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Original Research

Increased Cup Anteversion May Not Prevent Posterior Dislocation in Patients With Abnormal Spinopelvic Characteristics in Total Hip Arthroplasty

Matthew J. Grosso, MD [a,*], Christopher Plaskos, PhD [b], Jim Pierrepont, PhD, MEng [b], Arjun Saxena, MD, MBA [c]

[a] Connecticut Joint Replacement Institute, Hartford, CT
[b] Corin Ltd, Raynham, MA, USA
[c] Rothman Orthopaedic Institute, Philadelphia, PA, USA

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ABSTRACT

Background: The aims of this study were to (1) assess the degree of variation in acetabular component placement and combined anteversion in a large cohort of dislocating total hip arthroplasties; (2) assess the spinopelvic characteristics of the cohort; and (3) examine the association between cup anteversion and reported direction of instability.

Methods: A commercial database of 245 dislocating total hip arthroplasties referred for postoperative computed tomography and functional radiographic imaging and analysis were reviewed. Spinopelvic parameters and cup and stem positions were measured in the supine, standing, flex-seated, and anterior pelvic plane (APP) positions. Spinopelvic characteristics were stratified by high, neutral, and low cup anteversion using thresholds of >35° and <15° anteversion in standing, respectively.

Results: In the dislocation cohort, 62%, 45%, and 42% of cups were within the safe zone in supine, standing, and the APP, respectively ($P < .001$). Patients with high vs neutral or low cup anteversion had significantly stiffer spines, more posterior pelvic tilt in standing, greater changes in pelvic tilt, and higher sagittal imbalance. Of the 45 patients with high cup anteversion and reported instability direction, 60% and 40% were reported to have posterior and anterior instability, respectively, with no differences in spinopelvic characteristics.

Conclusions: In this dislocating cohort, there is a decreased percentage of cups within the safe zone in the APP and standing position compared to the supine reference. In addition, we found that patients having poor spinopelvic characteristics and high cup anteversion can still dislocate, suggesting that adjusting cup anteversion alone may not be sufficient for preventing instability.

Introduction

Instability following total hip arthroplasty (THA) can be a devastating complication. Recurrent dislocations can lead to high patient and societal costs due to increased admissions and revision surgeries, as well as overall reduced patient satisfaction [1,2]. While modern dislocation rates in THA are relatively low at ~1% [3,4], with approximately ~400,000 primary THAs performed annually in the United States, this incidence rate still creates a significant healthcare burden [5]. In addition, "true" dislocation rates within the first 2 years following surgery may be significantly higher, further increasing this burden [6].

There are several known contributing risk factors to instability following THA [7]. In the last decade, there has been an increased focus on abnormal spinopelvic (SP) parameters as a significant contributor to THA instability [8]. Several studies highlight the relationship of spinal abnormalities such as stiff spines and flatback deformity, and their relationship to increased dislocation rates [9-11]. Specifically, low lumbar flexion, negative pelvic tilt (PT), reduced changes in sacral slope (SS) from sit to stand, as well as pelvic incidence (PI), and lumbar lordosis (LL) mismatch are

* Corresponding author. Connecticut Joint Replacement Institute, 114 Woodland Street, Hartford, CT 06105, USA. Tel.: +1 860 714 4164.
E-mail address: mgrosso13@gmail.com

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strongly associated with dislocation risk [12,13]. With the identification of the problem, studies have sought to highlight potential solutions for this issue. Many recommendations focus on increasing supine target anteversion in specific patient subsets to compensate for SP pathology [14,15]. The effect of these recommendations on instability rates is still being examined, although a few studies report continued difficulties with dislocation in patients with abnormal SP parameters [12,16,17].

Currently, there are few large studies that examine the relationship between SP parameters and dislocating THAs. Vigdorchik et al. compared 48 patients with instability in primary THA to a control group to highlight the increased prevalence of SP abnormalities in unstable THAs [12]. However, no studies to date have examined cup orientation in the supine, standing, and anatomic (anterior pelvic plane [APP]) positions in a large group of unstable THAs or the direction of dislocation based on cup position, and these relationships to SP abnormalities. For example, does high cup anteversion limit posterior dislocation in instability patients with abnormal SP?

Therefore, the aims of this study were to (1) assess the degree of variation in acetabular component placement and combined anteversion in a large cohort of dislocating THAs; (2) assess the SP characteristics of the cohort; and (3) examine the association between cup anteversion and reported direction of instability.

Material and methods

A commercial database of symptomatic hip arthroplasties referred for postoperative 3D imaging and functional analysis was reviewed following institutional review board approval (The Corin Registry, WIRB and Copernicus Group WCG IRB no. 120190312). From this database, 322 cases referred for dislocation from June 2019 to July 2022 were reviewed (Fig. 1). Patients having >10 mm of under-restoration of leg length discrepancy or hip offset discrepancy (44) and those having >5 mm of under-restoration of both leg length and hip offset (14) were excluded from our analysis. Patients >90 years old (16), missing standing lateral radiographs (17), and having resurfacing implants (1) were also excluded. Two hundred forty-five cases were included in the final analysis. Mean age was 66 ± 11.5 years, 168 were women, and 136 were right hips. The cohort included patients from Australia (128), the United States (90), the United Kingdom (15), France (8), Austria (2), and Belgium (2).

All patients received computed tomography (CT) (Fig. 2) and functional radiographic (Fig. 3) imaging as part of standardized protocol. CT imaging included the regions of the pelvis, knee, and ankle in 2 mm slice increments with the patient positioned feet shoulder-width apart in a comfortable, neutral position. Radiographic imaging included 2 functional lateral views in standing and flex-seated positions with maximum forward flexion and femurs parallel to the floor. The following SP parameters were measured by trained engineers and quality controlled by a senior experienced observer (Fig. 4): LL, SS, PT, spinopelvic tilt, and PI. The following parameters were then calculated: sagittal spinal deformity (SSD = PI−LL); pelvic-femoral angle; hip user index (HUI); and combined sagittal index (CSI) [18]. To calculate pelvic-femoral angle, CSI, and HUI, femoral flexion was assumed to be a mean of 6° flexed in the standing and neutral in the seated position. Cup and stem positioning and femoral head size were measured by registering 3D computer models of the implants within the CT image volume (Fig. 2a). Supine cup inclination and anteversion were measured relative to the supine coronal plane in the CT scan and calculated using the radiographic definition [19]. Functional cup inclination and anteversion in standing and flex-seated positions were calculated using the change in PT from supine to that measured in the corresponding lateral radiograph and reported using the radiographic definition (Fig. 2b). Anatomical femoral version and stem version were calculated as the angle between the femoral stem neck and the posterior condylar axis in the axial plane of the CT (Fig. 2c). Combined anteversion was calculated in standing and seated positions and in the APP reference by adding the anatomic stem anteversion and the corresponding functional cup anteversion for each position. Anteinclination was calculated in the standing position.

Data analysis

Safe zones for the acetabular component were defined as: inclination: 30°-50° (all positions); anteversion: 5°-25° (APP); 15°-35° (standing); 10°-30° (supine); and for combined

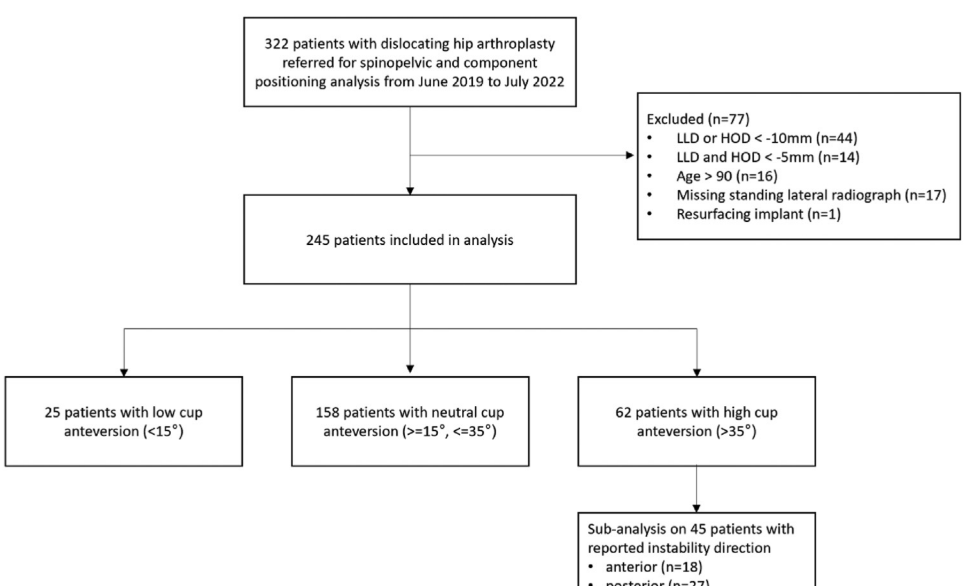

Figure 1. Flow diagram summarizing study cohort and exclusions. LLD, leg length discrepancy; HOD, hip offset discrepancy.

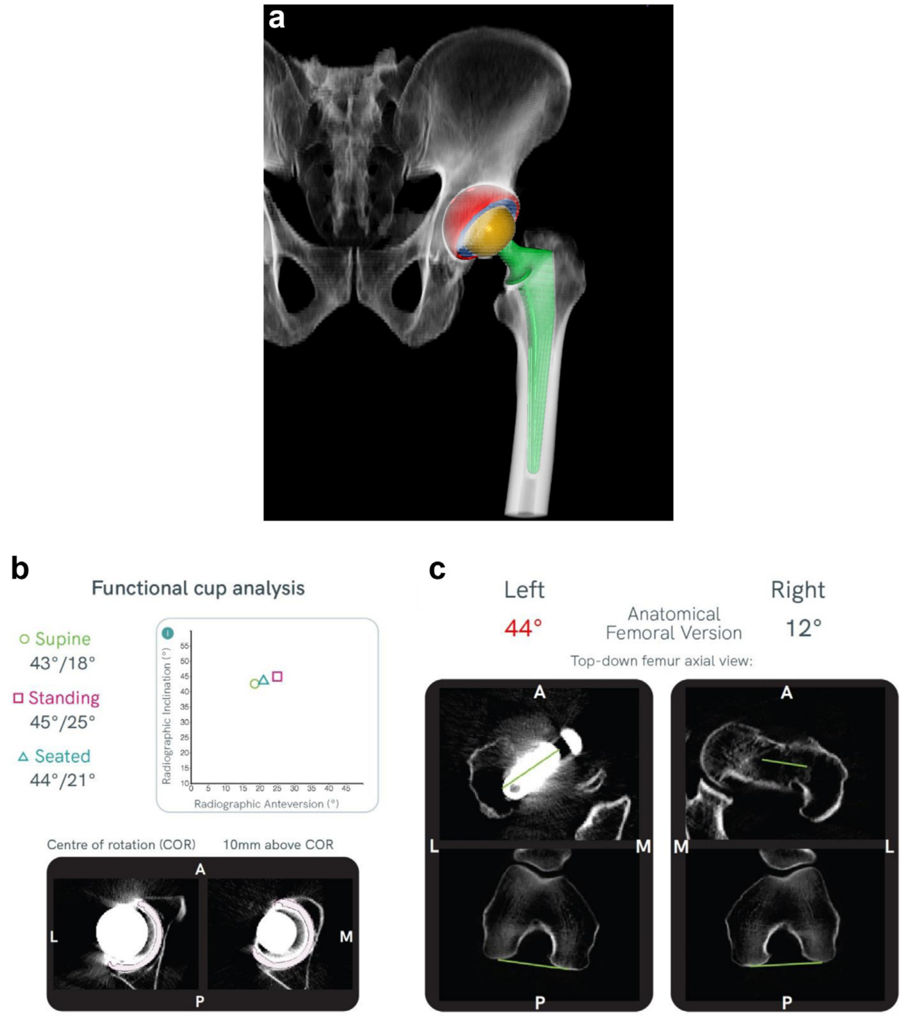

Figure 2. Measurements made on CT imaging: (a) Cup and stem positioning and femoral head size were measured by registering 3D computer models of the implants within the CT image volume. (b) Cup anteversion and inclination were measured in the supine position and transferred to the standing and seated positions. (c) Stem version and anatomical femoral version were measured as the angle between the neck axis and the posterior condyles on the operative and contralateral sides, respectively.

anteversion, as 20°-45° (APP); 30°-55° (standing); 25°-50° (supine), and the percentage of patients within each safe zone was calculated [20-23]. McNemar chi-squared tests were used to evaluate differences in the proportion of patients within each safe zone in the supine, standing, and APP positions. Patients were grouped as having high, neutral, and low cup anteversion using thresholds of >35° and <15° anteversion in standing, respectively. Descriptive statistics were used to report mean and standard deviation values for all SP parameters and implant positions for each cup anteversion group. Head size distributions are represented by median and 25th and 75th quartiles (interquartile range). Kruskal-Wallis or chi-squared tests were used to assess differences in SP and implant positioning parameters across the 3 cup anteversion groups, with post hoc pairwise Wilcox and Fischer tests to assess differences between individual groups, as appropriate. Analysis was performed in R using RStudio 2022.07.2.

Results

In the dislocation cohort, 62% (152/245), 45% (110/245), and 42% (103/245) of cups were within the safe zone in the supine and standing positions and APP reference, respectively, with significantly fewer patients in the standing ($P < .001$) and APP ($P < .001$) than supine safe zone (Fig. 5). In the standing position, 25% (62/245) and 10% (25/199) of cups had high and low anteversion, respectively.

Similarly, 64% (155/242), 62% (150/242), and 57% (139/242) of hips were within the combined safe zone in the supine and standing positions and APP reference, respectively, with significantly fewer patients in the APP than supine safe zone ($P = .042$). In the standing position, 32% (78/242) and 11% (26/242) of hips had high and low combined anteversion, respectively.

Patients with high vs neutral or low cup anteversion had stiffer spines (lower lumbar flexion), more posterior PT in standing (PT, spinopelvic tilt, SS), greater change in stand to seated and supine to stand PT ($dPT_{stand\_to\_seated}$ and $dPT_{supine\_to\_stand}$), higher sagittal spinal deformity, and higher HUI and CSI parameters (Table 1). There were no differences in stem or contralateral femur anteversion. Of the 45 patients with high cup anteversion and reported instability direction, 60% and 40% were reported to have posterior and anterior instability, respectively (Table 1). There were no significant differences identified in any SP or implant parameters in the high cup anteversion subgroup analysis based on dislocation

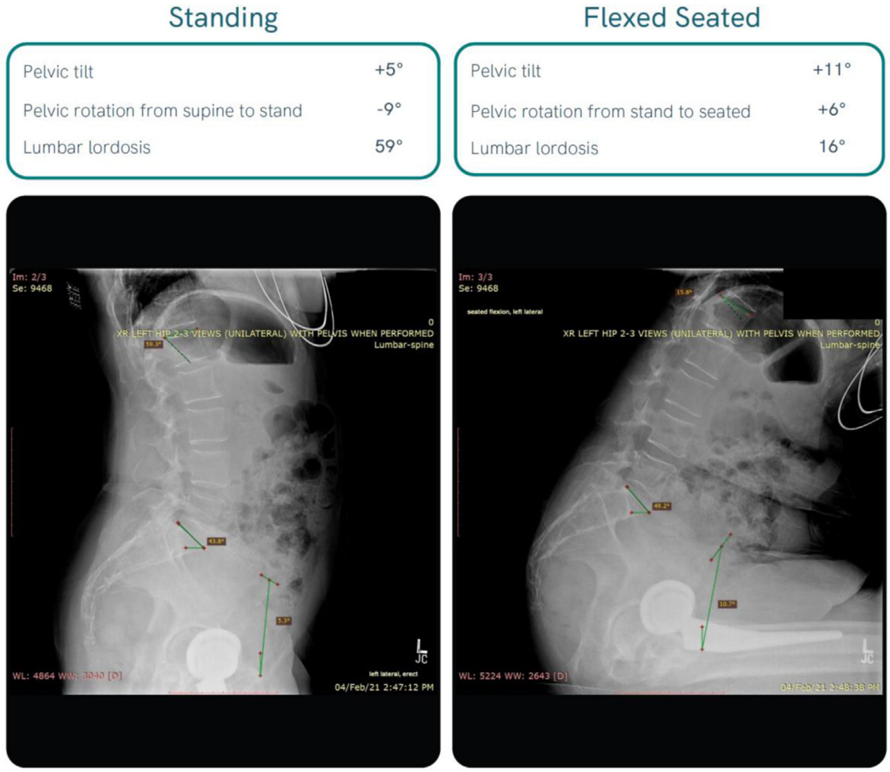

Figure 3. Measurements made on functional standing (left) and flex-seated (right) radiographs.

direction, except for contralateral femoral anteversion (posterior: 21°, anterior: 11°, $P = .014$, Supplementary Table S1). There were no differences in age or gender across the 3 cup anteversion groups or between anterior and posterior dislocators within the high cup anteversion group.

Discussion

The SP relationship has gained increased attention as a potential risk factor for dislocation following THA. Prior studies have demonstrated a higher prevalence of SP risk factors in patients with

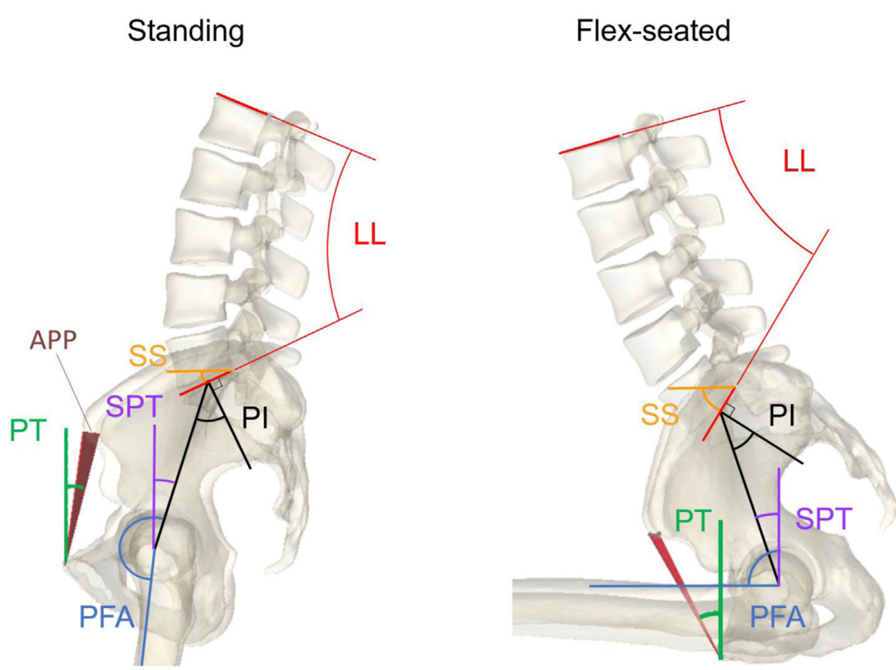

Figure 4. Illustration of spinopelvic (SP) parameters shown in standing and flex-seated: lumbar lordosis (LL), sacral slope (SS), pelvic tilt (PT), spinopelvic tilt (SPT), pelvic incidence (PI), pelvic femoral flexion (PFA), anterior pelvic plane (APP).

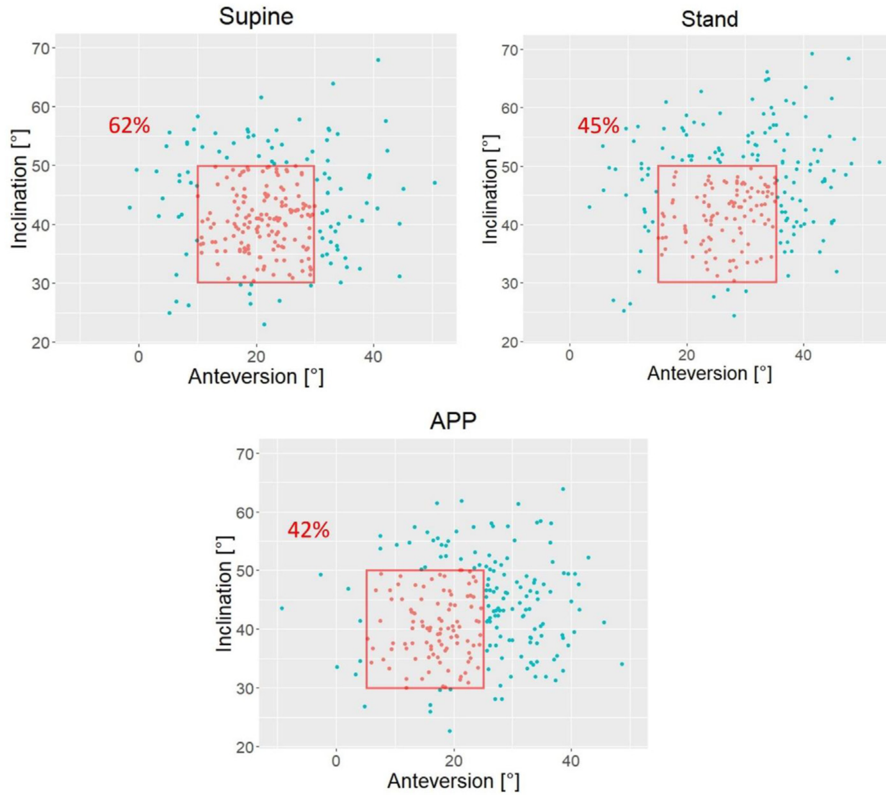

Figure 5. Cup inclination and anteversion in supine, standing, and in the APP reference. The percentage of cups within the supine safe zone was greater than in standing and APP.

postoperative dislocations [12]. In this database cohort study of 322 dislocating THAs, we report additional relationships between component positioning and SP parameters. This study utilized CT-based measurements for direct measurement of component position, which eliminates the inaccuracy associated with radiograph component measurement. The study results note a significantly decreased percentage of patients with cup version within the classically defined safe zones in the standing and APP positions compared to the supine position. We also report higher rates of abnormal SP function in patients with high cup anteversion. Finally, when examining these patients with high cup anteversion and abnormal SP parameters, we note that posterior dislocations still occur in many cases. This suggests that in patients with abnormal SP characteristics, cup positioning alone may not be sufficient to avoid dislocation.

This study's finding on safe zone distributions based on patient positioning is not surprising. As previously discussed, there is an increased rate of SP abnormalities in patients with THA instability [12]. SP abnormalities such as flatback and stiff spines lead to changes in cup position when moving from supine to standing. Therefore, in this cohort of dislocating patients, we expected significant differences in cup positioning based on patient positioning and the reference frame. While this was expected, there is sparse literature demonstrating these findings in a large cohort of dislocating hips, so we felt that these results add quantitative value to our knowledge on this topic. The majority of dislocating THAs in this cohort had cup position within the safe zone (62%) in the supine position compared to only 42% and 45% in the APP and standing positions, respectively. While previous studies have demonstrated the limited utility of the classical safe zone for predicting dislocation [24,25], these results suggest that applying this safe zone to patients in the standing or APP position may be more useful in predicting dislocation compared to the supine position.

The authors consider the most novel finding in this study to be the reporting of continued posterior dislocations in patients with high cup anteversion and abnormal SP parameters. Indeed, in the subset of 45 instability patients with high cup anteversion, the majority reported posterior instability issues (60%) compared to anterior instability (40%). Prior treatment algorithms for cup positioning in the setting of abnormal SP characteristics have suggested increasing supine cup anteversion as a tool to adjust for these abnormalities and reduce dislocation risk [14,15,26]. Our findings suggest that anteversion alone may not be sufficient to reduce posterior instability in patients with abnormal SP parameters. A target "safe zone" may be elusive in this population. Dual mobility has already been suggested as another tool to reduce instability rates in these patients [27]. Other considerations, such as additional constraint, additional offset, or lateral/anterior-based approaches to the hip, may also be useful in this subset of patients [26,28]. Mechanisms for the instability in this patient subset are still unclear. Potential hypotheses include dropout dislocation, strongly correlated abnormal SP parameters, and soft tissue integrity such as abductor mechanism insufficiency. In addition, surgical approach may play a role in further contributing to instability in this population.

This study is limited to a database cohort study of dislocating THAs. For the purposes of this study, we did not utilize a comparative nondislocating control group. Therefore, we can only note associations between risk factors, and not cause and effect. In addition, we are limited by the accuracy of the data collection system for this database. For example, direction of instability is based on a reported value or inferred from activity of dislocation, which can have significant room for error. Nevertheless, even if

Table 1
Spinopelvic and implant parameters as a function of low, neutral, and high cup anteversion.

Parameter (mean ± SD)	Low (<15°) n = 25	Neutral (15°-35°) n = 158	High (>35°) n = 62	*P*-value
LLA_{stand} (°)	55.8 ± 13.7	49.4 ± 14.8	44.7 ± 16.6	**.011**[ac]
LLA_{seated} (°)	19.2 ± 15.0	19.6 ± 16.4	22.5 ± 17.3	.461
LF (°)	36.5 ± 16.0	29.7 ± 17.6	22.4 ± 15.0	**.002**[bc]
SS_{stand} (°)	40.7 ± 8.8	34.8 ± 9.2	29.8 ± 11.0	**.000**[abc]
SS_{seated} (°)	42.4 ± 14.4	42.7 ± 15.3	43.1 ± 14.5	.968
dSS (°)	1.6 ± 11.4	7.9 ± 14.4	13.2 ± 14.4	**.001**[abc]
PT_{stand} (°)	0.0 ± 9.3	−6.7 ± 8.9	−12.6 ± 10.7	**.000**[abc]
PT_{seated} (°)	1.7 ± 15.7	1.3 ± 13.9	0.5 ± 16.2	.974
PT_{supine} (°)	4.0 ± 6.2	1.6 ± 7.3	−0.7 ± 7.9	**.031**[c]
$dPT_{stand\_to\_seated}$ (°)	1.6 ± 11.4	7.9 ± 14.4	13.1 ± 14.4	**.000**[abc]
$dPT_{supine\_to\_stand}$ (°)	−4.0 ± 4.9	−8.2 ± 5.4	−11.9 ± 6.4	**.000**[abc]
SPT_{stand} (°)	12.8 ± 9.8	20.6 ± 9.5	26.9 ± 10.5	**.000**[abc]
SPT_{seated} (°)	11.2 ± 16.3	12.6 ± 14.4	13.8 ± 16.8	.944
dSPT (°)	−1.6 ± 11.4	−7.9 ± 14.4	−13.2 ± 14.4	**.001**[abc]
PFA_{Stand} (°)	186.8 ± 9.8	194.6 ± 9.5	200.9 ± 10.5	**.000**[abc]
PFA_{Seated} (°)	95.2 ± 16.3	96.6 ± 14.4	97.8 ± 16.8	.945
dPFA (°)	91.6 ± 11.4	97.9 ± 14.4	103.2 ± 14.4	**.001**[abc]
PI (°)	53.5 ± 11.1	55.4 ± 10.8	56.6 ± 10.6	.535
SSD (°)	−2.2 ± 14.0	6.0 ± 15.6	11.9 ± 14.9	**.000**[abc]
HUI (%)	73 ± 12	77 ± 12	83 ± 11	**.001**[bc]
CSI_{Stand} (°)	202.2 ± 12.1	230.3 ± 14.4	252.6 ± 13.0	**.000**[abc]
CSI_{Seated} (°)	110.1 ± 18.3	132.3 ± 17.2	149.5 ± 18.3	**.000**[abc]
dCSI (°)	75.9 ± 56.4	86.0 ± 52.9	94.8 ± 47.9	**.002**[bc]
IN_{APP} (°)	43.8 ± 9.0	45.1 ± 8.2	47.2 ± 8.5	.100
IN_{supine} (°)	43.5 ± 8.9	42.6 ± 7.6	41.4 ± 7.6	.199
IN_{stand} (°)	44.2 ± 9.0	43.2 ± 7.8	41.4 ± 7.5	.342
AV_{APP} (°)	10.7 ± 3.0	26.5 ± 5.6	40.3 ± 4.1	**.000**[abc]
AV_{supine} (°)	7.9 ± 4.6	20.6 ± 5.5	31.8 ± 6.6	**.000**[abc]
AV_{stand} (°)	10.7 ± 7.5	21.7 ± 7.3	31.3 ± 9.1	**.000**[abc]
AI_{stand} (°)	15.0 ± 4.5	35.7 ± 8.3	51.7 ± 6.6	**.000**[abc]
Stem AV (°)	16.2 ± 15.3	13.9 ± 10.7	15.8 ± 9.9	.390
Contralateral femur AV (°)	16.5 ± 9.8	15.0 ± 10.9	16.8 ± 12.2	.282
Anterior: posterior instability (n)	6:14	25:79	18:27	.142
Head size by instability direction (med [IQR])	Ant: 34 [32-36] Post: 34 [32-36] *P* = 1	Ant: 34 [32-36] Post: 32 [32-36] *P* = .388	Ant: 36 [32-36] Post: 32 [32-36] *P* = .525	

LLA, lumbar lordosis angle; LF, lumbar flexion; SS, sacral slope; PT, pelvic tilt; SPT, spinopelvic tilt; PFA, pelvic-femoral angle; PI, pelvic incidence; SSD, sagittal spinal deformity (PI-LL); HUI, hip user index; CSI, combined sagittal index; IN, inclination; AV, anteversion; AI, anteinclination; IQR, interquartile range.
P value indicates significance between three groups using Kruskal-Wallis, Chi squared or Fischer test as appropriate, with pairwise significance indicated with 'a' for low and neutral, 'b' for neutral and high, and 'c' for low and high AV groups.
Bold indicates statistical significance.

there were large changes (~20%) in direction of instability, our message would stay consistent.

Conclusions

This study further enhances our knowledge of the SP relationship in patients with dislocating total hip arthroplasties. We demonstrate that standing and APP position of the cup are more closely associated with dislocations compared to the supine position. In addition, in patients with abnormal SP characteristics, high anteversion alone may not prevent posterior dislocations. Additional considerations, such as increased constraint with dual mobility or constrained liners, may be required in these high-risk patients.

Acknowledgments

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Conflicts of interest

C. Plaskos is a paid employee and receives stock options from Corin. M. Grosso is a paid consultant for Convatec and is an editorial board/committee member of the American Association of Hip and Knee Surgeons. J. Pierrepont is a paid employee and receives stock options from Corin. A. Saxena is a paid employee/consultant and receives stock option from Corin, is an editorial board member of Journal of Bone and Joint Surgery, The Journal of Arthroplasty (JOA), Journal of the American Academy of Orthopaedic Surgeons, and Journal of Surgical Orthopaedic Advances, and a board/committee member of Eastern Orthopedic Association (EOA) Board, American Association of Hip and Knee Surgeons Vice Chair Patient & Public Relations Committee, American Academy of Orthopaedic Surgeons Adult Reconstruction Hip Program Chair, and PA Ortho Board.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2023.101192.

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Appendix

Table S1
Mean spinopelvic and implant position parameters in high cup anteversion group by instability direction.

Parameter	Instability direction		*P*-value
	Posterior	Anterior	
LLAstand (°)	46.3	46.6	.935
LLAseated (°)	19.7	25.6	.51
LF (°)	27.7	20.1	.08
SSstand (°)	31.7	32.3	.835
SSseated (°)	42.2	42.1	.99
dSS (°)	9.9	10.1	.862
PTstand (°)	−13	−8.1	.224
PTseated (°)	−3	1.8	.269
PTsupine (°)	−1.4	2.6	.115
dPTstand_to_seated (°)	9.6	10.1	.921
dPTsupine_to_stand (°)	−11.5	−10.7	.853
SPTstand (°)	28.1	21.5	.123
SPTseated (°)	17.8	12.1	.176
dSPT (°)	−9.9	−10.1	.872
PFAStand (°)	202.1	195.5	.123
PFASeated (°)	101.8	96.1	.176
dPFA (°)	99.9	100.1	.862
PI (°)	59.7	53.9	.065
SSD (°)	13.5	7.3	.168
HUI (%)	0.8	0.8	.139
CSIStand (°)	254.3	247.4	.27
CSISeated (°)	153.7	148.4	.176
dCSI (°)	90.2	100.1	.873
INAPP (°)	48.8	46.3	.431
INsupine (°)	43.2	40.8	.398
INstand (°)	42.9	42.2	1
AVAPP (°)	39.8	41	.292
AVsupine (°)	31.7	33.4	.302
AVstand (°)	30.6	35.4	.135
AIstand (°)	52.2	51.9	.982
Stem AV (°)	16.5	11.8	.148
Contralateral femur AV (°)	21.1	11.5	.015