A simple angle-measuring instrument for measuring cemented stem anteversion during total hip arthroplasty

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Abstract
Background During total hip arthroplasty (THA), the accurate placement of the femoral components is an important determinant of the success of the procedure. This study assessed the accuracy of cemented stem placement using a new angle-measuring instrument. The primary objective was to investigate the accuracy of the intraoperative measurements of cemented stem anteversion obtained using the angle-measuring instrument. Our secondary objective was to evaluate the accuracy of stem positioning performed using the angle-measuring instrument.

Methods We compared the intraoperative stem anteversion measurements obtained using the angle-measuring instrument with postoperative stem anteversion measurements obtained using computed tomography in 149 hips (measurement accuracy). We also compared the target angle and postoperative stem anteversion in 105 hips (implantation accuracy).

Results The mean amount of intraoperative stem anteversion was 37.9°±10.1°, and the mean amount of postoperative stem anteversion was 37.0°±10.4°. The mean measurement accuracy was 0.9°±6.1°, and the absolute measurement accuracy was 4.9°±3.7°. The correlation coefficient for the relationship between the intraoperative and postoperative stem anteversion measurements was 0.824 (p=0.000). The mean amount of target angle was 37.4°±7.6°, and the mean amount of postoperative stem anteversion was 35.9°±9.1°. The mean implantation accuracy was 1.4°±5.6°, and the mean absolute implantation accuracy was 4.3°±3.6°. The correlation coefficient for the relationship between the intraoperative and postoperative stem anteversion measurements was 0.824 (p=0.000).

Conclusions The angle-measuring instrument is expected to allow cemented stems to be placed accurately, simply, and less invasively during THA and at significant cost savings.

Background
During total hip arthroplasty (THA), the accurate placement of the femoral and acetabular components is an important determinant of the early and long-term success of the procedure. Poor component orientation is associated with impingement, a reduced range of motion, dislocation, and increased component wear [1–7]. Many studies have reported the optimal positions for the acetabular
components, and the accuracy of acetabular component positioning using free-hand techniques, mechanically guided techniques, or navigation systems has also been investigated [8–11]. Other studies have examined the accuracy of intraoperative measurements of stem anteversion obtained using a goniometer or navigation systems during THA [12–16]. However, only one study has reported the accuracy of stem positioning using a navigation system during THA [17]. Moreover, there have not been any reports about the accuracy of stem positioning using a goniometer or mechanical guides. With cemented arthroplasty components, stem anteversion can be easily controlled by the surgeon. In contrast, in cementless arthroplasty, stem anteversion is restricted by the anatomy of the femoral neck, the diaphyseal bow, and the anterior-posterior isthmus at the level of the lesser trochanter created by the calcar femorale [18]. To measure cemented stem anteversion intraoperatively during THA, we developed a simple angle-measuring instrument based on a goniometer. The primary objective of this study was to investigate the accuracy of intraoperative cemented stem anteversion measurements obtained using the angle-measuring instrument. Our secondary objective was to evaluate the accuracy of stem positioning performed using the angle-measuring instrument.

Methods
Study population
The study protocol was approved by our hospital’s institutional review board (AMU 18183). Between August 2017 and November 2018, two experienced surgeons performed primary THA using a particular cemented femoral component in 142 patients (149 hips) at our hospital. During the same period, cementless THA was performed in patients aged <50 years who had good-quality femoral cortical bone. Measurement accuracy was defined as the difference between the intraoperative stem anteversion measurements obtained using the angle-measuring instrument and the postoperative stem anteversion measurements obtained via postoperative computed tomography (CT). The measurement accuracy of the angle-measuring instrument during the measurement of cemented stem anteversion was investigated in 149 consecutive hips (Table 1). Between December 2017 and November 2018, cemented stems were implanted using the angle-
measuring instrument during THA. Implantation accuracy was defined as the difference between the target stem anteversion angle and the postoperative stem anteversion angle measured on postoperative CT. Each cemented stem was placed at the target angle using the angle-measuring instrument, and the implantation accuracy of the angle-measuring instrument was investigated in 105 consecutive hips (Table 1).

**Surgical technique and measurements**

A standard posterolateral approach was used in the lateral decubitus position in all cases. A cementless cup (Continuum Cup; Zimmer, Warsaw, IN) and a cemented stem (CMK Original Concept Stem; Zimmer, Warsaw, IN) were used in all cases. The angle-measuring instrument was attached to the handle of the femoral broach and stem, which resulted in it being aligned perpendicularly to the femoral broach and stem (Fig. 1a). The pointer of the angle meter turns upward due to gravity. The anteversion of the femoral broach and stem was measured as the angle between the gravitational direction and the line running perpendicular to the prosthetic axis (the femoral broach or stem) under 90° hip flexion, maximum hip adduction, and 90° knee flexion, with the tibia placed in the vertical position (Figs. 1b and 1c).

The acetabular side was prepared first. Our target cup position for all patients was 40° abduction and 20° anteversion, similar to Domb et al [19]. And then femoral preparation was performed. The femur was prepared by using femoral hollow reamers and the femoral broach to remove diaphyseal cancellous bone. The selected component was the same size as the final femoral broach [20]. Cement was packed into the femoral canal with a cement gun, and the stem was inserted. After the stem implantation, stem anteversion was measured. The intraoperative stem anteversion measurements were compared with postoperative stem anteversion measurements obtained using postoperative CT to investigate measurement accuracy in 149 hips. All of the intraoperative measurements were performed by the same assistant surgeon.

When the final femoral broach was placed, the angle-measuring instrument was used to measure the anteversion of the femoral broach, and the target angle was decided. A recent study reported that the intraoperative stability test, especially measuring the IR angle (the range of internal rotation under
90° hip flexion and 0° abduction/adduction), is a useful method for predicting hip stability after THA. An IR angle of 51° was set as the cut-off point for such predictions [21]. After removing the acetabular osteophytes and femoral neck remnants, the target angle was decided by fine-tuning the femoral broach and neck length to acquire an IR angle of >51° without causing anterior instability. The cemented stem was placed at the target angle using the angle-measuring instrument in 105 hips, and the implantation accuracy of this method was investigated.

All patients underwent similar closure procedures and postoperative care. Postoperatively, stem anteversion was measured on CT. CT were obtained on all patients one week after surgery. Using a Multi slice CT scanner Aquilion 64 (TSX–101A) (Canon Medical Systems Co, Japan), consecutive scans, at 2-mm intervals, were performed from the level of the fourth lumbar vertebra proximally to the knee, including the entire distal femoral condyles. Stem anteversion was determined as the angle between the stem neck axis and the axis passing through the medial and lateral femoral condyles [22, 23]. All CT-based measurements of stem anteversion were performed by the same observer, and were repeated in a blind manner during the course of two sessions, which were at least one month apart. Intraobserver reliability was evaluated using the intraclass correlation coefficient. In addition, two observers independently made CT-based measurements, and interobserver reliability was evaluated using the interclass correlation coefficient.

The factors studied included sex, age, body mass index (BMI), the preoperative diagnosis, and the severity of knee osteoarthritis (OA). We divided the preoperative diagnoses into two groups, the OA group and non-OA group (osteonecrosis of the femoral head, rheumatoid arthritis, or femoral neck fractures) (Table 1). Knee OA was graded according to the classification of Kellgren and Lawrence [24] and then was divided into two stages, the early stage (grade 1 or 2) and the advanced stage (grade 3 or 4) (Table 1).

**Statistical analyses**

The data are reported using descriptive statistics, including mean, standard deviation, and range values. The normality of the data was assessed using the Shapiro-Wilk test, and the paired t-test, non-parametric Mann-Whitney U test, and correlation analyses were performed to evaluate measurement
accuracy and implantation accuracy. Univariate and multivariate linear regression analyses were conducted to analyze the potential risk factors that might affect the measurement error in measurement accuracy and implantation accuracy. P-values of <0.05 were considered significant. All statistical analyses were performed using SPSS version 25 (SPSS Inc., Chicago, IL).

Results
The mean amount of intraoperative stem anteversion, as measured by the angle-measuring instrument, was 37.9°±10.1° (range: 7°–66°), and the mean amount of postoperative stem anteversion, as measured by CT, was 37.0°±10.4° (range: 7°–64°). The mean measurement accuracy (intraoperative stem anteversion - postoperative stem anteversion) was 0.9°±6.1° (range: −14°–16°). The mean absolute measurement accuracy (|intraoperative stem anteversion - postoperative stem anteversion|) was 4.9°±3.7° (range: 0°–16°). The measurement accuracy was within 5° in 93 hips (62%) and within 10° in 138 hips (93%). The correlation coefficient for the relationship between the intraoperative and postoperative stem anteversion measurements was 0.824 (p = 0.000) (Fig. 2). Among the factors analyzed in the univariate analyses, the severity of knee OA was found to be significantly related to measurement accuracy (p = 0.000). Sex, age, BMI, and the preoperative diagnosis were not found to be significantly related to measurement accuracy (p = 0.865, 0.267, 0.089, and 0.553, respectively). Multivariate analysis showed that the severity of knee OA significantly influenced measurement accuracy (Table 2). The mean absolute measurement accuracy in the early stage knee OA group was 3.3°±3.2°, whereas it was 6.2°±3.5° in the advanced stage knee OA group (p = 0.000).

The mean amount of target angle was 37.4°±7.6° (range: 10°–65°), and the mean amount of postoperative stem anteversion, as measured by CT, was 35.9°±9.1° (range: 7°–64°). The mean implantation accuracy (target angle - postoperative stem anteversion) was 1.4°±5.6° (range: −9°–16°). The mean absolute implantation accuracy (|target anteversion - postoperative stem anteversion|) was 4.3°±3.6° (range: 0°–16°). The implantation accuracy was within 5° in 71 hips (68%) and within 10° in 98 hips (93%). The correlation coefficient for the relationship between the target angle and postoperative stem anteversion was 0.795 (p = 0.000) (Fig. 3). Among the factors
analyzed in the univariate analyses, age and the severity of knee OA were found to be significantly associated with implantation accuracy ($p = 0.049$ and 0.000, respectively). Sex, BMI, and the preoperative diagnosis were not found to be significantly related to implantation accuracy ($p = 0.850, 0.066, \text{and } 0.267$, respectively). Multivariate analysis showed that the severity of knee OA significantly influenced implantation accuracy (Table 3). The mean absolute implantation accuracy was $2.7^\circ \pm 2.6^\circ$ in the early stage knee OA group, whereas it was $5.8^\circ \pm 4.0^\circ$ in the advanced stage knee OA group ($p = 0.000$). Excellent intraobserver reliability was seen; i.e., the intraclass correlation coefficient was 0.983 (range: 0.977–0.988). In addition, excellent interobserver reliability was observed; i.e., the interclass correlation coefficient was 0.948 (range: 0.847–0.981).

No intraoperative or postoperative complications related to the measurements were noted.

Conclusions

We investigated the measurement accuracy of an instrument for measuring the angles of cemented stems during THA and examined the accuracy of stem positioning performed using the angle-measuring instrument. The mean absolute measurement accuracy was $4.9^\circ$, and the mean absolute implantation accuracy was $4.3^\circ$. As for implantation accuracy, 68% of cases were within $5^\circ$, and 93% were within $10^\circ$.

Generally, the intraoperative estimation of stem anteversion is performed based on surgeons’ visual assessments. Several studies have reported that there can be considerable differences between surgeons’ visual assessments of stem anteversion and postoperative measurements of stem anteversion [18, 22, 25]. Wines and McNichol found that compared with postoperative measurement stem anteversion measurements surgeons underestimated stem anteversion by a mean of $1.1^\circ$ (standard deviation: 10.4). Estimated measures may range from as low as $21.9^\circ$ below ($-2$ standard deviations) to $19.7^\circ$ above ($2$ standard deviations) the CT calculated measurement. They believed that these differences were clinically unacceptable [22]. Dorr et al. reported that there was a weak correlation between surgeons’ visual assessments of stem anteversion and postoperative stem anteversion measurements [18]. In addition, Woerner et al. found that compared with postoperative
measurement stem anteverision measurements surgeons underestimated stem anteverision by a mean of 7.3°±9.8° [25].

Several studies have investigated the accuracy of measurements obtained using a goniometer or navigation systems during THA [12-16] (Table 4). They reported that the mean absolute measurement accuracy ranged from 4.5°-7.3°. Thus, the mean absolute measurement accuracy value obtained in the present study (4.9°) seems to be acceptable. Several studies have reported that knee OA and the femorotibial angle significantly influenced measurement accuracy during THA [13, 16]. In the current study, knee OA was shown to significantly influence measurement accuracy during THA, which agrees with the latter studies.

Only one navigational study, which involved a CT-based navigation system, has examined stem implantation accuracy during THA [17]. Kitada et al. reported that the mean target angle was 34.2°±12.4°, and the mean postoperative stem anteverision angle was 31.7°±11.7°. Thus, the mean implantation accuracy value was -2.5°±6.1°. The absolute implantation accuracy was not reported. Our mean implantation accuracy value was 1.4°±5.6°, which is similar to the abovementioned value.

In a previous study, it was reported that stem anteverision implantation accuracy of within 5° was achieved in 60% of cases. In our study, stem anteverision implantation accuracy of within 5° was achieved in 68% of cases, suggesting that the angle-measuring instrument can be used to achieve accurate stem implantation. However, the stem anteverision implantation accuracy was >5° in almost 30% of cases. This suggests that the angle-measuring instrument should be used with caution, and that the instrument requires further improvement.

Improvements in our understanding of femoral morphology and anteverision and their influence on implant impingement and dislocation have caused surgeons to re-evaluate component positioning during THA [26]. Several studies have examined stem anteverision during THA [18, 27]. Dorr et al. proposed that stem anteverision should exhibit an approximate range of 10°-20°, whereas D’Lima et al. stated that it should display an approximate range of 10°-30°. The mean target angle in the present study was 37.4°. Although this was larger than those described in other studies, it was similar to some previously target angle [17]. As the present study included many cases of developmental
dysplasia of the hip, in which the degree of femoral anteversion was significantly large, we employed larger target angles [28]. Recently, the concept of the IR angle was reported to be a useful method for predicting hip stability after THA, and an IR angle of 51° was suggested to be an appropriate cut-off point for such predictions [21]. A recent study reported that stem anteversion had the strongest effect on the IR angle [29]. We fine-tuned stem anteversion prior to the final implantation, with the goal of achieving an IR angle of >51°. To achieve an appropriate IR angle, it is necessary to obtain precise intraoperative information about stem anteversion, and it is very important that surgeons are able to place cemented stems accurately during THA. We developed a simple angle-measuring instrument for performing intraoperative assessments of cemented stem anteversion. To evaluate the feasibility of using the angle-measuring instrument to aid femoral stem placement, the authors investigated the measurement accuracy of the angle-measuring instrument when it was used to assess cemented stem anteversion and the accuracy of stem positioning performed using the angle-measuring instrument. Our angle-measuring instrument is very simple, does not need a large computer console, is easy to use, and is cost-effective.

Our study had several limitations. First, it did not involve a case-control group. Second, only the posterolateral approach was examined. Danoff et al. reported that when a posterior approach is employed the cup anteversion safe zone is larger than was previously believed [30]. Thus, the optimal degree of stem anteversion might differ according to the approach employed. Third, the target angle was decided by fine-tuning the femoral broach to acquire an appropriate IR angle; however, the concept of combined anteversion has been proposed [31, 32]. Finally, we did not evaluate postoperative clinical outcomes; however, this was beyond the purpose of this study.

In conclusion, we developed a simple angle-measuring instrument to intraoperatively measure cemented stem anteversion and facilitate the accurate placement of cemented stems during THA. The angle-measuring instrument is expected to allow cemented stems to be placed accurately during THA.

**Abbreviations**

THA: Total hip arthroplasty; CT: Computed tomography; BMI: Body mass index; OA: Osteoarthritis
Declarations
Ethics approval and consent to participate
This study was approved by the institutional review board of our hospital with reference number AMU 18183. All participants provided informed consent.

Consent for publication
Not applicable.

Availability of data and materials
The datasets used and/or analysed in this study are available from the corresponding author on reasonable request.

Competing interests
The authors declare that they have no competing interests.

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Authors’ contributions
The study was conceived and designed by RM and HT. Data was acquired by RM, HT, YN, and HI. RM performed the statistical analysis and drafted the manuscript. The manuscript was edited by RM, HT, YN, and HI. The manuscript was reviewed and approved for final publication by all authors.

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Tables

Table 1. Subjects’ demographic data

| Parameters                        | Measurement accuracy | Implantation accuracy |
|-----------------------------------|----------------------|-----------------------|
| No. of hips/patients             | 149 hips (142)       | 105 hips (102)        |
| Sex, male/female                  | 26/116               | 19/83                 |
| Age (years)†                     | 68.9±9.8 (50-92)     | 69.2±9.7 (50-92)      |
| Height (cm)†                     | 153.0±7.7 (131-180)  | 153.0±8.1 (131-180)   |
| Weight (kg)†                     | 56.3±11.6 (33-102)   | 55.3±11.1 (33-84)     |
| Body mass index (kg/m²)†          | 23.9±4.3 (14.7-40.2) | 23.5±4.1 (14.7-38.3)  |

**Preoperative diagnosis**

|                         |                     |                     |
|-------------------------|---------------------|---------------------|
| Osteoarthritis (OA)     | 108                 | 79                  |
| Osteonecrosis of the femoral head | 15       | 8                   |
| Rheumatoid arthritis    | 9                   | 6                   |
| Femoral neck fracture   | 17                  | 12                  |

**The severity of knee OA**

| Grade |         |         |
|-------|---------|---------|
| 1     | 13      | 8       |
| 2     | 56      | 39      |
| 3     | 60      | 43      |
| 4     | 20      | 15      |

†Mean±SD (range)

Table 2. Multivariate linear regression analysis to identify factors that affect measurement accuracy
### Table 3. Multivariate linear regression analysis to identify factors that affect implantation accuracy

| Parameters                   | B     | SE    | β     | t    | p-value |
|------------------------------|-------|-------|-------|------|---------|
| Sex                          | 0.135 | 0.792 | 0.034 | 0.452| 0.652   |
| Age                          | -0.034| 0.031 | -0.009| -0.118| 0.906   |
| BMI                          | -0.118| 0.069 | -0.119| -1.574| 0.118   |
| Preoperative diagnosis       | 0.406 | 0.683 | 0.026 | 0.338| 0.736   |
| Severity of knee OA          | 2.883 | 0.564 | 0.388 | 5.111| 0.000*  |

B: unstandardized coefficient; SE: standard error; β: standardized coefficient; *p<0.05

### Table 4. The differences in measurement accuracy between intraoperative and postoperative stem anteversion measurements reported in the literature

| Studies                     | Type                   | Intraoperative stem anteversion | Postoperative stem anteversion | Absolute difference | Correlation coefficient |
|-----------------------------|------------------------|-------------------------------|-------------------------------|----------------------|-------------------------|
| Hirata et al. [13]          | goniometer             | 40.5±11.6°                    | 34.7±11.2°                    | 7.3±5.7°             | 0.798                   |
| Fujihara et al. [15]        | goniometer             | 22.7±8.4°                     | 19.9±8.4°                    | 4.6±4.1°             |                         |
| Lee et al. [16]             | goniometer             | 21.5±8.5°                     | 19.5±8.7°                    | 4.5±2.8°             | 0.837                   |
| Hirasawa et al. [12]        | CT-based navigation    |                               |                               | 5.2±4.8°             |                         |
| Fukunishi et al. [14]       | Imageless navigation   | 15.5±9.7°                     | 20.9±10.6°                   | 5.9±4.2°             |                         |
| Current study               | Angle-measuring instrument | 37.9±10.1°                   | 37.0±10.4°                   | 4.9±3.7°             | 0.824                   |
Figures

Figure 1

a- The angle-measuring instrument attached to the handle of the femoral broach b- The angle of the angle-measuring instrument The angle of the angle-measuring instrument was measured as the angle between the gravitational direction and the line running perpendicular to the prosthetic axis under 90° hip flexion, maximum hip adduction, and 90° knee flexion, with the tibia in a vertical position. α° represents the anteversion of the femoral broach and stem. c- Anteversion of the femoral broach and stem When the tibia was placed in a vertical position, the axis passing through the medial and lateral femoral condyles ran perpendicular to the gravitational direction. The anteversion of the femoral broach and stem was determined as the angle between the prosthetic axis and the line running perpendicular to the gravitational direction. The anteversion of the femoral broach and stem reflected the angle between the gravitational direction and the line running perpendicular to the prosthetic axis. α° indicates the anteversion of the femoral broach and stem.
The correlation between intraoperative and postoperative stem anteversion measurements

The intraoperative stem anteversion measurements exhibited a good correlation with the postoperative stem anteversion measurements (correlation coefficient: \( \gamma = 0.824, p = 0.000 \)).
The correlation between the target angle and the postoperative stem anteversion measurements. The target angle exhibited a good correlation with the postoperative stem anteversion measurements (correlation coefficient: $\gamma = 0.795$, $p = 0.000$).