΔLL-determined stiff spine. The correlation between ΔSS and ΔLL was 0.510 ($P < .001$). When isolating patients who underwent lumbar fusion, the correlation between ΔSS and ΔLL was 0.345 ($P < .001$).

Conclusions: ΔSS has a moderate correlation with ΔLL in patients presenting for evaluation of their lumbar spine but low correlation in patients with lumbar fusion. In our cohort, 20% of patients had a ΔSS-determined normal or hypermobile spine but a ΔLL-determined stiff spine, representing a potential high-risk dislocation cohort not captured by ΔSS alone. Arthroplasty surgeons should revisit classifying spinal motion based solely on ΔSS.

Introduction

Dislocation following total hip arthroplasty (THA) is one of the most common reasons why a revision surgery is performed [1,2]. Modern estimates of 1-year dislocation rates after primary THA are between 1.7% and 1.9% [3—5]. Patient-related risk factors for dislocation include increased age, concomitant medical comorbidities, such as rheumatoid arthritis and obesity, and higher American Society of Anesthesiologists scores [3—10].

Recently, spinopelvic imbalance, defined as decreased pelvic motion, has been identified as another significant risk factor [11]. In patients with previous lumbar fusion, dislocation rates are reported to increase to values between 2.96% and 5.2%, with the number and location of levels fused being important determining factors [12—17]. Furthermore, patients who have immobile spines, regardless of fusion status, are also at increased dislocation risk [11]. The lumbar spine, pelvis, and hip work together when moving from a standing to sitting position [18]. The pelvis tilts posteriorly and increases acetabular anteversion, while both the lumbar spine and hip joint flex. It is proposed that decreased motion through the lumbar spine demands a pathologic, compensatory increase in hip motion and, therefore, an increase in dislocation risk [18].

The change in sacral slope (ΔSS) when moving from a standing to sitting position has been used to define sagittal

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motion of the pelvis and has been adopted as a surrogate for spinal motion [19,20]. Based on ΔSS, patients are classified as having a stiff, normal, or hypermobile spine [20]. However, as the sacrum is fused to the pelvis, ΔSS is only a true measure of pelvic motion. Despite this, ΔSS remains interchangeably referred to as spinal motion, spinopelvic motion, and pelvic motion, leading to potential confusion among readers [19–21]. While ΔSS is assumed to correlate with lumbar motion, this relationship has not been demonstrated. Therefore, the purpose of this study was to assess the correlation between ΔSS and change in lumbar lordosis (ΔLL), an established measure of spinal motion, in patients with a lumbar spinal pathology, a population at high risk of dislocation if undergoing THA [11,12,22]. Our hypothesis was that ΔSS is not an accurate measure of spinal motion in patients with degenerative lumbar disease and, therefore, does not appropriately capture dislocation risk in this population following THA.

Material and methods

Data source

Institutional review board approval was obtained prior to study commencement. Consecutive patients older than 18 years presenting to a single surgeon's spine clinic from November 2020 to March 2021 were retrospectively studied. Patients were excluded if any radiographic variable was unable to be measured due to poor radiographic quality and if they had undergone prior THA. A chart review was performed to record patient demographic information and operative details. Lateral standing and sitting lumbar spine radiographs including the hip joint were reviewed.

Patient characteristics

Demographic variables examined included age, sex, and body mass index (BMI). Operative variables examined included date of surgery and procedure type. Osteoarthritis severity of each hip was graded per the Tönnis classification system on anterior-posterior pelvis radiographs [23]. Only the highest grade recorded was used for analysis.

Radiographic spinopelvic parameters

Radiographic parameters included SS, pelvic femoral angle (PFA), pelvic incidence (PI), pelvic tilt (PT), LL, lumbar tilt (LT), sagittal angle (SA), and total flexion (TF). The change (Δ) in each parameter except PI was assessed on lateral lumbar spine-pelvis-hip radiographs in relaxed-seated and standing positions.

SS was defined as the angle between the horizontal and S1 endplate. PFA was defined as the angle between a line drawn from the midpoint of the superior S1 endplate to the midpoint of the femoral head and a line parallel to the femoral shaft (Fig. 1). PI was defined as the angle between a line drawn perpendicular to the superior S1 endplate and a line drawn from the center of the superior S1 endplate to the midpoint of the femoral heads. PT was defined as the angle between a line drawn from the midpoint of the S1 endplate to the midpoint of the femoral head and a vertical line drawn up from the center of the femoral. LL was defined as the angle formed between a line parallel to the superior endplate of L1 and a line parallel to the superior endplate of S1. These have all been defined previously [18].

Two new radiographic parameters were included to better define sagittal motion (Fig. 1). LT was defined as the angle between

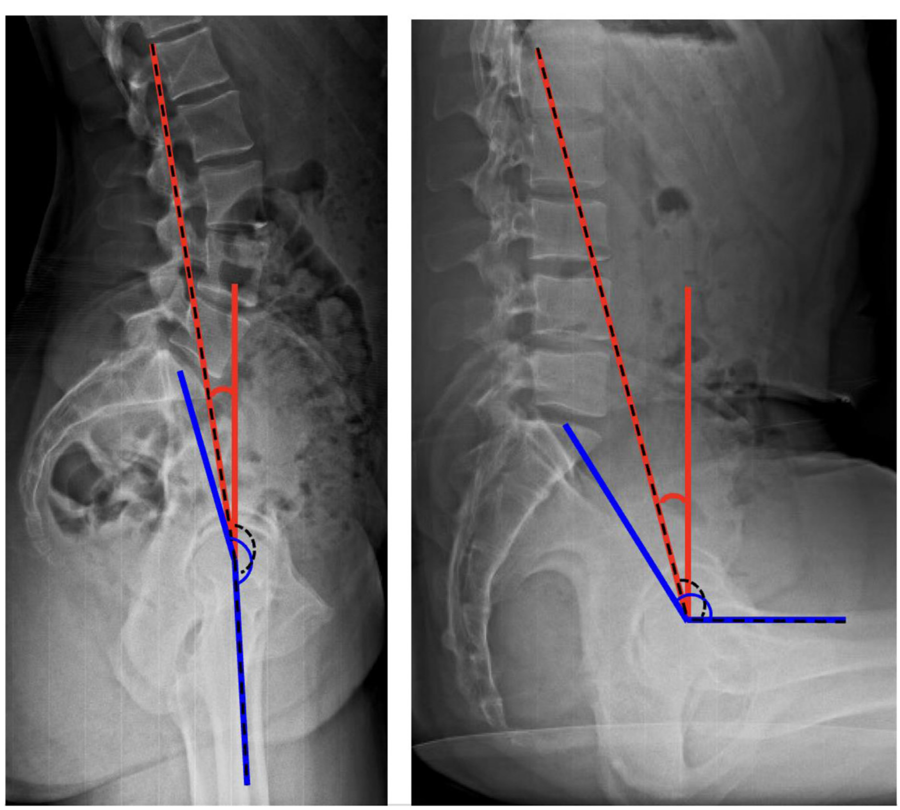

Figure 1. Standing (left) and sitting radiographs (right). Red = lumbar tilt (LT), blue = pelvic femoral angle (PFA), black dashed line = sagittal angle (SA).

a line drawn from the posterior aspect of the superior L1 endplate to the center of the femoral head and a vertical line drawn up from the center of the femoral head. The change in LT (ΔLT) quantified the posterior tilt of the lumbar spine in the sagittal plane. SA was defined as the angle between a line drawn from the posterior aspect of the superior L1 endplate to the center of the femoral head and a line parallel to the femoral shaft. It can be calculated as follows:

$$SA = LT + PFA - PT$$

TF was defined as change in SA (ΔSA) when moving from standing to sitting and is a measure of flexion contributed by both the lumbar spine and hip joint in the sagittal plane.

Data analysis

The correlation between ΔSS and ΔLL was assessed using the Spearman's rank correlation coefficient with hip osteoarthritis grade as a covariate. Patients were subsequently categorized as having a stiff (0°-9°), normal (10°-30°), or hypermobile spine (>30°) based on both ΔSS and ΔLL independently. These values have been previously used to define stiff, normal, and hypermobile spines when using ΔSS [20]. Classifications using ΔLL have used ΔLL <20° as a threshold for defining a stiff spine when using deep-seated radiographs [21]. As no predefined range was available based on ΔLL by using relaxed-seated radiographs, the decision was made to use ΔSS-based criteria to standardize the classifications between ΔSS and ΔLL.

The percentage of patients who had discordant spinopelvic motion classifications when using ΔSS compared to ΔLL was quantified. Patients who were classified as having a normal or hypermobile spine based on ΔSS but a stiff spine based on ΔLL were compared to the rest of the cohort (Fig. 2). These patients fall into a low dislocation risk based on ΔSS but have immobile spines based on ΔLL and, therefore, may have a high dislocation risk following THA. Differences in demographic and radiographic features between both cohorts were assessed using a Mann-Whitney U test for continuous variables and chi-squared analysis or Fisher exact test for categorical variables. Two subanalyses were conducted comparing (1) those who were fused against those who were not fused and (2) those who were fused by the degree of fusion. Statistical significance was set at $P < .05$. All statistical analyses were performed using SPSS (version 27; IBM, Armonk, NY).

Results

Overall, 149 patients were screened, of which 10 (6.7%) were excluded for having a prior THA, and 39 (26.2%) for poor radiographic quality. Therefore, 100 consecutive patients were included for analysis. The average age was 59.91 ± 16.2 years, the average

Figure 2. (a) Lateral spine-pelvis-hip radiographs of a patient with a hypermobile pelvis (ΔSS >30°) and a stiff spine (ΔLL <10°), that is, a patient with conflicting classifications. This patient has a ΔSS = 37° and a ΔLL = 3° and a large decrease in ΔLT of −39°. There is also minimal hip motion (ΔPFA = 25°) and total flexion (ΔSA = 23°). (b) A patient with a stiff pelvis (ΔSS <10°) and a stiff spine (ΔLL <10°), that is, a patient with matching classifications. ΔSS = 2°, ΔLL = 0°, ΔLT = −1°, ΔPFA = 76°, ΔSA = 77°. This patient is flexing entirely through the hips. (c) A patient with a hypermobile pelvis (ΔSS >30°) and hypermobile spine (ΔLL >30°), that is, a patient with matching classifications. dSS = 31°, dLL = 42°, dLT = −7°, dPFA = 64°, dSA = 85°. This patient has more lumbar flexion and, therefore, less hip motion than patient (b). Note the large change in LT in (a), a patient with conflicting classifications, compared to the small change in LT in (b) and (c), patients with matching classifications. Using ΔSS as a measure of spinal motion, patient (a) would have the same motion and dislocation risk as patient (c). However, when ΔLL and ΔLT are factored in, patient (a) and patient (c) have very different spinal motion and likely different dislocation risk. Standing (left) and sitting radiographs (right). LL, lumbar lordosis; LT, lumbar tilt; PFA, pelvic femoral angle; SA, sagittal angle; SS, sacral slope.

BMI was 28.3 ± 5.36 kg/m^2, and 44.0% were female. Forty-four (44%) patients had undergone a lumbar fusion surgery with an average follow-up period of 16.3 months (range: 0.73-132.0 months) and an average of 1.66 segments fused (range 1-4) (Table 1). Four patients (4%) underwent lumbar surgery without fusion, including microdiscectomy (1), microdiscectomy and laminoforaminotomy (1), laminoforaminotomy (1), and kyphoplasty (1). Fifty-six (56%) patients did not undergo surgery and presented with a primary diagnosis of lumbar degenerative disc disease (21), lumbar radiculopathy (16), degenerative scoliosis (6), spondylolisthesis (6), neurogenic claudication (2), or lumbar stenosis (1).

Based on ΔSS, 40 (40.0%) patients had a stiff spine, 56 (56.0%) patients had a normal spine, and 4 (4.0%) patients had a hypermobile spine. Based on ΔLL, 43 (43.0%) patients had a stiff spine, 47 (47.0%) patients had a normal spine, and 10 (10.0%) patients had a hypermobile spine. Forty-seven (47.0%) patients had the same classification when looking at ΔSS and ΔLL, whereas 53 (53.0%) had conflicting classifications (Fig. 2). Eighteen (18.0%) patients had a normal spine based on ΔSS but a stiff spine based on ΔLL. Two (2.0%) patients had a hypermobile spine based on ΔSS but a stiff spine when using ΔLL. Alternatively, 17 (17.0%) patients had a normal spine based on ΔLL but a stiff spine based on ΔSS. The Spearman correlation coefficient between ΔSS and ΔLL was 0.510 ($P < .001$). After controlling for hip osteoarthritis grade, the correlation coefficient remained the same ($P < .001$).

Patients who had a normal or hypermobile spine based on ΔSS but a stiff spine based on ΔLL had less hip motion as defined by ΔPFA ($P = .001$), more posterior lumbar tilt (ΔLT) ($P < .001$), and less TF (ΔSA) ($P = .001$) than the rest of the cohort (Fig. 2). These patients were also older ($P = .002$). There was no difference in BMI, grade of hip osteoarthritis, or lumbar fusion status (Table 2).

Subanalysis based on fusion status

Patients who underwent fusion had a greater ΔLT (−11.3° vs −5.5°, $P = .002$), less TF (ΔSA 58.9° vs 68.2°, $P = .031$), and were older (66.5 years vs 54.7 years, $P < .001$) than those who did not. There was no significant difference in other radiographic parameters (Table 3). The correlation between ΔSS and ΔLL in fused patients was 0.345 compared to 0.669 in patients who were not. For patients who were fused, there was no difference in radiographic parameters based on the number of levels fused (Table 4).

Table 1
Patient demographics.

Demographic	Mean ± SD
Age (y)	59.90 ± 16.22
BMI (kg/m^2)	28.32 ± 5.36
Highest OA grade	1.63 ± 0.87
Preoperative ODI	38.25 ± 21.93
ΔSS (°)	13.68 ± 9.38
ΔLL (°)	14.26 ± 10.99
ΔPFA (°)	58.55 ± 16.59
ΔLT (°)	−8.05 ± 8.63
ΔSA (°)	64.07 ± 17.21
	n (%)
Gender	
Female, n (%)	44 (44.0)
Male, n (%)	56 (56.0)
History of lumbar fusion surgery?	
Yes	44 (44.0)
No	56 (56.0)
Number of levels fused	
0	56 (56.0)
1	23 (23.0)
2	14 (14.0)
3	4 (4.0)
4	2 (2.0)
Mismatch between ΔSS and ΔLL	
Yes	47 (47.0)
No	53 (53.0)

BMI, body mass index; LL, lumbar lordosis; LT, lumbar tilt; OA, osteoarthritis; ODI, Oswestry Disability Index; PFA, pelvic femoral angle; SA, sagittal angle; SD, standard deviation; SS, sacral slope.

Table 2
Clinical and radiographic differences between patients identified as having hypermobile or normal spines based on ΔSS but stiff spines based on ΔLL ("cohort") and the remainder of the study patients ("control").

Characteristic	Control n = 80	Cohort n = 20	*P* value
	Mean (SD)	Mean (SD)	
Age (y)	57.40 (16.70)	69.91 (8.97)	**.002**
BMI (kg/m^2)	27.63 (4.80)	30.78 (6.57)	.055
Hip OA grade	36.26 (20.98)	45.89 (24.38)	.239
ODI	1.56 (0.81)	1.90 (1.07)	.165
ΔSS (°)	12.64 (9.46)	17.85 (8.01)	**.016**
ΔLL (°)	16.28 (11.08)	6.20 (5.83)	**<.001**
ΔPFA (°)	61.43 (14.98)	47.05 (18.08)	**.001**
ΔLT (°)	−6.29 (6.60)	−15.10 (11.89)	**<.001**
ΔSA (°)	67.64 (11.62)	49.80 (22.47)	**.001**
	Control n = 80	Cohort n = 20	*P* value
Sex			.268
Female	33	11	
Male	47	9	
Fusion status			.107
No	48	8	
Yes	32	12	

BMI, body mass index; LL, lumbar lordosis; LT, lumbar tilt; OA, osteoarthritis; ODI, Oswestry Disability Index; PFA, pelvic femoral angle; SA, sagittal angle; SD, standard deviation; SS, sacral slope.
Significant values are in bold.

Discussion

Patients with stiff spines, due to lumbar fusion or degenerative pathology, are at increased risk of dislocation following THA [13,24,25]. As such, some arthroplasty surgeons assess preoperative lateral standing and sitting radiographs to determine if patients have stiff, normal, or hypermobile spines using ΔSS [18]. In this study, ΔSS was found to have a positive but moderate correlation with ΔLL. Furthermore, when isolating patients who had undergone lumbar fusion, ΔLL and ΔSS were observed to have a low correlation. When examining ΔSS and ΔLL for concordance in categorizing spinal motion, 53% of patients had conflicting classifications. Specifically, 20.0% of patients had a normal or hypermobile spine based on ΔSS but a stiff spine based on ΔLL. These patients represent those whose dislocation risk is potentially not captured with a classification system based solely on ΔSS.

Classifications of spinopelvic motion have predominantly used pelvic motion to classify spinal motion. Kanawade et al. originally classified stiffness using PT and categorized patients as having stiff (<20°), normal (20°-35°), or hypermobile (>35°) pelvises, quoting that PT is directly correlated to spine stiffness [26]. The same group identified spinopelvic imbalance, defined as low ΔSS, as the cause of 90% of late dislocations [11]. Ike et al. went on to revise this classification and defined stiff, normal, and hypermobile spines as having ΔSS <10°, 10°-30°, and >30°, respectively, as was used in the present study [20]. Recently, Luthringer and Vigdorchik published the "Hip-Spine Classification for THA", where a stiff spine was defined as ΔSS < 10° [19]. When this classification was applied and changes in preoperative planning were made, dislocation rates significantly decreased following THA [27].

While these classifications have done an excellent job assessing patients at risk of dislocation, our results demonstrate that these

Table 3
Subanalysis examining differences between unfused and fused patients.

Spearman correlation	Unfused (n = 56)	Fused (n = 44)	*P* value
	0.669	0.345	
	Mean (SD)	Mean (SD)	
ΔSS (°)	12.30 (8.27)	15.43 (10.47)	.172
ΔLL (°)	15.61 (11.24)	12.55 (10.55)	.144
ΔPFA (°)	61.55 (14.34)	54.73 (18.55)	.104
ΔLT (°)	−5.50 (5.29)	−11.30 (10.78)	**.002**
ΔSA (°)	68.16 (13.04)	58.86 (20.37)	**.031**
Age (y)	54.73 (17.46)	66.48 (11.71)	**<.001**
BMI (kg/m^2)	27.27 (4.19)	29.68 (6.38)	.065
Hip OA grade	38.21 (21.11)	38.30 (23.23)	.997
ODI	1.63 (0.91)	1.64 (0.84)	.912

BMI, body mass index; LL, lumbar lordosis; LT, lumbar tilt; OA, osteoarthritis; ODI, Oswestry Disability Index; PFA, pelvic femoral angle; SA, sagittal angle; SD, standard deviation; SS, sacral slope.
Significant values are in bold.

criteria may not capture all high-risk patients. Care should be taken when terming ΔSS as "spinopelvic motion." The connection of the sacrum to the lumbar spine provided the rationale for the use of ΔSS as a measure of lumbar spine motion [26]. However, as the sacrum is fused to the pelvis, it cannot move independent of the pelvis. It is possible for the pelvis to tilt posteriorly and increase ΔSS without flexing the lumbar spine when the lumbar spine tilts posteriorly as a single construct in the sagittal plane. This was demonstrated by the 20.0% of patients with a normal or hypermobile ΔSS classification but a stiff ΔLL classification. As a result, these patients had less TF, more posterior LT, and less hip flexion than the rest of the cohort. The results of this study provide evidence in support of a shift towards a 3-part biomechanical framework involving the lumbar spine, sacrum-pelvis, and hip motion rather than "spinopelvic" and hip motion.

The correlation between ΔSS and ΔLL has been recently studied by another group. Haffer et al. assessed postoperative changes and spinopelvic biomechanics in 197 patients undergoing THA and found the correlation between ΔSS and ΔLL to be 0.789, which is higher than that observed in our study [28]. The difference is likely due to different study populations. ΔSS may be a suitable measure of spinal motion in the general population, but our results show it is less reliable in patients with a spinal disease, and even less so in patients who have undergone lumbar fusion. Given the importance of identifying patients with minimal spinal motion preoperatively, the use of ΔSS as the sole measure of spinal motion in this population may be a mistake. Haffer et al. theorized that the lumbar spine flexes to maintain erect posture and sagittal balance and, therefore, suggested a sagittal imbalance parameter should be used in addition to PFA and SS or PT when assessing patients' spinopelvic biomechanics. In our study, LT was used to measure sagittal imbalance. Patients who had minimal lumbar motion but normal or hypermobile pelvic motion were found to have large changes in LT. Patients who have hypermobile pelvic motion, as measured by ΔSS or ΔPT, minimal lumbar motion, as measured by ΔLL, but a large ΔLT are likely to be at increased risk of dislocation despite falling into a low-risk category based on ΔSS.

While ΔSS has been predominantly used as a measure of spinal motion, a smaller but growing body of literature has been published using ΔLL, suggesting potentially similar concerns over using ΔSS. Langston et al. studied a consecutive series of 4402 patients undergoing THA who had deep-seated radiographs [21]. Lumbar flexion <20° was significantly increased in patients who had unfavorable changes in PT, as defined by ΔPT >13° between standing and deep-seated positions. The group proposed that ΔLL <20° should be considered the threshold for defining lumbar stiffness when using deep-seated radiographs, which has been used in subsequent studies to define a stiff spine [29,30]. Furthermore, recent studies have also uncoupled pelvic and spinal motion. Kleeman-Forsthuber et al. published on the significance of PI on spinal motion, defined with LL, and pelvic motion, defined with PT [31]. Studies such as these that use ΔLL as a measure of spinal motion are likely more accurately classifying spinal motion than those using ΔSS.

This study has several limitations. First, all patients presenting to the spine clinic were included for analysis regardless of fusion status. However, a subanalysis was done comparing patients who had undergone fusion to those who had not. Furthermore, fusion status was not found to be significantly different between cohorts. Second, the majority of patients in this study did not have end-stage hip osteoarthritis. The decreased hip motion found in our cohort may correspond to the decreased hip motion found in patients prior to THA. However, future studies examining this relationship in different clinical contexts are warranted. Third, relaxed-seated radiographs were used in this study. Although deep-seated radiographs have been suggested to be more accurate at detecting spinal stiffness, relaxed-seated radiographs are currently more commonly used to detect spinopelvic motion, which increases the generalizability of the results presented here [18,29]. Lastly, spinopelvic parameters observed in this cohort were not correlated with dislocation or further changes after THA. Future studies expanding on associations demonstrated presently through evaluation of patients undergoing THA would be beneficial.

The numerous strengths of this study warrant mention. We present a thorough understanding of spinopelvic biomechanics that treats the spine, pelvis, and hip as separate entities and has not been clearly defined in the literature previously. In addition, we suggest a new sagittal parameter, ΔLT, that may be used to help further identify patients with minimal spinal motion and, therefore, increased dislocation risk. We used ΔLT in this study to better classify sagittal motion to demonstrate how SS can decrease without

Table 4
Subanalysis examining differences between fused patients by level of fusion.

Characteristic	1	2	3	4	*P* value
	(n = 23)	(n = 15)	(n = 4)	(n = 2)	
ΔSS (°)	13.78 (10.38)	16.43 (7.31)	27.00 (15.12)	13.00 (5.66)	.235
ΔLL (°)	14.35 (12.19)	11.86 (8.33)	9.50 (10.88)	6.50 (3.54)	.821
ΔPFA (°)	59.26 (13.90)	51.43 (18.75)	36.00 (24.10)	52.50 (41.72)	.201
ΔLT (°)	−8.70 (8.27)	−11.86 (7.70)	−27.50 (19.94)	−11.50 (12.02)	.163
ΔSA (°)	64.35 (13.97)	56.00 (20.51)	35.50 (28.52)	54.00 (48.08)	.17
Age (y)	63.97 (13.43)	69.54 (10.09)	64.93 (6.58)	75.15 (5.45)	.392
BMI (kg/m^2)	28.37 (4.81)	30.72 (7.78)	30.65 (9.65)	34.76 (3.61)	.547
ODI	36.75 (25.91)	36.15 (22.16)	56.00 (8.64)	35.50 (27.58)	.357
OA	1.57 (0.73)	1.71 (0.91)	1.50 (1.29)	2.00 (1.41)	.954

BMI, body mass index; LL, lumbar lordosis; LT, lumbar tilt; OA, osteoarthritis; ODI, Oswestry Disability Index; PFA, pelvic femoral angle; SA, sagittal angle; SS, sacral slope.
Values reported as n (standard deviation).

a reciprocal decrease in LL. However, more studies are necessary to determine the clinical utility of ΔLT. Lastly, this is the largest study to examine spinopelvic biomechanics when transitioning from a sitting to standing position in patients with a spinal disease.

Conclusions

In this single-institution study of consecutive patients presenting for evaluation of their lumbar spine, ΔSS was found to have a moderate correlation with ΔLL but a low correlation when isolating patients with lumbar fusion. Importantly, 20.0% of patients classified as having a normal or hypermobile spine using ΔSS had a stiff spine based on ΔLL, suggesting they may be at high risk of dislocation following THA despite falling into a low-risk category based on ΔSS. Results of this study suggest that risk of dislocation should be further investigated using a 3-part biomechanical framework involving the lumbar spine, pelvis, and hip joint and away from using sacral motion as a surrogate for lumbar spinal motion. The arthroplasty community should revisit classifying spinal motion based solely on ΔSS.

Conflicts of interest

Dr. R. K. Alluri is a paid consultant for Ecential-Robotics and HIA Technologies and is in the editorial or governing board of *International Journal of Spine Surgery* (IJSS). Dr. R. J. Hah is a paid consultant for NuVasive; receives research support as a principal investigator from SI-Bone, Inc., and ATEC Spine; is in the editorial or governing board of *Global Spine Journal* (GSJ); and is a member of the North American Spine Society (NASS) and Lumbar Spine Research Society (LSRS). Dr. N. D. Heckmann is a paid consultant for Intellijoint Surgical and MicroPort Orthpedics; has stock or stock options in Intellijoint Surgical; and is a member of the American Academy of Orthopaedic Surgeons (AAOS), American Joint Replacement Registry (AJRR), and American Association of Hip and Knee Surgeons (AAHKS). All other authors declare no potential conflicts of interest.

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