Efficacy of a simple intraoperative stem-anteversion measuring device in total hip arthroplasty

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Abstract

Background Background: Stem anteversion is important in reducing postoperative complications in total hip arthroplasty (THA). THA utilizing the combined-anteversion theory requires stem anteversion angle (SAA) measurement intraoperatively; however, intraoperative SAA estimation is difficult for surgeons without computer-assisted navigation system. We evaluated the accuracy of the SAA measured intraoperatively using a newly developed device by comparing the three-dimensional measurements using postoperative computed tomography (CT).

Materials & Methods In 127 hips in 127 patients who underwent unilateral THA at our hospital, we used our newly developed device that can be easily attached to rasping broach handles for measuring the SAA intraoperatively, which required the addition of the correction angle obtained in the preoperative epicondylar view. Postoperative SAA and its discrepancies from the measured intraoperative SAA with or without adding the correction angle were compared between the groups to evaluate the usefulness of the device.

Results The intraoperative SAA measured by the device was $17.93 \pm 7.53^\circ$. The true SAA measured on postoperative CT was $26.40 \pm 9.73^\circ$. The discrepancy between the intraoperative SAA and true SAA was $8.94 \pm 5.44^\circ$ (without the correction angle), and $4.93 \pm 3.85^\circ$ (with the correction angle). Accuracy with a discrepancy of <5 degrees was achieved in 77 (60.6%) and <10 degrees was achieved in 113 (89.0%). The accuracy was unaffected by the stem placement angle (varus/valgus, or flexion/extension), or ipsilateral knee osteoarthritis.

Conclusion The SAA measuring device, easily attachable to various rasping handles, is useful to measure the intraoperative SAA in a simple, economical, and noninvasive manner during THA.

Level of Evidence Therapeutic Level IV.

Introduction

Accurate placement of implants is essential for obtaining good results after a total hip arthroplasty (THA). Malpositioning of implants increases the risk of complications, such as dislocation, impingement, limitation of range of motion, and polyethylene wear and loosening [1–5]. Therefore, accurate implant placement is an important factor in avoiding these complications.

Many studies have reported ideal cup placement angles. In 1978, Lewinneck *et al.* defined the safe zone of the cup as an inclination of 40 ± 10 degrees and an anteversion of 15 ± 10 degrees; this remains the goal for some surgeons even today [1]. In clinical practice, tools, such as the computer-assisted navigation system [5, 6], accelerometer-based portable navigation [7], robotic-assisted system [8], and mechanical navigator [9–13], have proven useful in achieving accurate placement of acetabular components. However, there are very few reports about the ideal stem anteversion angle (SAA) on the femoral side. Some reports indicate that the anteversion angle of the femoral stem show wide variability. In 1991, Ranawat *et al.* proposed the concept of combined anteversion (sum of cup anteversion and femoral anteversion) in total hip arthroplasty [14]. Jolles *et al.* reported that combined anteversion increased the dislocation rate when they were out of 40–60 [15]. Another study by Widmer *et al.* proposed a formula by using a three-dimensional model analysis, where stem anteversion + $0.7 \times$ cup anteversion = 37.3, indicates an ideal situation to avoid implant-to-implant impingement [16]. In other words, stem anteversion, like cup anteversion, is a very important factor in reducing postoperative complications in THA. However, it is difficult for surgeons to estimate the SAA during surgery, without using a sophisticated measurement tool. Although the computer-assisted navigation system can set up the stem with high accuracy [6], it is very expensive and the procedure is complicated, requiring dedicated personnel. Performing surgery considering the combined-anteversion theory requires measurement of the angle of stem anteversion intraoperatively, but there are not many orthopedic surgeons who can use the computer-assisted navigation system.

Previously, we reported the development of a device that can accurately, easily, and stably set the cup placement angle in THA [10, 17]. We have now developed a device that can be easily used to measure the SAA during surgery. The purpose of this study was to verify the accuracy of the angle measured by this novel developed device during surgery by comparing measurements with those calculated by three-dimensional evaluation using postoperative computed tomography (CT) and three-dimensional templating software.

Material And Methods

This study protocol was approved by the institutional review board, and all patients provided written informed consent prior to participation. The trial was registered as a trial with the University Hospital Medical Information Network (UMIN) registration number UMIN000035913.

Study Population

The study consisted of 127 patients on whom primary THA was performed at our hospital from February 2019 to March 2020. There were 116 women and 11 men, all with osteoarthritis (OA) of the hip. All operations were performed using the anterolateral intermuscular approach in the lateral position. A single surgeon (KI) performed the procedure in all of the patients. The stems used were Taperloc (ZimmerBiomet, Warsaw, IN) in 62 patients, Actis (DePuySynthes, Warsaw, IN) in 26, AccoladeII (Stryker, Mahwah, NJ) in 25, and Entrada (OrthoDevelopment, Salt Lake, UT) in 14. Patients with a history of previous surgery on the affected hip joint, or the knee on the affected side, were excluded from the study. (Table 1) The novel device was used to measure the anteversion angle of the stem intraoperatively on all patients.

Table 1: Demographics of the 127 patients

Variables	Value
age at surgery (years)*	68.2 ± 10.3 (41~93)
Gender (male/female)	11 / 116
Body mass index (kg/m ²)*	
Male	25.2 ± 2.1 (22.9~29.6)
Female	24.1 ± 4.0 (15.6~35.0)
Preoperative diagnosis (number of hips)	
Osteoarthritis	121
Osteonecrosis	6
Osteoarthritis of the knee at the affected side	
KL 1	68
KL 2	38
KL 3	17
KL 4	4
Implant	
Taperloc	62
Actis	26
AccoladeII	25
Entrada	14
Post-op. stem placement angle from 3D measurements (°)*	
anteversion	26.40 ± 9.73
varus	1.89 ± 1.84
flexion	3.24 ± 1.67

*Values expressed as mean ± standard deviation, with range in parentheses.

Our newly developed device can be easily attached to various types of rasping broach handles to measure the twist angle of the rasp handle with respect to the direction of gravity (Fig. 1a,b). Generally, the SAA is defined as the anteverted angle of the stem from the

plane (table-top plane), which comprises the posterior contact points of the medial and lateral posterior condyles of the femur, and the posterior contact point of the greater trochanter [18]. The posterior contact points of both medial and lateral posterior condyles of the femur cannot be seen or accessed intraoperatively; therefore, the SAA cannot be measured using the axis of the posterior condyle of the femur as a reference. In order to solve this problem, a single Xp image of the epicondyle (Kanekasu view) was taken with metal markers attached 5 cm above and below the center of the tibial ridge in each patient preoperatively [19]. The correction angle formed by the perpendicular line of the tibial ridge line and the posterior condylar axis of the femur in the image was then measured (Fig. 2). By measuring this angle, it was possible to identify the posterior condylar axis from the direction of the tibial ridge line that is palpable intraoperatively. In previous studies, the axis connecting the two points, 5 cm above and below the center of the tibial ridge, is reported to be parallel to the tibial axis in 97% of individuals [20].

Device Operation and Measurements

After inserting the final rasping broach intraoperatively, the surgeon simply attaches the device to the rasping handle. In order to match the tibial ridge line of the lower leg with the direction of the center of gravity, the surgeon's assistant holds the lower leg so that the weighted chain and the tibial ridge line are parallel to each other (Fig. 1c). The tibial ridge line is easily palpable during surgery. The device has an in-built marker that is always pointed in the direction of the center of gravity (Fig. 1a). The corrected SAA is determined by adding the correction angle (the angle formed by the perpendicular line of the tibial ridge line and the posterior condylar axis of the femur in the preoperative epicondylar view) to the intraoperative SAA indicated by the device marker, when the lower leg (tibial ridge) is aligned with the direction of the center of gravity while the assistant is holding it.

At 3 months postoperatively, the true SAA was measured by CT using a three-dimensional templating software (LEXI, Zed Hip) (Fig. 3). The femoral coordinate systems were built on the surface models according to the following definitions. We defined the femoral axis as the line passing through the center of the third, fourth, and fifth portions in 14 equally divided sections of the femur. The femoral axis was reflected by the stem in the coronal and sagittal planes. We defined varus or valgus as the angle between the femoral axis and the stem axis each reflected on the coronal plane of the stem, and flexion or extension as the angle between the femoral axis and the stem axis each reflected on the sagittal plane of the stem. Varus or flexion was defined as the varus or flexion angle of the stem axis against the femoral axis on the corresponding defined coordinate plane. For anteversion or retroversion, we used the table-top plane, as previously described [18].

The accuracy of this device was verified by comparing the following: (A) the intraoperative SAA indicated by the device marker, (B) the corrected SAA obtained by adding the intraoperative SAA to the correction angle, and (C) the true SAA measured on postoperative CT. Subsequently, we analyzed the correlation between (A) and (C), or between (B) and (C). We also examined whether the discrepancy in accuracy was influenced by the stem placement angle (varus/valgus, flexion/extension), the grade of OA of the knee joint on the affected side, and the type of stem implant.

Statistical analysis

Statistical analyses were performed using SPSS version 26.0 (IBM Corp, Armonk, NY). Pearson's correlation coefficient was used to compare between (A) and (C), or between (B) and (C), as defined earlier. The absolute values of the correlation coefficients were calculated, with values < 0.40 defined as a weak correlation, values of 0.40 to 0.70 defined as moderate, and values ≥ 0.70 defined as a strong correlation. Student T test was performed to detect differences in the absolute value of the discrepancy between (A) and (C) or (B) and (C), among the groups (Varus > 3 vs. Varus ≤ 3 (including Valgus)) or the groups (Flexion > 3 vs. Flexion ≤ 3 (including Extension)). One-way ANOVA was performed to detect differences in the absolute value of the discrepancy between (A) and (C) or (B) and (C), among the Kellgren and Lawrence (KL) classification groups or the groups with each type of stems [21]. The level of significance was set at $p = 0.05$.

Results

The intraoperative SAA measured by the device was 17.93 ± 7.53 degrees (range: 1–44). The true SAA measured from postoperative CT was 26.40 ± 9.73 degrees (range: 0.18–45.67). Without considering the correction angle between the perpendicular line of the tibial ridge line and the posterior condylar axis of the femur (measured using an Xp epicondylar view), the absolute value of the discrepancy between the intraoperative SAA and the true SAA was 8.94 ± 5.44 degrees (range: 0–24.67), and there was a strong positive correlation between these two values ($r = 0.775$). Thirty-six of 127 cases (28.3%) had a discrepancy within 5 degrees from the true SAA, and 81 of 127 cases (63.8%) had a discrepancy within 10 degrees (Table 2).

Table 2: Discrepancy between intraoperative SAA with or without adding the correction angle and the true SAA measured by 3D measurement

Without adding the correction angle	number (%)	mean $\pm$ SD	<i>p value</i> _a	<i>r</i> ^b	With adding the correction angle	number (%)	mean $\pm$ SD	<i>p value</i> _a	<i>r</i> ^b
(A) intraoperative SAA indicated by the device (°)	127	17.93 $\pm$ 7.53	<0.001	0.775	Correction angle (°)	127	6.94 $\pm$ 3.13		
(C) true SAA measured by 3D measurements (°)	127	26.40 $\pm$ 9.73			(B) corrected SAA with adding the correction angle (°)	127	24.76 $\pm$ 8.24	<0.001	0.786
Discrepancy between (A) and (C) (absolute value) (°)	127	8.94 $\pm$ 5.44			(C) true SAA measured by 3D measurements (°)	127	26.40 $\pm$ 9.73		
range					Discrepancy between (B) and (C) (absolute value) (°)	127	4.93 $\pm$ 3.85		
-15 < $\leq$ -10	0 (0%)				range				
-10 < $\leq$ -5	3 (2.4%)				-15 < $\leq$ -10	4 (3.1%)			
-5 < $\leq$ 5	36 (28.3%)				-10 < $\leq$ -5	10 (7.9%)			
5 < $\leq$ 10	42 (33.1%)				-5 < $\leq$ 5	77 (60.6%)			
10 < $\leq$ 15	27 (21.3%)				5 < $\leq$ 10	26 (20.5%)			
15 < $\leq$ 20	13 (10.2%)				10 < $\leq$ 15	10 (7.9%)			
20 < $\leq$ 25	6 (4.7%)				15 < $\leq$ 20	1 (0.8%)			
					20 < $\leq$ 25	0 (0%)			

SAA, stem anteversion angle; SD, standard deviation; 3D, three-dimensional.

^a *p* value from Pearson's correlation coefficient

^b *value of the correlation coefficients*

On the other hand, when considering the correction angle, the corrected SAA with adding the intraoperative SAA with the correction angle was 24.76 $\pm$ 8.24 degrees (range: 4.64–44.50). The absolute value of the discrepancy between the corrected SAA and the true SAA was 4.93 $\pm$ 3.85 degrees (range: 0.01–18.36), and there was a strong positive correlation between these two values (*r* = 0.786).

Seventy seven of 127 cases (60.6%) had a discrepancy within 5 degrees from the true SAA, and 113 of 127 cases (89.0%) had a discrepancy within 10 degrees (Table 2). The discrepancy could be reduced when the correction angle (formed by the perpendicular line of the tibial ridge and the posterior condylar axis of the femur) was added. The correction angle was 6.94 ± 3.13 degrees (range: 0.39 to 14.25), and all cases had positive values (femoral-tibial articular surface lateral space was larger than medial space) (Fig. 4).

Based on the KL classification of OA knee, 68 patients were classified as KL-1, 38 patients as KL-2, 17 patients as KL-3, and 4 patients as KL-4 [21]; moreover, there was no association between the KL classification and the intraoperative SAA, the corrected SAA, the true SAA, the correction angle, or the discrepancies from the true SAA (Table 3).

Table 3: Comparison of each values and discrepancies between each KL group.

	Total	KL 1	KL 2	KL 3	KL 4	<i>p</i> value
number	127	68	38	17	4	
(A) intraoperative SAA indicated by the device ^a (°)	17.93 ± 7.53	17.82 ± 7.63	17.85 ± 6.93	16.21 ± 8.79	19.38 ± 7.15	0.096 _b
Correction angle ^a (°)	6.94 ± 3.13	6.74 ± 3.06	6.79 ± 3.09	7.42 ± 3.30	9.56 ± 3.85	0.314 _b
(B) corrected SAA with adding the correction angle ^a (°)	24.76 ± 8.24	24.36 ± 8.06	25.54 ± 7.75	23.63 ± 10.33	28.94 ± 7.00	0.193 _b
(C) true SAA measured by 3D measurements ^a (°)	26.40 ± 9.73	26.43 ± 9.37	28.01 ± 9.82	22.94 ± 11.60	25.47 ± 2.75	0.281 _b
Discrepancy between (A) and (C) (absolute value) ^a (°)	8.94 ± 5.44	8.75 ± 5.66	9.66 ± 5.37	8.11 ± 5.32	8.98 ± 2.83	0.460 _b
Discrepancy between (B) and (C) (absolute value) ^a (°)	4.93 ± 3.85	4.71 ± 3.53	4.76 ± 4.13	6.23 ± 4.12	4.82 ± 5.58	0.091 _b

KL, Kellgren and Lawrence; SAA, stem anteversion angle; 3D, three-dimensional.

^a The values are given as the mean and standard deviation.

^b The *p* values were determined with the One-way ANOVA test.

There was no correlation observed between the varus and valgus stem placement angles and the discrepancies from the true SAA. There was also no correlation between the flexion placement angle and the discrepancy. There was no significant difference between between cases of varus or valgus insertion over 3 degrees and cases of varus or valgus insertion less than 3 degrees, and between the flexion insertions over 3 degrees and flexion insertions of less than 3 degrees (Table 4, 5). In addition, there was no association between the types of stem implant and the intraoperative SAA, the corrected SAA, the true SAA, the correction angle, or the discrepancies from the true SAA (Table 6).

Table 4: Comparison of the discrepancies between cases of varus insertion more than 3 degrees and cases of varus or valgus insertion less than 3 degrees

	Total	Neutral Varus / Valgus ≤ 3	Varus Varus > 3	Valgus Valgus > 3	<i>p</i> <i>value</i>
number	127	93	34	0	
Varus / Valgus angle ^a (°)	1.89 ± 1.84	1.05 ± 1.30	4.21 ± 0.85	-	0.018
Discrepancy between (A) and (C) (absolute value) ^a (°)	8.94 ± 5.44	8.27 ± 5.31	10.79 ± 5.44	-	0.238
Discrepancy between (B) and (C) (absolute value) ^a (°)	4.93 ± 3.85	4.52 ± 3.76	6.05 ± 3.92	-	0.404

^a The values are given as the mean and standard deviation.

^b The *p* values were determined with the Student T test.

(A) intraoperative SAA indicated by the device (°)

(B) corrected SAA with adding the correction angle (°)

(C) true SAA measured by 3D measurements (°)

Table 5: Comparison of the discrepancies between cases of flexed insertion more than 3 degrees and cases of flexed or extended insertion less than 3 degrees

	Total	Neutral Flexion / Extension ≤ 3	Varus Flexion > 3	Valgus Extension > 3	<i>p</i> <i>value</i>
number	127	59	68	0	
Flexion / Extension angle ^a (°)	3.24 ± 1.67	1.81 ± 0.92	4.48 ± 1.08	-	0.013
Discrepancy between (A) and (C) (absolute value) ^a (°)	8.94 ± 5.44	9.40 ± 6.03	8.54 ± 4.87	-	0.532
Discrepancy between (B) and (C) (absolute value) ^a (°)	4.93 ± 3.85	5.30 ± 4.17	4.60 ± 3.54	-	0.628

^a The values are given as the mean and standard deviation.

^b The *p* values were determined with the Student T test.

(A) intraoperative SAA indicated by the device (°)

(B) corrected SAA with adding the correction angle (°)

(C) true SAA measured by 3D measurements (°)

Table 6: Comparison of each values and discrepancies between each type of stem

	Total	Taperloc	Actis	AccoladeII	Entrada	<i>p</i> <i>value</i>
number	127	62	26	25	14	
(A) intraoperative SAA indicated by the device ^a (°)	17.93 ± 7.53	19.14 ± 7.07	18.87 ± 8.85	16.30 ± 6.66	13.79 ± 7.10	0.058 _b
Correction angle ^a (°)	6.94 ± 3.13	7.42 ± 3.31	6.93 ± 3.00	5.57 ± 2.56	7.31 ± 3.10	0.095 _b
(B) corrected SAA with adding the correction angle ^a (°)	24.76 ± 8.24	26.31 ± 7.60	25.80 ± 9.64	21.87 ± 6.30	21.10 ± 9.55	0.103 _b
(C) true SAA measured by 3D measurements ^a (°)	26.40 ± 9.73	28.41 ± 8.71	26.83 ± 8.65	22.30 ± 10.20	24.07 ± 12.95	0.188 _b
Discrepancy between (A) and (C) (absolute value) ^a (°)	8.94 ± 5.44	9.51 ± 5.16	8.52 ± 5.17	6.81 ± 4.69	11.03 ± 7.36	0.089 _b
Discrepancy between (B) and (C) (absolute value) ^a (°)	4.93 ± 3.85	4.68 ± 3.71	5.26 ± 3.47	4.81 ± 4.33	5.63 ± 4.49	0.516 _b

Taperloc (ZimmerBiomet, Warsaw, IN), Actis (DePuySynthes, Warsaw, IN), AccoladeII (Stryker, Mahwah, NJ), Entrada (OrthoDevelopment, Salt Lake, UT); 3D, three-dimentional.

^a The values are given as the mean and standard deviation.

^b The *p* values were determined with the One-way ANOVA test.

Discussion

The results of this study demonstrate that it is possible to easily measure the SAA by using this device intraoperatively, which previously could not be measured during surgery without using an expensive and complicated support tool called navigation system, with an average absolute value discrepancy of 8.94 degrees. If corrected by taking an Xp image of the epicondylar view before surgery and measuring the correction angle formed by the perpendicular line of the tibial ridge and the posterior condylar axis of the femur, it was found that the corrected SAA can be easily recognized with a high accuracy of average absolute value discrepancy (4.93 degrees). Overall, 60.6% of cases had a discrepancy within 5 degrees of the true anteversion value, and 89.0% had a discrepancy within 10 degrees. In addition, it was found that this device can be easily attached to various models of rasping broach handles, without any difference in accuracy. Furthermore, the accuracy of the device was not affected by the stem placement angle (varus/valgus, or flexion/extension angle), or even if the knee joint on the affected side has OA.

Ranawat *et al.* have proposed the concept of combined anteversion (sum of acetabular anteversion and femoral anteversion) in THA for the first time [14], and Jolles *et al.* reported that when the combined anteversion deviates from 40–60 degrees, the dislocation rate increased [15]. Widmer *et al.* have determined that the ideal value is the sum of stem anteversion and 0.7*cup anteversion = 37.3 in the 3D model analysis [16]. In other words, stem anteversion, like cup anteversion, is an important factor in reducing postoperative complications of THA. There have been some reports stating that it is possible to set the cup anteversion with high accuracy at low cost by using the accelerometer-based portable navigation and mechanical navigator as opposed to using computer-assisted navigation [7, 9–13]. However, with regard to stem anteversion, there is almost no method for accurately determining the anteversion angle of the stem during surgery apart from computer-assisted navigation. Although the accuracy of stem anteversion using the gravity-guide reported by Fujihara *et al.* is 4.6 ± 4.1, it is necessary to attach the large device to the lower leg, and the procedure is complicated [22]. In addition, it cannot be used with various type of stems, and the accuracy in the OA of the knee on the affected side and influence of stem placement angle (varus/valgus or flexion/extension) is also unknown.

The stem anteversion is one of the important factors affecting the postoperative results of THA. However, because stem anteversion is influenced by the patient specific femoral anteversion, the level of femoral neck osteotomy, and the stem flexion/extension angle, it is often difficult to adjust stem anteversion during surgery, and it is likely to be different from that planned preoperatively. Dorr *et al.* reported that there is a wide variability in the SAA when the stem is set without using the computer-assisted navigation [23], and the surgeon's estimated anteversion often results in a discrepancy of 10 degrees or more. When measured by postoperative CT, of the 109 cases in their study in which the intended range of stem anteversion was 10 to 20 degrees and set using the surgeon's estimation, only 45% of them achieved 10–20 degrees, and 47% achieved less than 10 degrees, and 7% of cases had more than 20 degrees [24]. Sendtner *et al.* reported that stem anteversion ranged from – 19° retrotorsion to 33° antetorsion. Normal anteversion (10–15°) was present in 8.3% of patients, and the prevalence of abnormal stem antetorsion was 92% [25]. In addition, it is reported that the difficulty of intraoperative control of the SAA differs between the types of stems. Imai *et al.* have reported that the single tapered-wedge stem, described by Khanuja *et al.* [26], has a large adjustment range for the SAA. On the other hand, the fit-and-fill type stem has a small adjustment range for the SAA [27]. With the exception of our novel developed device, the computer-assisted navigation system may be the only way to measure the angle of stem anteversion during surgery accurately. Kitada *et al.* reported that the discrepancy between the SAA indicated by the navigation during surgery and the SAA measured using postoperative CT was 77% within 5 degrees and 97% within 10 degrees [6]. However, navigation is not available to many surgeons.

This study has the following strengths. First, an important aspect was that the affected side was scrutinized for the presence of OA of the knee. Many patients who undergo THA have OA of the knee on the same side. In this study, we showed that our device can be used with high accuracy regardless of the presence of OA of the knee. Additionally, the two markers were attached on the tibial ridge during epicondylar view Xp. The axis connecting the two points 5 cm above and below the center of the tibial ridge has been reported to coincide with the lower leg axis in 97% [20]. The tibial ridge line is easily palpable intraoperatively, and the addition of this Xp contributed to the increase in accuracy. Second, the postoperative CT evaluation in this study used three-dimensional templating software. Stem anteversion, varus/valgus and extension/flexion angles were measured with high accuracy.

Our study had a few limitations. First, in order to match the tibial ridge line of the lower leg to the direction of the center of gravity during surgery, the surgeon's assistant held the weighted chain and the tibial ridge line in parallel, but a possible discrepancy may have occurred because they were visually aligned. Second, there may be differences in the final rasp and real stem placements, resulting in discrepancies.

Conclusions

The SAA measuring device used in our study could be extremely useful because it can easily and accurately measure the SAA during THA and can be used regardless of the type of stems. Therefore, it could be a simple, economical, noninvasive, and useful alternative tool to computer-assisted navigation for performing THA according to the combined-anteversion theory.

Abbreviations

THA: total hip arthroplasty

SAA: stem anteversion angle

CT: computed tomography

UMIN: University Hospital Medical Information Network

OA: osteoarthritis

KL: Kellgren and Lawrence

Declarations

Ethical approval:

This study protocol was approved by the institutional review board.

Consent for publication:

All authors agree for the publication.

Competing interests:

not applicable

Conflict of Interest:

The authors declare that they have no conflict of interest.

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Authors' contributions:

KI- planning, operation & writing; YO- data collecting; YM- recruiting patients; AK- evaluating; HN- directing.

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Figures

Figure 1

(a) The device and the weighted chain. The stem-anteversion angle (SAA) measuring device has an in-built marker that is always pointed in the direction of the center of gravity. (b) The device can easily be attachable to the various types of rasping broach handles. (c) The intraoperative SAA was indicated by the device marker, when the surgeon's assistant holds the lower leg so that the weighted chain (the direction of the center of gravity) and the lower leg (tibial ridge line that fingers pointed out) are parallel to each other.

Figure 2

The way to take a preoperative epicondylar view. (a) two metal markers attached 5 cm above and below the center of the tibial ridge. (b) 1mm metal marker in the center of 20mm acrylic plate. (c) Positioning of the patient for taking XP. (d) The white arrow indicates the correction angle, consisted of the perpendicular line of the tibial ridge (lower leg) axis and the posterior condylar axis. Two metal markers within the solid line of the white circle. The red dotted line shows the tibial ridge line.

Figure 3

Stem alignment determined by 3D templating software with computed tomography. (a) AP view for the varus angle (b) Lateral view for the flexion angle. The blue dotted line shows the axis of the femoral axis, and the red solid line shows the stem axis. Varus or flexion angle is calculated from the angle between the two lines. (c) Axial view. The blue dotted line shows the posterior condylar line (table top plane) and the red solid line shows the stem neck axis. The anteversion angle is calculated from the angle between the two lines.

Figure 4

The distribution of the correction angle formed by the perpendicular line of the tibial ridge line and the posterior condylar axis of the femur in the preoperative epicondylar view. The correction angle was a positive value (femoral-tibial articular surface lateral space was larger than medial space) in all cases.