Achievement of optimal implant alignment using taper wedge stems with cup-first THA through the MIS antero-lateral approach

Taishi Okada[1,2] · Shigeo Fukunishi[2] · Shinichi Yoshiya[2] · Toshiya Tachibana[1] · Yuki Fujihara[1] · Yoshinobu Masumoto[1] · Makoto Kanto[1] · Yu Takeda[1]

Abstract

Purpose Combined anteversion (CA) technique (stem-first procedure) has become generally accepted as an ideal means to achieve optimal CA value in THA. However, we hypothesized that CA technique for patients with various native femoral anteversions could pose a risk of anterior or posterior cup protrusion. In the present study, we examined whether it is possible to use the taper wedge stem to change the stem version to achieve optimal CA while avoiding cup protrusions with the cup-first procedure through minimally invasive (MIS) antero-lateral approach.

Methods Eighty-one patients underwent cup-first THA with a taper wedge stem. The acetabular cup was placed following the preoperative planning of the cup alignment to avoid anterior cup protrusions using CT-based navigation. Following the CA theory, anteversion of the taper wedge stem was changed to the target anteversion from the patient's native femoral anteversion. The native femoral anteversion, the change in version angle of the stem, postoperative CA and the length of anterior cup protrusions were evaluated in postoperative CT measurements.

Results The native femoral anteversion averaged $25.7° \pm 8.9°$ (range 8°–45°). Cases with increased and decreased stem anteversion were observed in 42 hips (51.8%) and 33 hips (40.7%), respectively. The amount of increased and decreased version angles averaged $7.7° \pm 4.8°$ (range 2°–21°) and $7.8° \pm 5.1°$ (range 2°–20°), respectively. Postoperative CA values averaged $36.7° \pm 3.4°$ (range 29.4°–44.2°) and anterior cup protrusion length averaged $2.0 \, mm \pm 2.6 \, mm$ (0 ~ 8.8 mm) in axial view and $0.4 \, mm \pm 1.0 \, mm$ (0 ~ 3.6 mm) in sagittal view. Anterior cup protrusion of more than 10 mm was not observed in any hips.

Conclusion This procedure can be considered as an option to achieve optimal CA anteversion while avoiding anterior cup protrusion in THA.

Keywords Total hip arthroplasty · Combined anteversion · Taper wedge stem · CT navigation · Cup protrusion

Introduction

In total hip arthroplasty (THA), combined anteversion (CA) and the sum of the anteversion angles of the cup and stem are used as parameters to assess the appropriateness of overall prosthetic alignment [1, 2]. In order to achieve an optimal CA value during THA, Amuwa and Dorr first proposed a CA technique for component positioning in THA, which

prepared the stem first so that the femoral stem anteversion is known before the cup preparation [3, 4]. The reason why the stem is prepared first is due to the difficulty in changing the femoral stem anteversion using a cementless stem in the narrow femoral canal. Following their paper, this CA technique (stem-first procedure) has generally become accepted as an ideal means to achieve optimal CA values in THA. However, in cases with various native femoral anteversion in secondary osteoarthritis with dysplastic hips, the cup anteversion strongly influences the stem anteversion during cementless THA using this CA technique [5]. In this situation, it is possible that the acetabular component cannot be set in the anatomical position in the acetabulum, and the acetabulum may not sufficiently cover the cup [6].

On the other hand, persistent groin pain after THA seems to have become a common complication. Several studies

✉ Taishi Okada
okadataishi20@yahoo.co.jp

1   Department of Orthopedic Surgery, Hyogo College of Medicine, 1-1, Mukogawa-cho, Nishinomiya, Hyogo, Japan

2   Nishinomiya Kaisei Hospital, 1-4, Ohama-cho, Nishinomiya, Hyogo, Japan

have focused on groin pain after THA due to malpositioning of the acetabular component [5, 7–12]. In addition, iliopsoas impingement is a potential cause of groin pain after THA, and large cup protrusions from the anterior acetabular rims have been reported to be a risk factor for iliopsoas impingement [5, 11]. In a previous study by Okada et al. in 2019, they used this CA technique combined with imageless navigation in 104 consecutive series and achieved optimal CA as Dorr described [3, 4, 6]. The results of optimal CA were satisfactory and achieved 39.49° ± 5.03° (range 31.0°–53.0°); however, 60 of 104 (57.6%) hips revealed anterior cup protrusions of more than 3 mm from the anterior acetabular rim in postoperative CT evaluations. Masumoto et al. proposed cup-first procedure in hybrid THA using CT-based navigation systems for cup positioning to achieve optimal CA while avoiding anterior cup protrusions [13]. Their study using cemented stem achieved satisfactory results in implant alignment and cemented stem, which provide higher versatility for any types of proximal femur compared to cementless stem. However, straight cemented stem was not suitable for MIS surgery, especially using the antero-lateral approach. In the present study, we examined whether it would be possible to use the cementless taper wedge stem to change the stem version to achieve optimal CA while avoiding anterior cup protrusion following cup-first THA through the MIS antero-lateral approach.

Materials and methods

This study was approved by the Institutional Review Board of Hyogo College of Medicine (No. 2265). We explained our surgical concepts to the patients, and informed consent for the use of CT-based navigation was obtained from all patients included in the study.

Study design and population

This study was a prospective, non-randomized observational study in a limited time period. Inclusion criteria in this study were patients who underwent THA with a standardized surgical procedure using the same cementless cup (Trident Acetabular Shell, Stryker Orthopedics, NJ, USA) and cementless stem (Accolade II, Stryker Orthopedics, NJ, USA) (Fig. 1) implants. Eighty-one patients who underwent primary THA between April 2018 and March 2019 were included in this study. We defined the exclusion criteria as patients with: revision THA; primary THA using any acetabular reinforcement devices due to severe acetabular bone defect; primary THA concomitant with subtrochanteric osteotomy; and stovepipe-type femur, which was defined as having a canal flare index of less than 3.0 [14] (Fig. 2). For the hips with revision THA or primary THA concomitant
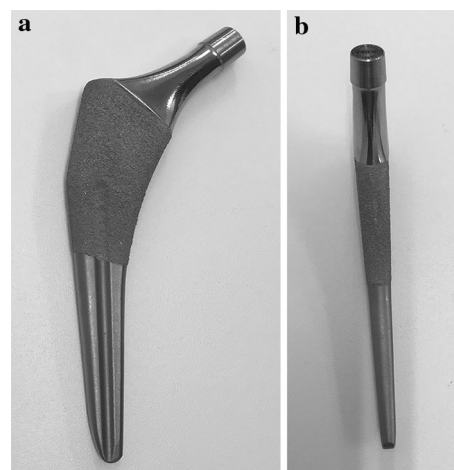

Fig. 1 Photograph of the taper wedge stem (Accolade II, Stryker Orthopedics, NJ, USA) Left: antero-posterior view; right: lateral view

with subtrochanteric osteotomy and stovepipe-type femur, we used cemented stem for the femur. For the hips with primary THA using acetabular reinforcement devices, we used cemented cups without navigation for the acetabulum.

Preoperative planning

Preoperative planning of the implant positioning was based on our previous study with hybrid THA based on the proposal by Masumoto et al.[13]. All included patients underwent preoperative CT examination (Somatom, Siemens, Munich, Germany) from the level of the pelvis to the posterior femoral condyle. The tabletop plane was used as the reference plane for the measurement of the native femoral anteversion, as described by Kingsley and Olmsted [15]. The femoral neck axis was defined as the transverse slice on the most proximal portion of the inferior neck that has no head portion, as proposed by Sugano [16]. The native femoral anteversion was defined as the angle between the femoral neck axis and the tabletop plane (Fig. 3). 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 using the workstation for the CT-based navigation, the functional pelvic plane (FPP) was used as the reference plane for the cup positioning [17]. In our preoperative planning, radiographic cup inclination was fixed at 40 degrees, while radiographic cup anteversion was aimed at approximately 20 degrees. However, sufficient cup coverage in the original acetabulum based on individual anatomy is given priority over cup placement based on the CT-based planning to ensure adequate cup coverage. In our theory, the cup placement at the acetabulum and avoiding anterior or posterior protrusion are prioritized over achieving the target radiographic anteversion angle,

Fig. 2 Flow diagram of the distribution of patient population in the study


```
103 THAs
since April 2018 to March 2019

    Excluded
    Revision THA: 8hips

    Excluded
    Primary THA with subtrochanteric osteotomy: 1hip
    Primary THA with acetabular reinforcement device: 3hips

    Excluded
    Stove type femur: 8 hips

    Excluded
    Other cementless stem for unrelated reasons: 2hips

81 primary THAs
with taper wedge stem including in the study
```
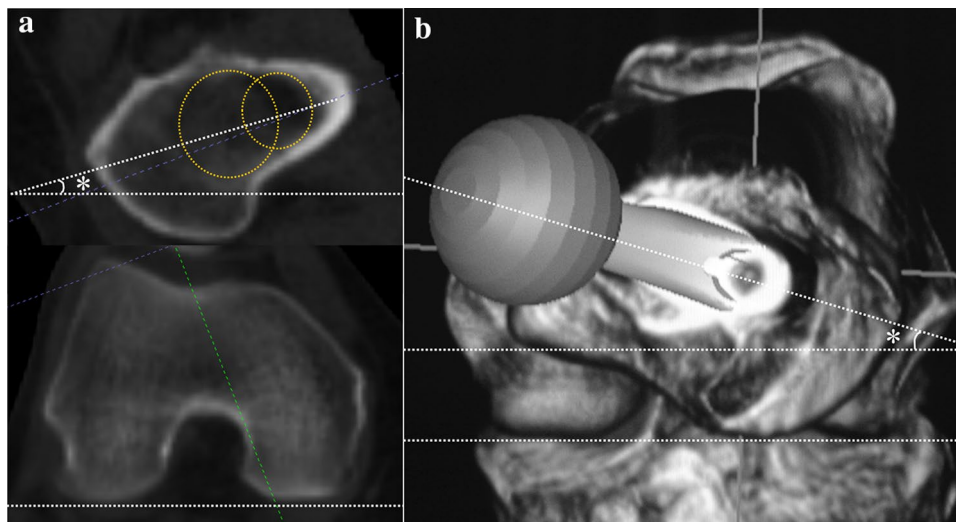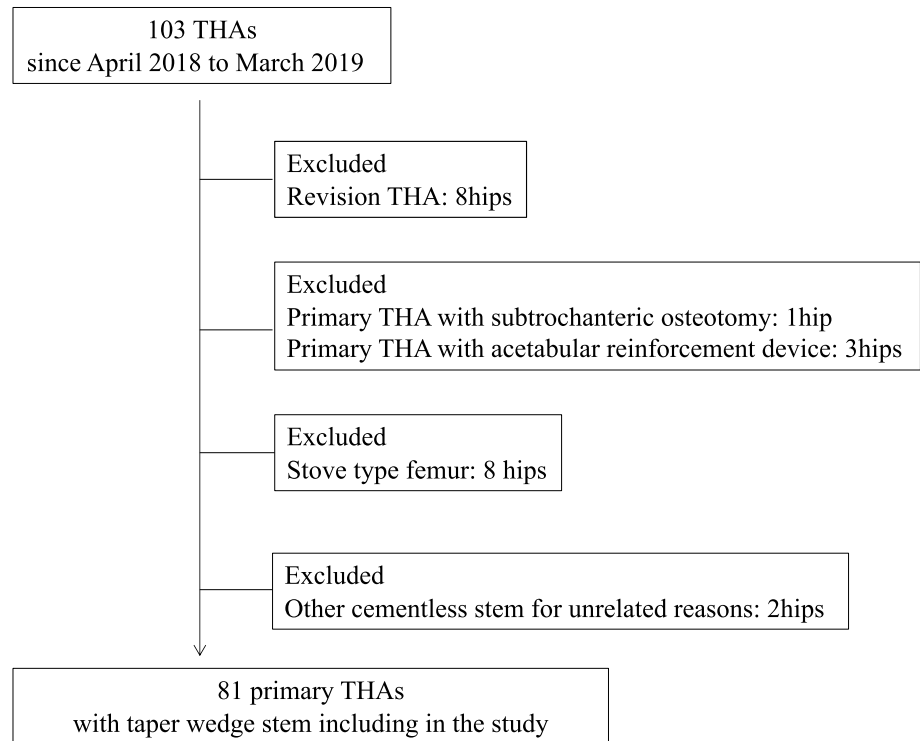

Fig. 3 The native femoral anteversion and postoperative femoral stem anteversion. **a** The femoral neck axis was defined as the transverse slice on the most proximal portion of the inferior neck that has no head portion. The native femoral anteversion was measured as the angle between the femoral neck axis and the tangential line to the bilateral posterior femoral condylar margin on the tabletop plane. The white asterisk indicates the native femoral anteversion. **b** 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 in the workstation of the CT navigation. The white asterisk indicates the postoperative stem anteversion

which is aimed at approximately 20 degrees. Preoperative target angle of the femoral stem anteversion used the CA theory, following the mathematical formula of ($37.3 =$ femoral stem anteversion $\times 0.7 +$ cup anteversion) by Widmer [18].

Surgical procedures

The THA procedure was performed by either of the two senior surgeons (TO and SF) using a modified Watson–Jones 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 cementless stem (Accolade II, Stryker Orthopedics, NJ, USA), a ceramic 32-mm head (BIOLOX delta V40 Ceramic Head, Stryker Orthopedics, NJ, USA) and a non-elevated ultra-high molecular weight polyethylene liner (Trident X3 insert, Stryker Orthopedics, 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 $\times 0.7 +$ cup anteversion). Following this mathematical formula, a taper wedge stem (Accolade II) was used in order to change the stem anteversion to the target stem anteversion from the native femoral anteversion. In order to attain consistency in stem anteversion, we have developed a simple instrument, the Gravity guide (G-guide), for intraoperative assessment and adjustment [13, 19, 20]. During the rasping of the femur, the G-guide was attached to the rasp handle to evaluate the anteversion when inserting the rasp, which enabled the G-guide to measure the angle of the final rasp (Fig. 4).

We have defined the exclusion criteria during surgery, which were cases where the surgeon decided that it was difficult to achieve the target stem anteversion using a taper wedge stem due to the femoral canal being too narrow or being discordant to the endosteal shape of the proximal femur, and cases where the difference between the target angle and native femoral anteversion was too large. The exclusion criteria also applied to cases where the surgeon confirmed the insufficiency of primary fixation using the taper wedge stem during stem implantation. These cases required cemented stems to achieve the target stem anteversion and sufficient stem fixation and thus were excluded from this study.

Postoperative evaluations

Postoperative clinical assessments were made to determine the existence of complications, such as stem subsidence, deep infection, deep venous thrombosis, dislocation, postoperative groin pain and postoperative thigh pain. All included patients underwent postoperative CT (Somatom; Siemens, Munich, Germany) examinations at one or two weeks after surgery. Regarding stem alignment, sagittal stem alignment was calculated from the angle between the stem axis and the proximal femoral axis in the sagittal plane, and coronal stem alignment was calculated from the angle between the stem axis and the proximal femoral axis in the coronal plane. We defined anterior sagittal tilt and valgus tilt as positive values (Fig. 5). Regarding measurement of the postoperative cup anteversion and inclination angle, the virtual computer-aided illustration of the acetabular component was superimposed onto the actual acetabular component of the postoperative CT images in the workstation of the CT navigation, and the postoperative cup anteversion and inclination were calculated as described by Kajino et al.[21] (Fig. 3). Anatomical angles were obtained from the postoperative CT measurements, and intraoperative cup alignment was converted to reflect radiological definition for fair comparison [22]. 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 in the workstation of the CT navigation. Parameters adopted for the analysis were as follows: radiographic cup inclination, radiographic cup anteversion, stem anteversion

Fig. 4 **a** Photograph showing the intraoperative setup of the G-guide using a modified Watson-Jones approach with the patients in the lateral decubitus position. **b** The part of *G*-guide that was attached to the lower leg was used to ascertain perpendicularity of the lower leg axis. **c** The part attached to the handle of the rasp provides information for the orientation of the final rasp
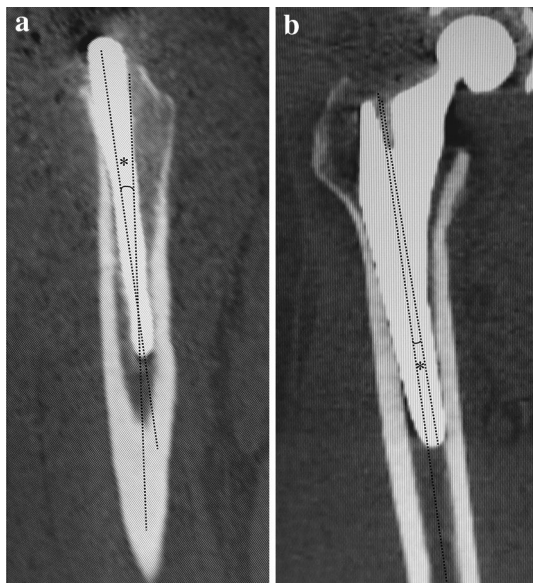
Fig. 5 Measurement of the stem alignment. **a** Sagittal stem alignment was calculated from the angle between the stem axis and the proximal femoral axis in the sagittal plane. The black asterisk indicates sagittal tilt, and the anterior sagittal tilt defined positive values. **b** Coronal stem alignment was calculated from the angle between the stem axis and the proximal femoral axis in the coronal plane. The black asterisk indicates coronal tilt, and the valgus tilt defined positive values

and amount of variation between the native femoral anteversion and the postoperative stem anteversion. Furthermore, we applied Widmer's mathematical formula (CA = cup anteversion + 0.7 × stem anteversion) to these parameters, and we evaluated the postoperative CA values through CT evaluation [14]. The resultant postoperative values were compared to the target value of Widmer's formula (37.3°). In assessing the appropriateness of the overall alignment, CA values of 25° to 50° were regarded as satisfactory [4]. 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 postoperative CT images. Anterior cup protrusions of more than 3 mm on either the axial or sagittal view on the CT image were defined as protrusion positive. The slice showing the head center on the CT image was selected to measure the length of the cup protrusion [6]. (Fig. 6).

Statistical analysis

All statistical analyses were conducted using SPSS (version 19; IBM SPSS Statistics, Inc, Chicago, IL, USA) for Windows. Continuous data were analyzed using the nonparametric Student's t test, and $P < 0.01$ was considered significant. The correlation between the intraoperative assessment value and the postoperative CT evaluation was statistically analyzed using the Pearson correlation coefficient test.

Results

The minimum follow-up period was defined as 1 year, and the follow-up period averaged 19 ± 3.3 months (range 12 to 24). There were 21 male and 60 female patients with the mean age of 66.7 ± 10.2 (range 38 to 86) years. Preoperative diagnosis included developmental dysplasia in 63 hips, osteonecrosis of the femoral head in 8 hips, primary osteoarthritis in 5 hips, femoroacetabular impingement-related osteoarthritis in 2 hips, post-traumatic osteoarthritis in 1 hip, metastasis of femoral neck in 1 hip and synovial osteochondromatosis-related osteoarthritis in 1 hip (Table 1).

No hips required switching to the cemented stem during surgery for any reasons. No patients were excluded due to having: too small of a femur, inappropriate canal dimensions, or being discordant to the endosteal shape of the proximal femur, where the Accolade II stem could not obtain sufficient metaphyseal contact during surgery. At the time of the follow-up, all patients were satisfied with the outcome
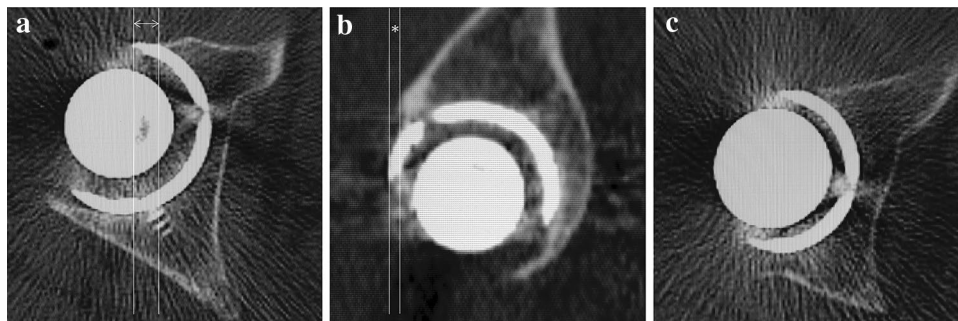

Fig. 6 Protrusion length from the cup edge to the acetabular bony boundary was measured on axial and sagittal views on postoperative CT images on the slice passing through the center of the head. **a** The white arrow represents the protrusion length on the axial view. **b** The

white asterisk represents the protrusion length on the sagittal view. **c** The radiograph showing that an oversized cup was implanted compared to the original acetabulum. The acetabular cup revealed protrusion of both anterior and posterior on the axial view

Table 1 Patients' characteristics

Parameters	Value
Gender (female/male)	60/21
Age at surgery (years)	$66.7 \pm 10.2 (38–86)$
Follow up period (months)	$19 \pm 3.3 (12–24)$
Preoperative diagnosis (number of hips)	
Developmental dysplasia	63
Osteonecrosis of the femoral head	8
Primary osteoarthritis	5
Femoroacetabular impingement-Related osteoarthritis	2
Post-traumatic osteoarthritis	1
Metastasis of femoral neck	1
Synovial osteochondromatosis-related osteoarthritis	1

of the arthroplasty. There were no major complications, such as intraoperative fracture of the proximal femur, dislocation, deep venous thrombosis or deep infection encountered during the study period. In addition, no patients complained of postoperative groin pain or thigh pain during the study period. No hips required revision surgery, and plain radiographs demonstrated no subsidence of the femoral stem, component migration nor radiolucent lines.

Cup anteversion

The assessment of the radiographic cup anteversion indicated that preoperative CT-based planning value, intraoperative navigation value and postoperative CT evaluation value averaged $18.3° \pm 3.2°$ (range 11°–26°), $17.5° \pm 3.2°$ (range 10°–23°) and $17.5° \pm 3.2°$ (range 9.8°–22°), respectively. The Pearson correlation coefficient was 0.86 between the intraoperative navigation and postoperative CT measurement values (Table 2).

Stem alignment

Postoperative sagittal alignment of the stem averaged $0.7° \pm 1.4°$ (range 0°–7.0°). No stem revealed posterior sagittal tilt, and 57 hips (70.3%) revealed neutral position.

Anterior sagittal tilt of more than 3° occurred in 9 hips (1.1%). Postoperative coronal alignment of the stem averaged $0.4° \pm 0.9°$ (range 0°–3.0°). No stem revealed varus tilt and 62 hips (76.5%) revealed neutral position. Valgus tilt of more than 3° occurred in 6 hips (0.7%).

Comparison of the native femoral anteversion, target stem anteversion and postoperative femoral stem anteversion

The native femoral anteversion fluctuated and averaged $25.7° \pm 8.9°$ (range 8°–45°). The calculated target stem anteversion following Widmer's mathematical formula after cup placement during surgery averaged $27.8° \pm 4.6°$ (range 20°–38.5°), while the postoperative femoral stem anteversion averaged $27.2° \pm 4.9°$ (range 17°–39°). The Pearson correlation coefficient was 0.63 between the intraoperative calculated target angle and postoperative CT measurement (Table 2).

Cases with increased stem anteversion were seen in 42 hips (51.8%) and increased version angle averaged $7.7° \pm 4.8°$ (range 2°–21°) (Fig. 7). Cases with decreased stem anteversion were seen in 33 hips (40.7%), and decreased version angle averaged $7.8° \pm 5.1°$ (range 2°–20°) (Table 3).

Table 2 Comparison of anteversion between intraoperative measurement and postoperative CT evaluation

	Intraoperative measurement	Postoperative CT measurement	Correlation coefficient	P
Cup anteversion (°)	17.5 ± 3.2 (range 10–23)	17.5 ± 3.2 (range 9.8–22)	0.86	0.45
Stem anteversion (°)	27.8 ± 4.6 (range 20–38.5)[a]	27.2 ± 4.9 (range 17–39)	0.63	0.22
Combined anteversion (°)[b]	32.7 ± 0.9 (range 30.1–36.4)	36.7 ± 3.4 (range 29.4–44.2)	0.48	<0.001

[a]The calculated target stem anteversion following the Widmer's mathematical formula after cup placement

[b]Combined anteversion: cup anteversion: 0.7×stem anteversion

Fig. 7 Pre- and postoperative CT images in the cases with increased version. **a** The white dotted line indicates the femoral neck axis. **b** The white dotted line indicates the postoperative stem axis, and increased version angle was measured as 21° in this case
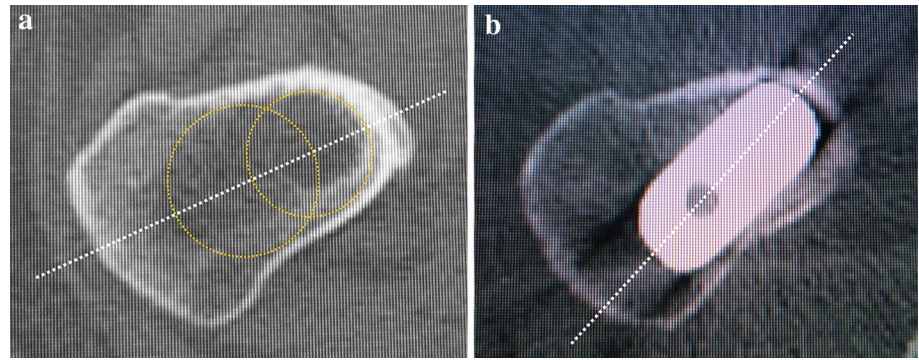

Table 3 Comparison of the native femoral anteversion and postoperative femoral stem anteversion

Native femoral anteversion (°)	25.7 ± 8.9 (range 8–45)	
Postoperative stem anteversion (°)	27.2 ± 4.9 (range 17–39)	
Discrepancy between native femoral anteversion and stem anteversion	Increased anteversion	Decreased anteversion
Cases (N)	42	33
Discrepancy (°)	7.7 ± 4.8 (range 2–21)	7.8 ± 5.1(range 2–20)

Achievement of CA

In the assessment of overall alignment, the calculated Widmer's CA values during surgery and postoperative CT evaluation were 32.7° ± 0.9° (range 30.1°–36.4°) and 36.7° ± 3.4° (range 29.4°–44.2°), respectively. (Table 1). The Pearson correlation coefficient was 0.48 between the intraoperative calculated values and postoperative CT measurement (Table 2). All hips achieved CA within 25–50 degrees.

Cup protrusion length

Preoperative CT-based planning was conducted so that no cases of anterior protrusion from the acetabular rim would occur. Anterior cup protrusion length averaged 2.0 mm ± 2.6 mm (0–8.8 mm) in axial view and 0.4 mm ± 1.0 mm (0–3.6 mm) in sagittal view. Additionally, cup protrusion length of more than 3 mm was indicated in 10 hips (12.3%). Two hips revealed both anterior and posterior cup protrusions due to oversized cups being implanted compared to the original acetabulum. No hips with anterior cup protrusion of more than 10 mm were observed.

Discussion

Several papers have described that in patients with developmental dysplasia of the hip (DDH), the native femoral anteversion could vary more than in normal subjects or patients with primary osteoarthritis [23, 24]. In these DDH patients with large native femoral anteversion, the cup anteversion is strongly influenced by the existence of a large

stem anteversion during cementless THA with the CA technique. The acetabular component might be placed at a lower anteversion value compared to the native acetabular anteversion value. However, in this situation, the acetabular component cannot be placed in the anatomical position in the acetabulum, because anterior protrusion of the cup in the acetabulum might occur.

On the other hand, several studies have focused on the relationship between iliopsoas impingement and large anterior cup protrusions from the acetabular rim. Park et al. proposed that large differences between the native acetabular version and the cup anteversion correlate with iliopsoas impingement in the multivariate logistic regression analysis [11]. Ueno also described that the axial protrusion length of the cup of more than 12 mm and the sagittal protrusion length of the cup of more than 4 mm were determined as independent predictors of symptomatic iliopsoas impingement [5]. We hypothesized that the conventional CA technique for patients with large native femoral anteversions could pose a risk of postoperative iliopsoas impingement. On the other hand, native femoral anteversion in the present study varied. The native femoral anteversion fluctuated and averaged 25.7° ± 8.9° (range 8°–45°). Cases with increased stem anteversion were seen in 42 hips (51.8%), and cases with decreased stem anteversion were seen in 33 hips (40.7%), though 63 of 81 hips were DDH patients.

In the study by Masumoto et al. in 2019, they proposed a cup-first hybrid THA with CT-based navigation [13]. In this procedure, sufficient cup coverage in the original acetabulum based on individual anatomy is given priority over cup placement in the CT-based planning to avoid anterior cup protrusion. The target stem anteversion was determined

following Widmer's mathematical formula [18] after cup implantation. The cemented stem was inserted according to the target stem anteversion angle. The results of optimal CA were satisfactory, and cup protrusion was avoided. Postoperative CA values were $35.1 \pm 6.7°$, the cup protrusion length averaged $2.0 \text{ mm} \pm 2.6 \text{ mm}$ (0–8.8 mm) in the axial view and $0.4 \text{ mm} \pm 1.0 \text{ mm}$ (0–3.6 mm) in the sagittal view. Additionally, cup protrusion length of more than 10 mm was observed in no hips. However, the modified Hardinge approach was used in the previous study mentioned above, which uses cemented stem (Exeter) without MIS. Recently, MIS THA has become generally accepted as the conventional THA in order to achieve early recovery [25, 26]. The Exeter stem has been reported to have long-term favorable clinical outcomes and excellent survivorship [27–30]. However, most of the reports on Exeter used conventional posterior approach or direct lateral approach without MIS. This type of straight cemented stem needs sufficient rasping at the posterior-lateral corner in the proximal femur to avoid varus implantation [31, 32]. THA using straight cemented stems with the MIS antero-lateral approach might cause a partial tear in the insertion of the gluteus medius. To avoid muscle damage, in this study, we dissected one-third of the gluteus medius following the modified Hardinge approach.

In the present study, we considered whether it is possible to use the taper wedge stem in order to change the stem version to achieve optimal CA while avoiding anterior cup protrusion following cup-first THA using the MIS approach. Regarding optimal CA in THA, most papers report using cementless stem with the stem-first procedure, most likely due to the fact that the first reported CA technique by Dorr used cementless anatomical type stem [4]. This type of stem cannot change the femoral stem anteversion in a narrow femoral canal, and the stem anteversion strongly influences the native femoral anteversion. The taper wedge stem, on the other hand, is relatively thin and flat and is designed to engage the metaphyseal cortical bone on the medial–lateral plane. They have a higher degree of rotational freedom compared to the anatomical stem, therefore was used for version change in our cup-first procedure. Additionally, the taper wedge stem could be suitable for MIS antero-lateral THA. The results of the stem alignment in the present study showed favorable outcomes compared to other previous studies, with a sagittal tilt of more than 3° seen in 1.1%, and coronal tilt of more than 3° seen in 0.7% [33, 34]. In regard to the CA theory, our new CA technique (cup-first procedure) with a taper wedge stem achieved optimal CA value of $36.7° \pm 3.4°$ (range 29.4°–44.2°), and a taper wedge stem increased anteversion to $7.7° \pm 4.8°$ (range 2°–21°) and decreased anteversion to $7.8° \pm 5.1°$ (range 2°–20°). No cases applied to the exclusion criteria; thus, we did not need to switch to a cemented stem from a taper wedge stem during surgery. Additionally, this study has shown that this procedure could avoid anterior cup protrusions and might prevent groin pain caused by iliopsoas impingement as previous studies with cemented stem has shown [13].

To the best of our knowledge, no papers have clearly stated the possible range of version change using a taper wedge stem. Taniguchi et al. reported results of increased anteversion value in a taper wedge stem compared to a metaphyseal stem in dysplastic hips [35]. They performed the original CA technique without any intention of controlling the stem anteversion. The anteversion increase was $17.2° \pm 8.3°$ when using a metaphyseal filling stem and $22.7° \pm 11.6°$ when using a taper wedge stem. They concluded that the large variation of anteversion in the taper wedge stem occurred without any intention of controlling the stem anteversion. Therefore, when using the taper wedge stem, they recommend the use of three-dimensional software for preoperative planning to reduce the variation in stem anteversion. In our present study, the use of the G-guide effectively reduced the variability of the stem anteversion during surgery in our cup-first procedure [13, 19, 20]. On the other hand, Taniguchi et al. could not define the possible range of version change in their papers [35, 36]. However, they defined the exclusion criteria in their study. Cases with femoral neck anteversion of more than 60° and less than $-15°$ were not included in their study. Furthermore, they used a modular-type stem in order to change the stem version intentionally. In the present study, the value of maximum version change by the taper wedge stem was observed to be 21° in increase and 20° in decrease. We did not need to change the taper wedge stem to the cemented stem due to insufficient stem stability or difficulty of the version change during surgery. Due to this study being a clinical trial with a one-year limited period, the number of patients was small. Variation in the native femoral anteversion was not large, which averaged $25.7° \pm 8.9°$ (range 8°–45°), and patients with eccentric large native femoral anteversion and retroversion were not included in the patient population. The fact that the necessary version change varied only within 20° may have contributed to achieving initial fixation using taper wedge stems. Additionally, a stovepipe-type femur was excluded from the present study, considering the difficulty in achieving sufficient initial fixation. This type of femur has been categorized as a risk factor associated with failure of osteointegration using a taper wedge stem [37]. As mentioned above, the fact that the necessary version change varied only within 20° and stovepipe-type femurs were excluded may have led to satisfactory results in the present study.

There are several limitations to this study. First, the postoperative follow-up period was quite short. Observation of future progress is necessary to monitor later progress of stress shielding or failure of osteointegration depending on the stem anteversion change in the

femur. Second, by using the anterior or the antero-lateral approach, femoral stem is sometimes implanted in the flexion position (anterior sagittal tilt) due to the difficulty of elevation of the proximal femur. However, our measurement values in postoperative CT evaluations did not consider the sagittal alignment of the stem. Hirata et al. reported that the sagittal stem alignment could influence the stem anteversion [33]. They described that when the sagittal stem alignment is tilted 1° anteriorly, the stem anteversion decreased by 2.3°. Additional evaluations of the relationship between sagittal alignment and the stem anteversion will be necessary for a further detailed analysis. Third, the rotation of the distal femur could possibly change due to changing the stem anteversion in this procedure. As a result, it might have influenced the patella–femoral tracking and gait posture [38, 39]. Fortunately, no patients complained of discomfort due to rotational change of the lower extremity. Therefore, further detailed analysis is needed as we were not able to evaluate these parameters in the present study. Forth, regarding evaluation, the focus was only on radiographic assessment in this study. Therefore, it was not possible to determine clinical outcomes, such as symptomatic iliopsoas impingement or postoperative thigh pain. However, no patient complained of typical anterior hip pain nor thigh pain during the follow-up period in the present study.

In summary, cup-first procedure in THA with cup navigation and controlled stem anteversion using the taper wedge stem with the G-guide was performed through the MIS antero-lateral approach. This procedure can be considered an option to achieve optimal CA anteversion while avoiding anterior cup protrusions. Following the results of the present study, we currently perform cup-first THA with taper wedge stem for patients without a stovepipe-type femur, as long as the required version change value sits within 20° of decreased and increased stem anteversion. However, we use cemented stem for cases that require version change value of more than 20° and cases with stovepipe-type femurs.

Compliance with ethical standards

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

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.

References

1. Ranawat CS, Maynard MJ (1991) Modern techniques of cemented total hip arthroplasty. Tech Orthop 6:17–25
2. Jolles BM, Zangger P, Leyvraz PF (2007) Factors predisposing to dislocation after primary total hip arthroplasty. J Arthroplasty 17(3):282–288
3. Amuwa C, Dorr LD (2008) The combined anteversion technique for acetabular component anteversion. J Arthroplasty 23(7):1068–1070
4. Dorr LD, Malik A, Dastane M, Wan Z (2009) Combined anteversion technique for total hip arthroplasty. Clini Ortop Relat Res 467(1):119–127
5. Ueno T, Kabata T, Kajino Y, Inoue D, Ohmori T, Tsuchiya H (2018) Risk factors and cup protrusion thresholds for symptomatic iliopsoas impingement after total hip arthroplasty: a retrospective case-control study. J Arthroplasty 33(10):3288–3296
6. Okada T, Fukunishi S, Takeda Y, Fukui T, Fujihara Y, Okahisa S, Masumoto Y, Yoshiya S (2019) Total hip arthroplasty using stem first technique with navigation: the potential achievement of the optimal combined anteversion being a risk factor for anterior cup protrusion. Eur J Orthop Surg Traumatol 29(4):807–812
7. Trousadale RT, Cabanela ME, Berry DJ (1995) Anterior iliopsas impingent after total hip arthroplasty. J Arthroplasty 10(4):546–549
8. Henderson RA, Lachiewicz PF (2012) Groin pain after replacement of the hip: aetiology, evaluation and treatment. J Bone Joint Surg Br 94(2):145–151
9. Cyteval C, Sarrabere MP, Cottin A, Assi C, Morcos L, Maury P, Taourel P (2003) Iliopsoas impingement on the acetabular component: radiologic and computed tomography findings of a rare hip prosthesis complication in eight cases. J Comput Assist Tomogr 27(2):183–188
10. Lachiewicz PF, Kauk JR (2009) Anterior iliopsoas impingement and tendinitis after total hip arthroplasty. J Am Acad Orthop Surg 17(6):337–344
11. Park KK, Tsai T-Y, Dimitriou D, Kwon Y-M (2016) Three-dimensional in vivo difference between native acetabular version and acetabularcomponent version influences iliopsoas impingement after total hip arthroplasty. Int Orthop 40(9):1807–1812
12. Dora C, Houweling M, Koch P, Sierra RJ (2008) Iliopsoas impingement after total hip replacement. The results of non-operative management, tenotomy or acetebular revision. J Bone Joint Surg Br 89(8):1031–1036
13. Masumoto Y, Fukunishi S, Fukui T, Yoshiya S, Nishio S, Yuki Fujihara Y, Okahisa S, Okada T, Kanto M, Goshi A, Morio F, Takeda Y (2019) New combined anteversion technique in hybrid THA: cup first procedure with CT-based navigation. Eur J Orthop Surg Traumatol. (Online ahead of print)
14. Noble PC, Alexander JW, Lindahl LJ, Yew DT, Granberry WM, Tullos HS (1988) The anatomic basis of femoral component design. Clini Orthop Relat Res 235:148–165
15. Kingsley PC, Olmsted KL (1948) A study to determine the angle of anteversion of the neck of the femur. J Bone Joint Surg Am 30(3):745
16. Sugano N, Noble PC, Kamaric E (1998) A comparison of alternative methods of measuring femoral anteversion. J Comput Assist Tomogr 22(4):610–614
17. Miki H, Yamanashi W, Nishi T, Sato Y, Yoshikawa H, Sugano N (2007) Anatomic hip range of motion after implantation during total hip arthroplasty as measured by navigation system. J Arthroplasty 22(7):946–952
18. Widmer KH, Zurfluh B (2004) Compliant positioning of total hip components for optimal range of motion. J Orthop Res 22(4):815–821

19. Fujihara Y, Fukunishi S, Nishio S, Takeda Y, Fukui T, Okahisa S, Yoshiya S (2016) Clinical study for the use of *G*-guide in measurement of stem antetorsion during total hip arthroplasty. Orthopedics 39(2):e271–e275

20. Fujihara Y, Fukunishi S, Fukui T, Nishio S, Takeda Y, Okahisa S, Yoshiya S (2019) Comparison of *G*-guide and image-free navigation system in accuracy of stem anteversion assessment during total hip arthroplasty. Open Orthop J 13:109–116

21. Kajino Y, Kabata T, Maeda T, Iwai S, Kuroda K, Tsuchiya T (2012) Dose degree of pelvic deformity affect the accuracy of computed tomography-based hip navigation? J Arthroplasty 27(9):1651–1657

22. Murray DW (1993) The definition and measurement of acetabular orientation. J Bone Joint Surg Br 75(2):228–232

23. Zhang J, Wang L, Mao Y, Li H, Ding H, Zhu Z (2014) The use of combined anteversion in total hip arthroplasty for patients with developmental dysplasia of the hip. J Arthroplasty 29(3):621–625

24. Sugano N, Noble PC, Kamaric E, Salama JK, Ochi T, Tullos HS (1998) The morphology of the femur in developmental dysplasia of the hip. J Bone Joint Surg Br 80(4):711–719

25. Malik A, Dorr LD (2007) The science of minimally invasive total hip arthroplasty. Clini Ortop Relat Res 463:74–84

26. Woolson ST (2006) In the absence of evidence-Why bother? A literature review of minimally invasive total hip replacement surgery. Instr Course Lect 55:189–193

27. Ling RSM, Charity J, Lee AJC, Whitehouse SL, Timperiey AJ, Gie GA (2009) The long-term results of the original Exeter polished cemented femoral component: a follow-up report. J Arthroplasty 24(4):511–517

28. Carrington NC, Sierra RJ, Gie GA, Hubble MJW, Timperiey AJ, Howell JR (2009) The Exeter universal cemented femoral component at 15 to 17 years. J Bone joint Surg (Br) 91(6):730–737

29. Petheram TG, Whitehouse SL, Kazi HA, Hubble MJW, Timperiey AJ, Wilson MJ, Howell JR (2016) The Exeter universal cemented femoral stem at 20 to 25 years: a report of 382 hips. Bone Joint J 98(11):1411–1449

30. Keeling P, Howell JR, Kassam AM, Sathu A, Timperiey AJ, Hubble MJW, Wilson MJ, Whitehouse SL (2019) Long-term survival of the cemented Exeter universal stem in patients 50 years and younger: an update on 130 hips. J Arthroplasty (Online ahead of print)

31. Macpherson GJ, Hank C, Schneider M, Trayner M, Elton R, Howie CR, Breusch SJ (2010) The posterior approach reduce the risk of thin cement mantles with a straight femoral stem design. Acta Orthop 81(3):292–295

32. Wroblewski BM, Siney PD, Fleming PA, Bobak P (2000) The calcar femorale in cemented stem fixation in total hip arthroplasty. J Bone Joint Surg (Br) 82(6):842–845

33. Hirata M, Nakashima Y, Itokawa T, Ohishi M, Sato T, Akiyama M, Hara D, Iwamoto Y (2014) Influencing factors for the increased stem version compared to the native femur in cementless total hip arthroplasty. Int Orthop 38:1341–1346

34. Yoshitani J, Kabata T, Kajino Y, Takagi T, Ohmori T, Ueno T, Ueoka K, Tsuchiya H (2018) The effect of flexion alignment in total hip arthroplasty with cementless taper-wedge femoral stem. Eur J Orthop Surg Traumatol 28:1625–1632

35. Taniguchi N, Jinno T, Koga D, Hagino T, Okawa A, Haro H (2017) Cementless hip stem anteversion in dysplastic hip: a comparison of tapered wedge vs metaphyseal filling. J Arthroplasty 32:1547–1552

36. Taniguchi N, Jinno T, Koga D, Ochiai S, Haro H (2019) Comparative study of stem anteversion using a cementless taper wedge stem in dysplastic hips between the posterolateral and anterolateral approaches. Ortho Traumatol Surg Res 105(7):1271–1276

37. Cooper HJ, Jacob AP, Rodrigues JA (2011) Distal fixation of proximally coated taper wedged stems may predispose to a failure of osteointegration. J Arthroplasty 26(6):78–83

38. Tokuhara Y, Kadoya Y, Kim M, Shoundou M, Kanno T, Masuda T (2011) Anterior knee pain after total hip arthroplasty in developmental dysplasia. J Arthroplasty 26(6):955–960

39. Liska F, Deimling C, Otto A, Willinger L, Kellner R, Imhoff AB, Burgkart R, Voss A (2018) Distal femoral torsional osteotomy increases the contact pressure of the medial patellofemoral joint in biomechanical analysis. Knee Surg Sports Traumatol Arthrosc Accessed 29 Sep 2018