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ORIGINAL ARTICLE • HIP - ARTHROPLASTY

New combined anteversion technique in hybrid THA: cup-first procedure with CT-based navigation

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Abstract

Purpose Combined anteversion (CA) technique (stem-first procedure) is generally accepted as the optimal technique to attain an appropriate CA value in total hip arthroplasty (THA). However, cup anteversion is strongly influenced by the native femoral anteversion. Accordingly, anterior protrusion of the cup in the acetabulum might occur. The purpose of the present study is to investigate the achievement of the optimal CA while avoiding anterior cup protrusion and examine the significance of our new CA technique with cup-first procedure in hybrid THA.

Methods Seventy-nine hybrid THAs with the cup-first procedure used a CT-based navigation system for cup positioning. In the preoperative planning, cup anteversion was aimed at approximately 20°. However, in actuality, sufficient cup coverage in the original acetabulum based on individual anatomy is given priority over cup placement based on CT-based planning to ensure adequate cup coverage. The target stem anteversion was determined following Widmer's mathematical formula (37.3 = femoral stem anteversion × 0.7 + cup anteversion). Cemented stem was inserted according to the target stem anteversion angle.

Results Regarding the assessment of overall alignment, the calculated Widmer's CA values during surgery and postoperative CT evaluation were 34.1° ± 6.0° (range 20.7°–51.2°) and 35.1° ± 6.7° (range 21.6°–50.7°). There were 72 hips (91.1%) within 25°–50° of CA. Cup protrusion length averaged 2.0 mm ± 2.6 mm (0–8.8 mm) in the axial view and 0.4 mm ± 1.0 mm (0–3.6 mm) in the sagittal view. Cup protrusion length of more than 5 mm was indicated in 10 hips, and no hips observed more than 10 mm.

Conclusion Our new CA technique (cup-first procedure) with hybrid THA was able to achieve optimal CA value while avoiding anterior cup protrusion.

Keywords Combined anteversion · Hybrid THA · CT navigation · Cup protrusion

Introduction

The combined anteversion (CA) in the hip is the sum of the anteversion of the acetabulum and the femur. McKibbin first introduced this concept based on the results of anatomical studies of infant cadavers and showed that the physiologic CA ranged from 30° to 40° [1]. In total hip arthroplasty (THA), the combined anteversion and the sum of the anteversion of cup and stem are used as parameters to assess the appropriateness of overall prosthetic alignment. There are recent studies dealing with the optimization of prosthetic alignment following the concept of CA. For example, Ranawat proposed that the CA value should be within the range of 25°–45° [2]. Jolles examined multiple predisposing factors for dislocation after THA and showed that the dislocation rate increased by 6.9 times when the CA value was outside the range of 40° and 60° [3]. Regarding theoretical analysis, there have been several computer simulation studies investigating the appropriate CA range to avoid implant-on-implant impingement [4–7]. Based on the results of the computerized 3D model analysis, Widmer proposed a formula (cup AV + 0.7 stem AT) to figure out the optimal CA value as the "new safe zone" value and defined the ideal

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value as 37.3° to achieve an essential range of motion while avoiding prosthetic impingement [5]. In order to attain better control of the CA value during THA, Amuwa and Dorr first proposed the CA technique for component positioning in THA, which prepared the stem first so that the femoral stem anteversion is known before cup implantation [8, 9]. Following their paper, CA technique (stem-first procedure) has become generally accepted for the optimal CA value in THA. On the other hand, cup anteversion strongly influences the native femoral anteversion in the stem-first procedure using cementless stem. In the cases of large femoral anteversion or femoral retroversion, it is possible that the acetabular component may not be set in the anatomical position of the acetabulum with CA technique. Thus, anterior or posterior protrusion of the cup in the acetabulum might occur. Furthermore, protrusion of the cup above the anterior acetabular rim could cause groin pain after THA [10–16]. The purpose of the present study is to investigate the accuracy of component positioning with optimal CA while avoiding anterior cup protrusion and to examine the significance of our new CA technique with the cup-first procedure in hybrid THA.

Materials and methods

Study design and population

We explained our surgical concept to the patients, and informed consent for the use of CT-based navigation was obtained from all patients included in the study. Seventy-nine patients who underwent primary THA between 2016 and 2018 were included in this study. Minimum follow-up period was defined as 1 year, and the average follow-up period was 1 year and 5 months (range 1–3 years). There were 15 male and 64 female patients with the mean age of 68.7 ± 11.0 (range 37–89) years. Preoperative diagnosis included developmental dysplasia in 57 hips, osteonecrosis of the femoral head in 6 hips, primary osteoarthritis in 5 hips, Rheumatoid arthritis in 4 hips, femoroacetabular impingement-related osteoarthritis in 4 hips, post-traumatic osteoarthritis in 2 hips and synovial osteochondromatosis-related osteoarthritis in 1 hip. We did not use any acetabular reinforcement devices, metal augmentation or bulk bone graft due to severe acetabular bone defect, and thus those subjects were excluded from the study.

Preoperative planning

All included patients underwent preoperative CT (Somatom, Siemens, Munich, Germany) examination from the level of the pelvis to the posterior femoral condyles to measure the native femoral anteversion. The CT data were transferred as DICOM files to a desktop computer. Tabletop plane is used as the reference plane for the measurement of native femoral anteversion. In order to simulate the tabletop plane, the 3D model of the femur using the software was repositioned to align the most prominent points of posterior condyles and the posterior point of greater trochanter, as described by Kingsley and Olmsted [17]. The femoral neck axis was defined at the transverse slice on the most proximal portion of the inferior neck that has no head portion, as proposed by Sugano [18]. The native femoral anteversion was measured as the angle between the femoral neck axis and the tabletop plane. All THAs used CT-based navigation systems (CT-based Hip Navigation version 1.1, Stryker Navigation, Freiburg, Germany) for cup positioning. In the preoperative planning of the workstation for CT-based navigation, the functional pelvic plane (FPP) was used as the reference plane for the cup positioning [19]. Radiographic cup inclination was fixed at 40°, while radiographic cup anteversion was aimed at approximately 20° [20]. However, sufficient cup coverage in the original acetabulum based on individual anatomy is given priority over cup placement based on CT-based planning to ensure adequate cup coverage. In our theory, the cup placement at the acetabulum is proceeded to prioritize avoiding anterior or posterior protrusion over the target radiographic anteversion angle, which is basically aimed at approximately 20°. Preoperative target angle of the femoral stem anteversion used the CA theory, following the mathematical formula of 37.3 = femoral stem anteversion × 0.7 + cup anteversion by Widmer [5].

Surgical procedure

In the THA procedure, surgeries were performed by either of the two senior authors (YM and TF) using a modified Hardinge approach with the patients in the lateral decubitus position in all cases. The CT navigation system was utilized to determine the cup alignment. All hips were implanted with a cementless cup (Trident Acetabular Shell, Stryker Orthopedics, NJ, USA), a cemented stem (Exeter V40 Femoral Stem, Stryker Orthopedics, NJ, USA), ceramic 32-mm head (BIOLOX delta V40 Ceramic Head, Stryker Orthopaedics, NJ, USA) and non-elevated ultra-high molecular weight polyethylene liner (Trident X3 insert, Stryker Orthopaedics, NJ, USA). We performed the cup-first procedure in all cases; the acetabular cup was placed following the preoperative planning of the cup alignment using the navigation. In addition, the surgeon confirmed the anterior and posterior edge of the acetabulum to avoid protrusion of the cup during surgery. At the time of the cup implantation, the surgeon confirmed the final cup anteversion value using the navigation monitor so that the target stem anteversion could be determined following the mathematical formula (37.3 = femoral stem anteversion × 0.7 + cup anteversion).

In order to attain consistency in stem anteversion, we have developed a simple instrument, the gravity guide (G-guide), for intra-operative assessment and adjustment [21, 22]. During surgery, the G-guide was utilized to evaluate the stem anteversion when inserting the final rasp, which enabled the G-guide to control the angle of the final rasp (Fig. 1). After the final rasp was inserted following the target anteversion, the implant–implant impingement and the bony impingement were assessed through an impingement test using the final rasp and trial head. The surgeon decided the actual stem anteversion angle based on the result of the impingement test. The actual target stem anteversion angle slightly changed from the anteversion angle of the final rasp. Finally, the cemented stem was inserted at the actual target angle in the femoral canal using G-guide (Fig. 2).

Postoperative evaluations

Postoperative clinical assessments were made to determine the existence of complications, such as deep infection, deep venous thrombosis, dislocation and postoperative groin pain.

All included patients underwent postoperative CT (Somatom; Siemens, Munich, Germany) examination at 1 week after surgery. Accuracy of the implant positioning was assessed using the navigation system and G-guide through postoperative CT images. Regarding the comparison of intra-operative cup alignment and postoperative CT measurements, the postoperative coordinate plane was semiautomatically adjusted to the preoperative coordinate plane using the contour of the pelvis in the workstation of navigation. Therefore, this allowed us to compare the results in the same pelvic plane. Subsequently, the virtual computer-aided illustration of the acetabular component was superimposed on the CT images of the actual

Fig. 2 Postoperative radiograph of hybrid THA

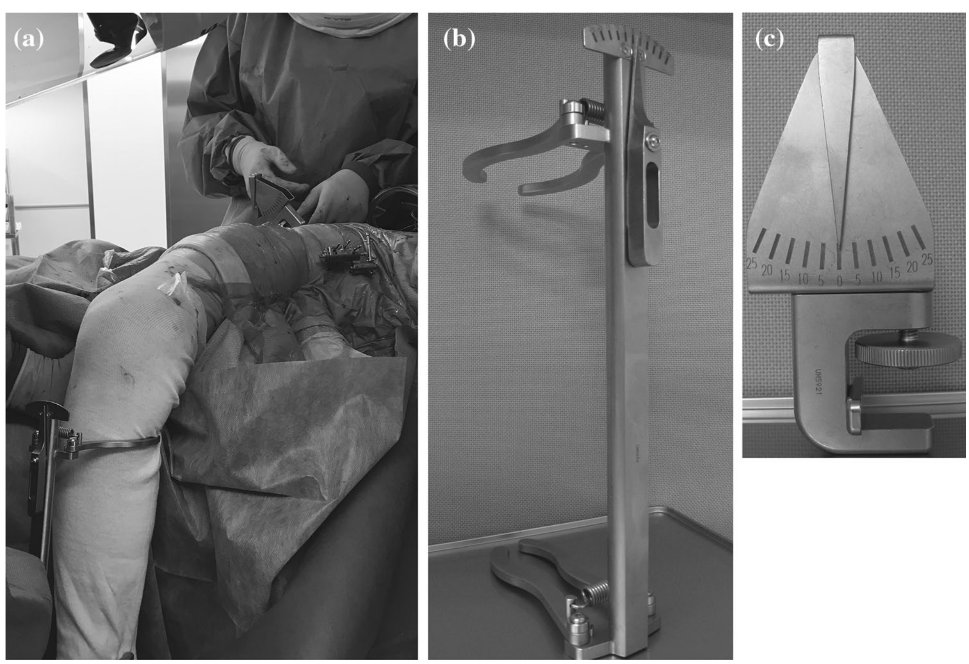

Fig. 1 Photograph showing the intra-operative setup of the G-guide. The G-guide was used to evaluate the stem anteversion at the time of insertion of the final rasp (**a**). The part of the G-guide that was attached to the lower leg was used to ascertain perpendicularity of the lower leg axis (**b**). The part attaches to the handle of the rasp provides information for the orientation of the final rasp (**c**)

acetabular component, and postoperative cup anteversion and inclination were calculated following our previous study [23]. Regarding calculation of the angles for prosthetic alignment, anatomical angles obtained from postoperative CT measurements and intra-operative cup alignment were converted to the angle of the radiological definition for fair comparison [20]. Parameters adopted for the analysis were as follows: radiographic cup inclination, radiographic cup anteversion and stem anteversion. In order to test the accuracy of the navigation system, the intra-operative navigation results and the corresponding values obtained from the postoperative CT measurements were compared. Stem anteversion was defined as the angle formed between the proximal femoral stem axis and the tangential line to the bilateral posterior femoral condylar margin on the tabletop plane. Furthermore, we applied Widmer's mathematical formula (CA = cup anteversion + 0.7 × stem anteversion) to these parameters, and we evaluated and compared the CV values during surgery and postoperative CA values through CT evaluation [5]. The resultant postoperative values were compared with the target value of their formula (37.3°). In the assessment of the appropriateness of the overall alignment, CA values of 25°–50° were regarded as satisfactory [9]. Additionally, the length of the cup protrusion from the anterior edge of the acetabulum to the anterior edge of the cup was measured on axial and sagittal views in the postoperative CT images. The slice showing the head center on the CT image was selected to measure the length of the cup protrusion [24] (Fig. 1).

Result

At the time of follow-up, all patients were satisfied with the outcome of the arthroplasty. There were no major complications, such as dislocation, deep venous thrombosis or deep infection encountered during the study period. In addition, no patients complained of postoperative groin pain during the study period No hips required revision surgery during the study period, and plain radiographs demonstrated no component migration nor radiolucent lines (Fig. 3).

Comparison of cup alignment using intra-operative navigation and postoperative CT measurements

Regarding the accuracy of the navigation systems in 79 consecutive THAs, comparison of intra-operative navigation value and postoperative CT evaluation indicated that the cup radiographic inclination and radiographic anteversion were 39.2° ± 2.4° (range 34.1°–44.2°), 13.9° ± 2.9° (range 8.1°–22.6°) intra-operatively and 39.8° ± 2.7° (range 33.3°–45.4°), 13.7° ± 3.5° (range 6.0°–25.5°) postoperatively. Absolute discrepancy between intra-operative and postoperative assessments was 1.3° ± 1.6° (range 0°–5.0°) and 1.2° ± 1.7° (range 0°–5.0°), respectively (Table 1).

Comparison of the native femoral anteversion between intra-operative guide and postoperative CT measurements

The intra-operative stem anteversion value in the G-guide evaluation required corrections to be made using the angle obtained in the clinical epicondylar axis (CEA) in the

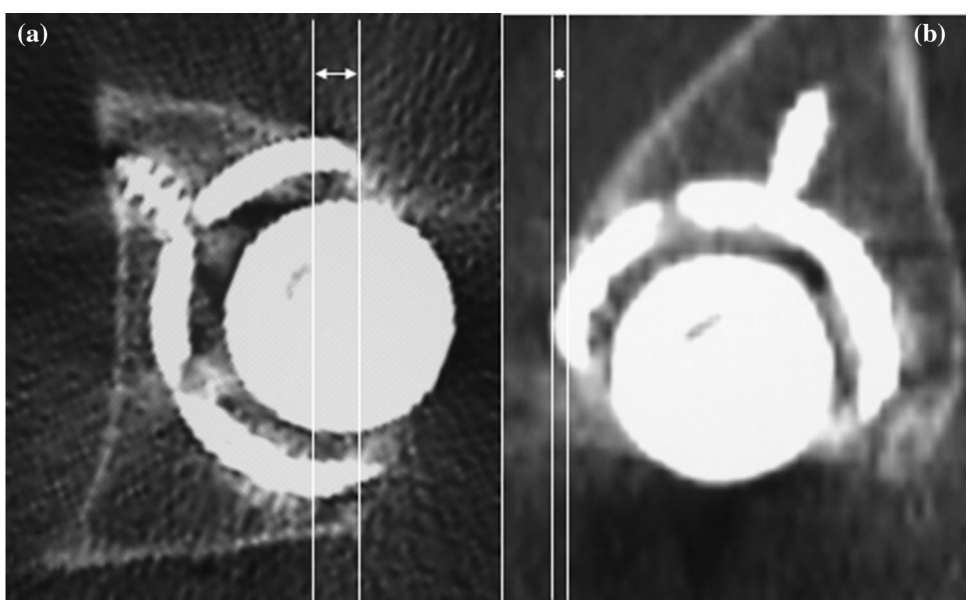

Fig. 3 Protrusion length from the cup edge to the acetabular bony boundary was measured on the axial and sagittal views on postoperative CT images on the slice passing through the center of the head. **a** The white arrow represents the protrusion length on the axial view. **b** The white asterisk represents the protrusion length on the sagittal view

Table 1 Comparative assessment of prosthetic alignment between intra-operative measurement values and postoperative CT measurement values

	Radiographic cup inclination	Radiographic cup anteversion	Stem anteversion	Combined anteversion[a]
Intra-operative measurement values (°)	39.2 ± 2.4	13.9 ± 2.9	29.0 ± 8.0[b]	34.1 ± 6.0
Postoperative CT measurement values (°)	39.8 ± 2.7	13.7 ± 3.5	30.4 ± 8.7	35.1 ± 6.7
Absolute discrepancy (°)	1.3 ± 1.6	1.2 ± 1.7	3.8 ± 3.6	3.0 ± 2.8

[a]Combined anteversion: cup anteversion + 0.7 × stem anteversion

[b]Intra-operative stem anteversion: intra-operative G-guide value + clinical epicondylar axis

Table 2 Native femoral anteversion and assessment of accuracy of the G-guide

Native femoral anteversion (°)	CEA[a] angle (°)	Intra-operative G-guide values (°)	Intra-operative G-guide values + CEA (°)	Postoperative CT measurement values (°)
25.1 ± 10.3	6.3 ± 1.8	22.7 ± 7.8	29.0 ± 8.0	30.4 ± 8.7

[a]*CEA* clinical epicondylar axis

preoperative CT measurement, as our previous study proposed [21, 22]. Therefore, the angle of CEA should be added to the intra-operative stem anteversion values obtained from the G-guide during surgery. The average native femoral anteversion and CEA angle in the study population were 25.1° ± 10.3° and 6.3° ± 1.8°, respectively. In the comparative analysis, the corrected G-guide values (the sum of the intra-operative G-guide angle and CEA angle) and the postoperative CT measurement values averaged 29.0° ± 8.0° and 30.4° ± 8.7° (Table 2), respectively. The absolute discrepancy between the corrected G-guide and the postoperative CT angle was 3.8° ± 3.6° (Table 1).

Achievement of CA

In the assessment of overall alignment, the calculated Widmer's CA values during surgery and postoperative CT evaluation were 34.1° ± 6.0° (range 0.7°–51.2°) and 35.1° ± 6.7° (range 21.6°–50.7°) (Table 1), respectively. There were 74 hips (93.6%) with CA within 25°–50°.

Cup protrusion length

Cup protrusion length averaged 2.0 mm ± 2.6 mm (0–8.8 mm) in the axial view and 0.4 mm ± 1.0 mm (0–3.6 mm) in the sagittal view. Additionally, cup protrusion length of more than 5 mm was indicated in 10 hips. However, no hips observed more than 10 mm.

Discussion

Amuwa and Dorr proposed the CA technique (stem-first procedure) in order to attain better control of the CA value in cementless THA, which prepared the stem first so that the femoral stem anteversion is known before the cup implantation [8]. Additionally, Dorr published a subsequent paper using imageless navigation combined with the CA technique [9]. In the present study, the resultant postoperative CA value was 37.6° ± 7° (range 19°–50°), and the safe zone of 25°–50° was attained in 45 of 47 hips (96%) with the proposed procedure. Nakashima et al. reported the results on the CA technique using a manual goniometer for stem anteversion and a manufacturers' cup inserter for cup anteversion [25]. They compared the clinical and radiographic assessments between the CA technique group and the cup-first group. The results showed that the cup-first group was 5.8 times more likely to develop dislocations compared to the CA technique group. In our previous study, postoperative CA was compared between the cup-first procedure and stem-first procedure in cementless THA with the use of imageless navigation for both the cup and stem [26]. In the assessment of overall alignment, the satisfactory range (37° ± 5°) of Widmer's CA value was achieved only in 38.7% of patients in the cup-first group in the study. Adoption of the CA in stem-first technique improved the corresponding rate to 93.5%. However, there was a limitation in our previous study in which we applied the exclusion criteria to the patients whose native femoral AT was more than 53° and less than 0°. The CA technique for adjustment using Widmer's CA values for cementless stem could not be adopted to these severely abnormal native femoral anteversion values of the hip. For cases with stem anteversion of more than 53°, cup anteversion had to be set to the retroversion; however, this procedure modification may increase the risk for anterior protrusion. In regards to individual differences in the native femoral anteversion, Koerner measured the femoral anteversion of 328 normal subjects and the result was averaged 8.84° (SD 9.66°) [27]. Husmann measured the femoral anteversion in 300 patients with primary osteoarthritis before THA and reported that the variance of native femoral anteversion in this patient population ranged from

0.29° to 44.5° (SD 8.7°) [28]. In patients with DDH, native femoral anteversion could vary more than normal subjects and patients with end-stage osteoarthritis resulted in other diagnosis [29–31]. In Sugano's research on native femoral anteversion in age-matched control patients with DDH, he reported that femoral anteversion averaged between 10° and 14°, and the incidence of anteversion of more than 40° was present in only 7% in the age-matched control patients compared to 23% in DDH [31]. In these DDH patients with large native femoral anteversion, the cup anteversion strongly influenced large stem anteversion during cementless THA with CA technique. In this situation, it is possible that the acetabular component could not be set in the anatomical position in the acetabulum, and the acetabulum could not sufficiently cover the cup with CA technique. Anterior protrusion of the cup in the acetabulum might have appeared.

On the other hand, several studies have focused on groin pain after THA due to malpositioning of the acetabular component [10–16]. In addition, the iliopsoas impingement is a potential cause of groin pain after THA, and large cup protrusion from the acetabular rim has been reported to be a risk factor for the iliopsoas impingement. Park proposed that large differences between the native acetabular version and the cup anteversion correlate with iliopsoas impingement in the multivariate logistic regression analysis [14]. Ueno also described that axial protrusion length of the cup of more than 12 mm and sagittal protrusion length of the cup of more than 4 mm were determined as independent predictors of symptomatic iliopsoas impingement [15]. Cyteval and Dora also discuss the axial protrusion length in the symptomatic iliopsoas impingent. They reported that the protrusion lengths averaged at 19.18 mm (12–30) and 5.8 mm (2–10) [12, 16]. In our previous study, we retrospectively evaluated the length of anterior protrusion of the cup in 104 consecutive series of stem-first THA with imageless navigation to achieve optimal CA [24]. The result of optimal CA was satisfactory and achieved 39.49° ± 5.03° (range 31.0°–53.0°); however, 60 of 104 (57.6%) hips revealed anterior cup protrusion in postoperative CT evaluation. In addition, axial cup protrusion length of more than 5 mm was indicated in 36 hips, including 13 hips with more than 10 mm. In the present study, 79 hips with the cup-first procedure using CT-based navigation in hybrid THA were able to avoid anterior protrusion of the cup and achieved sufficient host bone coverage of the cup. The cup protrusion length of more than 5 mm was indicated in 10 hips, and no hips observed more than 10 mm. The cup anteversion angle was known before deciding the target stem anteversion angle during surgery. The cement stem controlled the version in order to achieve the optimal CA using G-guide in the femur. We reported the accuracy of G-guide in measuring the stem anteversion, and the discrepancy between the intra-operative and postoperative measurements was 4.6° ± 4.1° [21]. The acceptable accuracy with a discrepancy of less than 5° was achieved in 66 hips (69%), and that of less than 10° was achieved in 85 hips (89%). The use of the G-guide effectively reduced the variability of the stem anteversion.

There are several limitations to this study. First, the postoperative follow-up period was quite short, and we focused only on radiographic evaluation. Furthermore, we were not able to determine the relationship between the symptomatic iliopsoas impingement and cup protrusion. However, no patient complained of typical anterior hip pain during the follow-up period in the present study. Following the present cases and previous studies [12, 14–16], we expect that anterior cup protrusion of approximately less than 10 mm will not develop symptomatic iliopsoas impingement. However, observation of future progress is necessary for the later potential presence of groin pain. Second, we could not evaluate the pelvic tilt in the patients' dynamic postures, which are standing, sitting and supine positions. Several studies have considered individually targeted CA for patients with a severe pelvic tilt with large differences in their pelvic tilt between the supine and standing positions [32, 33]. The preoperative planning with CT-based navigation in this study was based on the FPP in the supine position; therefore, our procedures were only able to consider the pelvic tilt in the supine position. Meanwhile, Tamura described helpful results that patients with a pelvic tilt of more than 10° posteriorly from supine to standing position did not develop anterior dislocation 10 years postoperatively, and that the FPP in the supine position could be a good reference for preoperative planning [34]. From a clinical perspective, we could tolerate a low CA and a slight anterior protrusion during surgery regarding patients with a severe pelvic tilt. However, further detailed analyses of the patient's dynamic posture are necessary to obtain clear evidence. Third, the rotation of the distal femur changed due to the decrease in stem anteversion in this procedure. As a result, it might be possible to influence the patella–femoral tracking and gait posture [35, 36]. However, we were not able to evaluate these parameters in the present study. Fourth, we focused on the cup protrusion related to the cup anteversion. However, other reasons, such as oversized cup and lateralized cup position, may have caused the anterior cup protrusion [37, 38].

In summary, our new CA technique (cup-first procedure) with hybrid THA could achieve optimal CA value, and this procedure could avoid anterior cup protrusions and might prevent groin pain caused by iliopsoas impingement.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

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