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*Original Article*

# The Preoperative Anterior Pelvic Plane Angle Predicts Cup Anteversion Changes at 1 Year after Total Hip Arthroplasty

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**We investigated global alignment changes following total hip arthroplasty (THA) and predictive alignment parameters for increased cup anteversion (CA) by retrospectively analyzing the primary THA data of 75 patients treated at our hospital (49 women, 26 men; age 65.1 ± 5.7 years, BMI 28.3 ± 3.4 kg/m$^2$). Global alignment parameters, *i.e.*, the anterior pelvic plane angle (APPa) and proximal femoral shaft angle (PFSa) and other alignment parameters were measured. CA was evaluated based on the patients' standing coronal radiographs. ΔCA was defined as the difference in CA from 2 weeks before to 1 year after each THA. We classified the cases as stable (S) (CA < 10°; n = 63) and pelvic retroversion (R) (CA ≥ 10°; n = 12) groups. Associations between ΔCA and alignment parameters were evaluated by linear regression and a receiver operating characteristic (ROC) analysis. A significant decrease in the PFSa occurred between the 2-week and 1-year post-THA timepoints (7.8 ± 4.3° vs. 4.2 ± 3.6°, $p < 0.001$), with no notable change in other alignment parameters. At 1-year post-THA, the CA of 12 (16%) patients had increased to 4.5 ± 4.4°. Only the preoperative APPa was positively associated with ΔCA (β = 0.165, $p = 0.020$). The ROC analysis revealed that the optimal cut-off value for increased CA in the APPa is 2.1° (area under the curve, 0.700; $p = 0.020$; odds ratio, 4.80). The APPa change predicted increased CA, which emphasizes the importance of the use of preoperative standing radiography for identifying the optimal cup positioning for post-THA changes in CA.**

**Key words:** total hip arthroplasty, global alignment, anterior pelvic plane, cup anteversion, pelvic tilt

The coexistence of hip osteoarthritis (OA) and spinal disease was originally proposed as a hip-spine syndrome [1]. Approximately 20-60% of individuals who undergo a primary total hip arthroplasty (THA) experience low back pain following the surgery [2]. Hip OA is also associated with degenerative lumbar diseases [3]. A study of 500 patients who underwent a THA revealed that patients experienced a resolution of their low back pain by 2 years after the surgery [4].

A focus on post-THA changed in global alignment among individuals with hip OA concerns the use of compensatory mechanisms, including hip flexion contracture and pelvic anteversion coupled with reduced lumbar kyphosis that helps maintain an upright posture [5, 6]. Patients with severe hip OA display global malalignment with an increased sacral slope and decreased spinopelvic and C7 tilts [7, 8]. Although a THA improves patients' hip flexion contracture, lumbar flexibility, and disc height [9], its impacts on global

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alignment have been unclear.

A progressive increase in pelvic retroversion in the standing position after THA has been observed [10, 11]. A 1° pelvic retroversion after a THA increases the cup inclination angle by 0.3° and increases the cup anteversion (CA) angle by 0.8° [12, 13]. Increased CA angles are associated with complications such as implant failure, edge loading, impingement, and anterior dislocation [14, 15]. Achieving appropriate cup placement is thus crucial for preventing complications; however, predicting future CA angle increases prior to a THA is challenging.

We conducted the present study to investigate changes in global alignment parameters after THAs performed the anterolateral supine (ALS) approach. We also sought to identify the optimal cut-off values of preoperative global alignment parameters for predicting increased CA. We hypothesized that some of these parameters may be predictive of increased CA.

## Patients and Methods

***Patients.*** The patient cohort was comprised of 75 of the 146 patients who underwent a unilateral THA at our hospital by the ALS approach using a short, tapered wedge stem (Taperloc Microplasty; Zimmer Biomet, Warsaw, IN, USA) and a G7 Acetabular System (limited- or multi-hole Shell, Neutral Liner, Biolox Delta Ceramic Head; Zimmer Biomet) during the period from January 2019 through February 2023. We excluded the cases of the patients who underwent a THA with the posterolateral approach, a THA for femoral fracture/osteonecrosis, bilateral THA, or a THA using a dual mobility liner and those with incomplete radiographs. This study was conducted in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans, and it was approved by our institution's ethics committee (IRBNO#2333). The requirement for patients' informed consent was waived based on the study's retrospective design and use of anonymized patient data.

***Evaluation of global alignment parameters.*** Radiographic evaluations were performed using the RAD Speed Pro radiographic system (Shimadzu, Kyoto, Japan). The angles and diameters were measured in degrees and millimeters, respectively, to a single decimal place. Patients underwent standing lateral radiographs 2 weeks before and 1 year after their THAs. The radiographs were taken with the patient in a weight-bearing, free-standing position with his or her arms flexed at 45° and the hips and knees fully extended. Each patient's global spine alignment parameters were measured radiographically, including cervical lordosis (CL, °; *i.e.*, the Cobb angle between the superior endplates of C2 and C7), the sagittal vertical axis (SVA, mm; *i.e.*, the distance between the plumb line from the center of C7 to the posterior edge of the upper sacral endplate), the T1 pelvic angle (TPa, °; *i.e.*, the angle between the line from the femoral head axis to the center of the T1 vertebra and the line from the femoral head axis to the middle of the S1 superior endplate) [16], thoracic kyphosis (TK, °; *i.e.*, the Cobb angle between the superior endplate of T4 and T12), and lumbar lordosis (LL [°], Cobb angle between the superior endplates of L1 and S1). A negative value indicated lumbar kyphosis (°).

As illustrated in Fig. 1, pelvic alignment parameters were also measured as part of the 2-week pre-THA and 1-year post-THA examinations, including the sacral slope (SS, °; *i.e.*, the angle between the superior plate of S1 and a horizontal line), the pelvic incidence (PI, °; *i.e.*, the angle between a line connecting the midpoint of the superior plate of S1 and the axis of the femoral heads and the line perpendicular to the superior plate of S1), the spinopelvic tilt (SPT, °; *i.e.*, the angle between a line connecting the midpoint of the superior plate of S1 and the axis of the femoral heads and vertical line), the anterior pelvic plane angle (APPa, °; *i.e.*, the angle between a vertical reference line and the plane formed by the two anterior superior iliac spines and the pubic symphysis, where positive values indicate pelvic anteversion), and the proximal femoral shaft angle (PFSa, °; *i.e.*, the angle between the femoral axis and vertical line) (Fig. 1).

Two independent observers assessed the interobserver reliability of the sagittal alignment parameters, using 20 randomly selected images. The interobserver reproducibility was (95% confidence interval [CI] 0.95-0.99) for all of the parameters. In addition to inter-observer reliability, intra-observer reproducibility was assessed by one observer (SI) measuring 20 randomly selected radiographs after a 4-week interval. The intra-observer intraclass correlation coefficient ranged from 0.89 to 0.99.

***Evaluation of the standing CA angle.*** Each

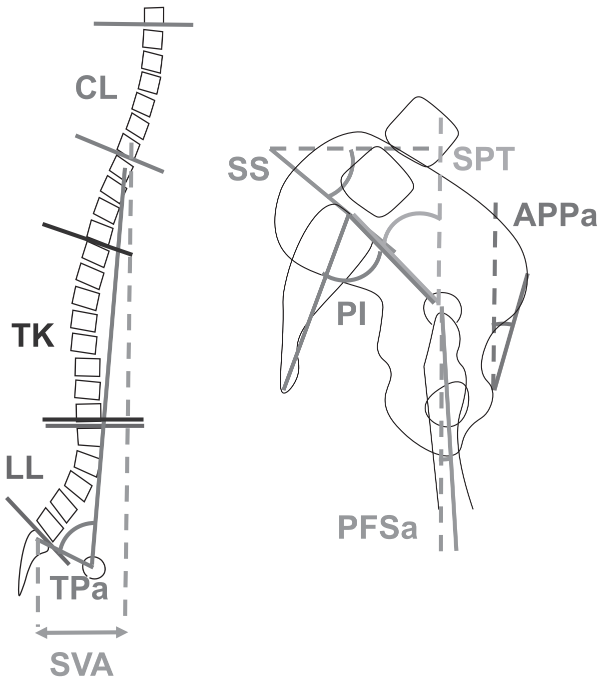


Fig. 1 Schema of the radiographic measurements. APPa, anterior pelvic plane angle; CL, cervical lordosis; LL, lumbar lordosis; PFSa, proximal femoral shaft axis; PI, the pelvic incidence angle; SPT, spinopelvic tilt; SS, sacral slope; SVA, sagittal vertical axis; TK, thoracic kyphosis; TPa, the T1 pelvic angle.

patient underwent standing lateral radiography 2 weeks before and 1 year after the THA. The CA angle was assessed based on weight-bearing radiographs as described [17]. The short and long diameters of the ellipses of the acetabular component were measured, and the CA was calculated as $\sin^{-1}$ (short diameter/long diameter). The 95%CI values of the interobserver reproducibility of the CA results were 0.95-0.99. We defined ΔCA as the difference in CA between the 2-week pre-THA and 1-year post-THA values. Positive values indicated pelvic retroversion. We classified the patients into the pelvic retroversion (R) group with ΔCA values >10° and the stable (S) group with ΔCA values <10°.

***Clinical evaluations.*** The ranges of hip flexion and abduction angles were recorded before each THA and at the final follow-up. The occurrences of dislocation, aseptic loosening, and revision surgeries were assessed. Hip function was evaluated using the Japanese Orthopedics Association (JOA) hip score [18], a 100-point scale comprising four subcategories: pain (0-40 points), range of motion (0-20 points), ability to walk (0-20 points), and activities of daily living (ADLs) (0-20 points), with higher scores indicating better function. The patients' JOA hip scores obtained 2 weeks before and 1 year after their THAs were evaluated.

***Statistical analyses.*** Demographic data and radiographic parameters are presented as the mean ± standard deviation. Changes in alignment parameters were compared using paired *t*-tests. Since some data were not normally distributed according to the Shapiro–Wilk test, we used the $\chi^2$-test and the Mann–Whitney *U*-test for categorical and continuous variables, respectively, to compare demographic data and radiographic parameters between the R and S groups.

Associations between ΔCA and radiographic parameters were evaluated using Spearman's rank correlation. We estimated the correlations between the ΔCA and the following parameters by conducting a linear regression analysis: age, sex, body mass index (BMI), SS, LL, APPa, SPT, TK, SVA, TPa, CL, PI-LL, and PFSa with the parameters as the dependent variables. The correlation model was established based only on the selected parameters using a stepwise method, with variables entered and excluded at $p > 0.05$.

Based on the results of this regression analysis, we performed a receiver operating characteristic (ROC) analysis to estimate the predictive cut-off values for increased CA (ΔCA ≥ 10°). The false-positive fraction was plotted against the 1-true-positive fraction, and the cut-off point was defined as the point of the maximum slope, which was identified by the area under the curve (AUC). The cut-off value and odds ratio (OR) at this point were estimated. All analyses were performed using a commercial statistical package (SPSS ver. 29.0; IBM, Armonk, NY, USA), with statistical significance set at $p < 0.05$.

## Results

The final patient cohort was 75 patients comprising 26 men and 49 women, with a mean age and BMI of 65.1 ± 5.7 years and 28.3 ± 3.4 kg/m$^2$, respectively. Thirty-seven THAs were performed on right hips; 38 were performed on left hips. The mean pre- and post-operative radiographic parameters are summarized in Table 1. Only the PFSa showed a significant reduction after the THAs ($p < 0.001$).

As shown in Table 2, among all 75 patients, the CA

Table 1 Changes in global alignment before and after THA

| Parameter | Pre-operation | Post-operation | *P*-value |
|---|---|---|---|
| CL | 16.7 ± 10.4 | 14.9 ± 10.7 | 0.094 |
| SVA | 66.8 ± 43.7 | 61.0 ± 40.9 | 0.097 |
| TPA | 19.7 ± 10.4 | 19.7 ± 10.9 | 0.398 |
| TK | 28.1 ± 14.3 | 26.7 ± 11.5 | 0.087 |
| LL | 28.7 ± 14.3 | 27.3 ± 13.3 | 0.090 |
| PI | 47.1 ± 3.6 | 46.9 ± 4.6 | 0.353 |
| PI-LL | 18.9 ± 13.9 | 19.6 ± 13.4 | 0.116 |
| SS | 30.7 ± 11.1 | 29.0 ± 11.6 | 0.070 |
| SPT | 18.6 ± 8.3 | 15.9 ± 14.3 | 0.085 |
| APPa | −1.5 ± 8.2 | −2.1 ± 10.7 | 0.456 |
| PFSA | 7.8 ± 4.3 | 4.2 ± 3.6 | < 0.001 |

Mean ± standard deviations of alignment parameters are shown. Comparisons between before and after THA were performed using paired *t*-tests. Statistical significance was set at $p < 0.05$. THA, total hip arthroplasty; CL, cervical lordosis; SVA, sagittal vertical axis; TPA, T1 pelvic angle; TK, thoracic kyphosis; LL, lumbar lordosis; PI, pelvic incidence; SS, sacral slope; SPT, spinopelvic tilt; APPa, anterior pelvic plane angle; PFSA, proximal femoral shaft axis.

had increased by an average of 4.5 ± 4.4° at 1 year after the THA. Twelve of the patients (16%) showed ΔCA values > 10° (the R group). The preoperative APPa values were significantly higher in the R group (5.1 ± 6.9°) compared to the S group (n = 63) (−2.3 ± 8.1°) ($p = 0.019$). The other global alignment parameters showed no significant differences between the two groups. There were no cases of dislocation, aseptic loosening, or revision surgery.

Both the S and R groups showed significant improvements in their operated hip's range of motion and JOA scores after the THA, with no significant difference in clinical outcomes between the two groups (Table 2).

Among the preoperative global alignment parameters, only the APPa was significantly correlated with ΔCA (r = 0.030, $p = 0.020$, Fig. 2). The logistic regression analysis performed to further investigate the influence of the preoperative parameters on increased CA revealed that the preoperative APPa was positively associated with ΔCA (β = 0.165, $p = 0.020$) but not age ($p = 0.307$), BMI ($p = 0.224$), or the other global alignment parameters (Table 3).

As depicted in Fig. 3, the results of the ROC demonstrated that the optimal APPa cut-off value for increased CA was 2.1° (AUC 0.700, $p = 0.020$, OR, 4.80). When we applied this cut-off value, 26 of 75 THAs (38%) showed a preoperative APPa > 2.1°. Among them, 30%

Table 2 Preoperative radiographic parameters and clinical outcomes in patients with and without increased cup anteversion

| Parameter | S group (ΔCA ≤ 10°) | R group (ΔCA > 10°) | *P*-value |
|---|---|---|---|
| Number | 65 | 12 | |
| Age (years) | 60.7 ± 10.2 | 61.8 ± 14.6 | 0.299 |
| BMI (kg/m²) | 24.7 ± 4.1 | 26.1 ± 3.8 | 0.299 |
| CL | 16.1 ± 12.1 | 19.1 ± 10.4 | 0.118 |
| SVA | 70.4 ± 45.3 | 50.1 ± 32.7 | 0.231 |
| TPA | 20.7 ± 10.6 | 8.3 ± 19.6 | 0.123 |
| TK | 28.6 ± 13.4 | 28.1 ± 12.6 | 0.404 |
| LL | 27.5 ± 14.1 | 31.8 ± 15.5 | 0.416 |
| PI | 46.8 ± 3.0 | 48.5 ± 5.7 | 0.275 |
| PI-LL | 19.4 ± 13.9 | 16.6 ± 11.4 | 0.507 |
| SS | 30.6 ± 10.3 | 32.1 ± 15.0 | 0.732 |
| SPT | 19.1 ± 8.6 | 16.8 ± 9.5 | 0.404 |
| APPa | −2.3 ± 8.1 | 5.1 ± 6.9 | 0.019 |
| PFSA | 7.4 ± 4.4 | 3.9 ± 4.3 | 0.494 |
| Pre-flexion angle (°) | 92.4 ± 13.5 | 101.5 ± 14.5 | 0.123 |
| Pre-abduction angle (°) | 20.3 ± 7.2 | 19 ± 15.8 | 0.445 |
| Pre-JOA pain | 11.4 ± 9.7 | 11 ± 9.9 | 0.908 |
| Pre-JOA gait | 10.2 ± 4.5 | 9 ± 4.6 | 0.564 |
| Pre-JOA ADL | 11.7 ± 3.1 | 9.9 ± 3.2 | 0.248 |
| Post-flexion angle (°) | 107.8 ± 12.3 | 115 ± 9.7 | 0.082 |
| Post-abduction angle (°) | 28.6 ± 5.6 | 30 ± 0 | 0.411 |
| Post-JOA pain | 35.5 ± 8.7 | 39 ± 2.2 | 0.162 |
| Post-JOA gait | 15.8 ± 4.5 | 16.9 ± 4.0 | 0.641 |
| Post-JOA ADL | 16.9 ± 3.2 | 18.2 ± 3.1 | 0.494 |

Mean ± standard deviations of radiographic parameters and clinical outcomes are shown. Comparison in patients with and without increased ΔCA was performed by the Mann–Whitney *U* test. Statistical significance was set at $p < 0.05$. S-group, stable group (CA < 10°); R-group, pelvic retroversion group (CA > 10°); BMI, body mass index; CL, cervical lordosis; SVA, sagittal vertical axis; TPA, T1 pelvic angle; TK, thoracic kyphosis; LL, lumbar lordosis; PI, pelvic incidence; SS, sacral slope; SPT, spinopelvic tilt; APPa, anterior pelvic plane angle; PFSA, proximal femoral shaft axis; JOA, Japanese Orthopedic Association; ADL, activities of daily living.

of the THAs (8/26) exhibited a CA increase ≥ 10°, demonstrating 70% sensitivity and 67% specificity.

## Discussion

The results of our retrospective analyses of 75 patients highlight the association between a larger preoperative APPa in the standing position and increased CA at 1 year post-THA. Although no significant sagittal global alignment changes occurred between before and after the THAs, our findings demonstrate that preoperative standing lateral radiography is useful for

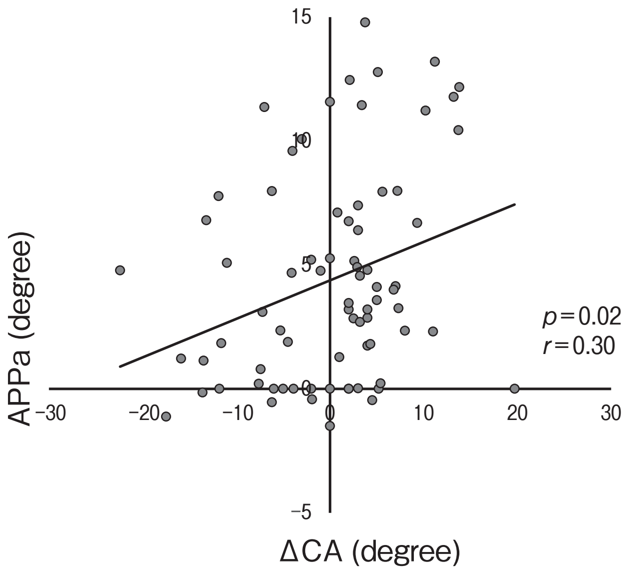


**Fig. 2** Scattergram of the patients' preoperative anterior pelvic plane angle (APPa) and ΔCA values (n=75). The APPa was positively correlated with ΔCA ($p=0.020$). CA, cup anteversion.

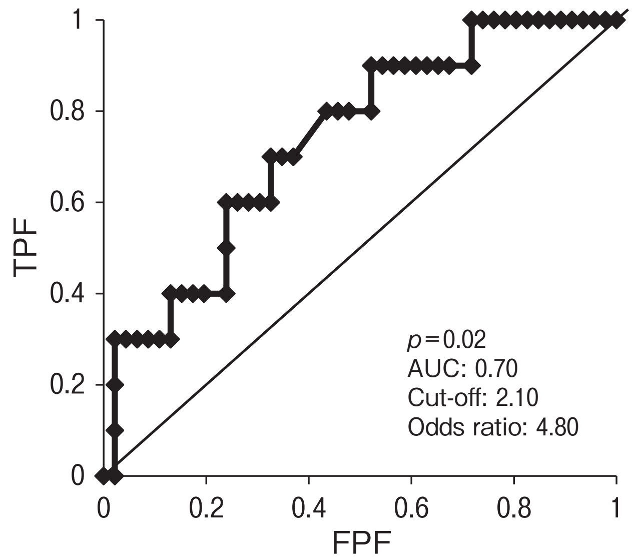


**Fig. 3** The receiver operating characteristic (ROC) curves for the APPa and for predicting an increased ΔCA. APPa, anterior pelvic plane angle; AUC, area under the curve; CA, cup anteversion; FPF, false-positive fraction; TPF, true-positive fraction.

**Table 3** Multivariate analyses of the factors associated with increased cup anteversion

| Parameter | Univariate crude | | | Multivariate adjusted (stepwise) | | |
|---|---|---|---|---|---|---|
| | β | P | R2 | β | P | R2 |
| Age | −0.05 | 0.307 | 0.019 | | | |
| Sex | 0.13 | 0.948 | 0.000 | | | |
| BMI | 0.29 | 0.224 | 0.001 | | | |
| SS | −0.15 | 0.292 | 0.012 | | | |
| LL | −0.13 | 0.359 | 0.000 | | | |
| APPa | 0.165 | 0.02 | 0.079 | 0.165 | 0.02 | 0.079 |
| SPT | 0.005 | 0.699 | 0.000 | | | |
| PI | 0.05 | 0.777 | 0.000 | | | |
| T4/12 TK | 0.04 | 0.95 | 0.000 | | | |
| SVA | −0.01 | 0.782 | 0.000 | | | |
| TPA | 0.04 | 0.161 | 0.000 | | | |
| CL | 0.19 | 0.309 | 0.000 | | | |
| PI-LL | 0.14 | 0.28 | 0.000 | | | |
| PFSA | 0.14 | 0.224 | 0.000 | | | |

Adjusted linear regression analyses were performed with CA as the dependent variable and age, sex, BMI, SS, LL, APPa, SPT, TK, SVA, TPA, CL, PI-LL, and PFSA as dependent variables as independent variables. β indicates the adjusted correlation coefficient; BMI, body mass index; CL, cervical lordosis; SVA, sagittal vertical axis; TPA, T1 pelvic angle; TK, thoracic kyphosis; LL, lumbar lordosis; PI, pelvic incidence; SS, sacral slope; SPT, spinopelvic tilt; APPa, anterior pelvic plane angle; PFSA, proximal femoral shaft axis; JOA, Japanese Orthopaedic Association.

planning cup positioning for future CA increases.

A close association between spine disorders and hip disorders, termed 'hip-spine syndrome' [1] has been reported [19]. Changes in the spinal alignment have been observed in patients with hip OA [19,20]. Day *et al.* reported that patients with severe hip OA showed lower pelvic tilt (PT) and TK values and higher SVA and TPa values compared to those with low-grade hip OA [20]. Other research groups have reported changes in global spinal alignment after THA [5,21,22].

Jain *et al.* observed significant post-THA increases in the SPT and T1-slope CL and a decrease in the CL and SVA [5], whereas Haffer *et al.* described a significant increase in the SS and decreases in the PT, APPa, and PFA after THAs [22]. However, Piazzolla *et al.* reported that the sagittal spine alignment (including the PT, SS, LL, TK, TPa, and SVA) changed after THA in patients with low back pain but not in patients without low back pain [23]. In a study by Kanto *et al.*, the LL, TK, APP, and SVA showed no significant differences between before and after THA [24]. Sagittal-alignment changes after THA thus remain a matter of debate.

Our present study did not reveal significant changes in the patients' global spinal alignment after their THAs. These conflicting results between the present and past investigations may be due to the studies' differing sample sizes, patient ages, and/or presence/absence of low back pain. Notably, the relatively advanced age of the present patients may have contributed to the diminished compensatory responses in spinal alignment post-THA.

Patients' pelvic tilt (PT) typically increases posteriorly after a THA [12,25]. Taki *et al.* reported that (*i*) the standing sagittal PT angle had increased posteriorly by 4° at 1 year post-THA, and (*ii*) the changes in the sagittal PT angle seemed to have reached a plateau at 1 year after THA [25]. An investigation by Kyo *et al.* indicated that the sagittal PT angle had increased posteriorly by 9.5° at 1 year post-THA, with 54% of their THA patients showing a posterior pelvic tilt angle > 10° [26]. A study that included a 20-year follow-up documented 5° and 10° posterior increases in the supine and standing sagittal PT angles, respectively [27]. Conversely, Blondel *et al.* observed no significant differences in the standing sagittal PT angle between before and 3 years after THAs [28]. They also reported that none of their patients showed a > 10° changed in the sagittal PT angle between before and 3 years after a THA. Our present findings revealed that the patients' sagittal PT angles tended to increase 1 year after their THAs, emphasizing the importance of appropriate cup positioning for the sustained success of THAs in the long term.

A 1° posterior pelvic tilt leads to a 0.3° increase in the cup inclination angle and CA at approx. 0.7° [12,13], which may cause implant failure, edge loading, impingement, and/or dislocation [14,15,29]. Despite the lower dislocation rate achieved by anterior approaches (*e.g.*, the ALS approach and the direct anterior approach), the rate of anterior dislocation has been shown to be higher when the anterior approach (38.2%) is used compared to the posterior approach (19.2%) [30]. A computer simulation study indicated that a posterior pelvic angle > 16°-18° during movements such as sitting-to-standing, squatting, and bending forward poses a heightened risk for dislocation due to prosthetic impingement [31]. We thus hypothesized that an increase in CA ≥ 10° indicates a higher risk of anterior dislocation. In our patient cohort, 17% exhibited a $\Delta$CA > 10°, and the highest $\Delta$CA recorded was 14.8°.

Limitations of this study include the restricted inclusion criteria that were used because of the relatively small sample size. Moreover, we did not assess the patients' contralateral hip for OA or spinal disease. However, Jain *et al.* compared spinal alignment changes in primary THA cases with low- and high-grade contralateral hip OA, and they observed no significant differences among the contralateral hip OA-graded groups [5]. Our present evaluation focused on sagittal alignments in the standing position, overlooking the dynamic mobility that the pelvis and spine display during standing, walking, and sitting [32]. The position change in the sagittal alignment may provide interesting insights.

In addition, repeated imaging on different days to assess posture reproducibility was not feasible in the present study because of radiation exposure concerns. Although intra-observer reliability was assessed in this study, subtle variations in patient posture and pelvic morphology, especially in cases of developmental dysplasia of the hip, may still affect measurements. Moreover, postoperative pelvic retroversion may result from multiple factors, including preoperative hip flexion contracture and sagittal spinal deformity. We did not assess the patients' hip extension range or perform a subgroup analysis, due to the small sample size. Further investigations with larger patient cohorts and detailed subgroup analyses are necessary to address these issues.

In conclusion. patients' preoperative anterior pelvic plane angle (APPa) could be a potential predictor of increased cup anteversion (CA), emphasizing the importance of conducting preoperative standing radiography when planning the optimal cup positioning for future CA changes after a THA.

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