Arthroplasty Today 18 (2022) 89–94

Contents lists available at ScienceDirect

Arthroplasty Today

journal homepage: http://www.arthroplastytoday.org/

Original Research

Referencing the Tibial Plateau With a Probe Improves the Accuracy of the Posterior Slope in Medial Unicompartmental Knee Arthroplasty

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A R T I C L E I N F O

Article history:
Received 24 May 2022
Received in revised form 12 August 2022
Accepted 28 August 2022
Available online xxx

Keywords:
Posterior tibial slope
Referencing method
Probe
Medial tibial plateau
Accuracy
Medial unicompartmental knee arthroplasty

A B S T R A C T

Background: There is currently no consensus on intraoperative references for determining the posterior tibial slope (PTS) in medial unicompartmental knee arthroplasty (UKA). The medial tibial plateau could serve as a direct reference for determining the native PTS through the placement of a hook probe in the anteroposterior direction of the medial tibial plateau. This study aimed to examine the accuracy of this new referencing method.

Methods: We consecutively performed 55 medial UKAs using our new method (study group), and the preoperative and postoperative PTS on lateral knee radiographs were examined. These outcomes were then compared with those of consecutive 50 medial UKAs performed using the conventional method (control group), which immediately preceded the start of the use of the new method.

Results: The correlation coefficient between the preoperative and postoperative PTS of the study group was larger than that of the control group (0.887 and 0.482, respectively). The mean implantation error of the PTS in the study group was smaller than that of the control group ($-1.1^\circ \pm 1.3^\circ$ and $-3.0^\circ \pm 3.2^\circ$, respectively; $P < .0001$). The percentages of knees within 2° of implantation error were 73% and 34% in the study and control groups, respectively ($P < .0001$). The root mean square errors in the study and control groups were 1.7° and 4.3°, respectively.

Conclusions: The direct referencing method with a probe can significantly improve the accuracy of tibial sagittal alignment.

Introduction

Unicompartmental knee arthroplasty (UKA) is an excellent treatment alternative to total knee arthroplasty in patients with unilateral compartment knee osteoarthritis (OA) [1]. Despite the success of the procedure, studies have reported that UKA is associated with higher revision rates after the surgery than total knee arthroplasties [2-4]. Early failure of UKAs may be due to errors in component alignment and its procedure being technically demanding, especially when minimally invasive surgical approaches are used [5-7]. Sixty percent of the components may be misaligned in the frontal plane by >2° from the preoperative plan with conventional instrumentation methods [8], and the placement of tibial implants in a high degree of varus can result in early failure [5,8,9]. In the case of sagittal alignment of the tibia, early failures have been linked to an excessive posterior tibial slope (PTS) [10,11]. Additionally, aseptic loosening of tibial implants is the leading cause of UKA revision [12], and implant alignment and fixation have been reported to affect clinical outcomes [11].

For a conventional surgical procedure of UKA, the frontal and sagittal alignment of the tibial implant is determined by aligning the cutting block of the tibial extramedullary guide parallel to the native tibial slope in the frontal and sagittal planes, respectively, [13]. Through minimally invasive approaches, surgeons determine the PTS by observing only the anterior half of the medial tibial plateau (MTP) because the entire MTP cannot be exposed owing to

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https://doi.org/10.1016/j.artd.2022.08.017

the retention of the anterior cruciate ligament. Otherwise, they align the vertical rod of the guide parallel to the tibial or fibular shaft axis observing the lateral aspect of the leg and cut the proximal tibia along a posterior inclination of 5° or 7° built in the cutting block. However, it is difficult to identify correctly the sagittal axes of the tibia or fibula on an operating table, further complicating the accurate placement of the tibial implant based on the native PTS or the PTS of a preoperative plan [5,6,9].

Computer navigation and robotic assistance have been introduced to reduce the number of outliers and improve the accuracy of the placement of UKA implants compared to the preoperative plan [8,14]. Computer navigation improved lower-limb alignment after medial UKAs but did not lead to a better tibial implant alignment than the conventional method [14-16]. Robot-assisted surgeries were, therefore, introduced to further improve and enhance the accuracy of bone preparation, even for minimally invasive techniques [7,8,17-19]. However, the availability of these technologies to all patients undergoing UKA is limited.

Recently, using preoperative computed tomography (CT) and magnetic resonance image (MRI) data of patients who underwent medial UKA, we proposed that the MTP can be used as a direct reference to recreate the native PTS by placing a hook probe in the anteroposterior (AP) direction on the MTP [20,21]. This study aimed to determine the error and variance of PTS in medial UKA using a minimally invasive approach when using this new referencing method of the MTP. Our hypothesis was that this new method can significantly improve the accuracy of the PTS in medial UKAs compared to the conventional alignment method.

material and methods

Patients

A senior surgeon (M.A.) determined the indication for a medial UKA for all patients and performed all the surgeries in this study. The patient selection followed the criteria recently reported by Seng et al. [22], which are beyond the classical indication of UKA proposed by Kozinn and Scott [23]. That is, the criteria in this study included predominant medial compartment disease, negative anterior drawer sign, femorotibial angle (FTA) less than 190° on a standing radiograph, and flexion deformity less than 15°. Knees with inflammatory arthritis, posterior depression of the subchondral bone of the MTP on a lateral radiograph, advanced patellofemoral OA, and lateral compartment OA with joint space narrowing were not considered for UKAs. Preoperative MRI examination of all knees was performed to confirm the indication for surgery. Between January 2021 and March 2022, 55 consecutive knees that met the criteria were enrolled as our study group. All knees underwent a medial UKA using the new referencing method to determine the PTS. The mean age of the patients was 74.9 ± 9.1 years (range: 48-89 years), with 16 men and 39 women. The severity of OA was grade 2, 3, and 4 in 16, 29, and 10 patients, respectively. The mean preoperative FTA on standing AP radiographs was 180.3° ± 3.1°, and the mean preoperative PTS was 9.8° ± 2.9° (Table 1). Our control group consisted of consecutive 50 medial UKAs performed with the conventional method. The surgeries in the control group were performed between October 2019 and December 2020. The mean age of the patients in the control group was 74.0 ± 8.5 years (range: 45-90 years), with 19 men and 31 women. The severity of OA was grades 2, 3, and 4 in 17, 27, and 6 patients, respectively. The mean preoperative FTA was 179.8° ± 3.3°, and the mean preoperative PTS was 10.2° ± 3.1° (Table 1). Patient demographics were not statistically different between the 2 groups (Table 1).

Surgical technique

All surgical procedures were performed through a medial mini-parapatellar skin incision and arthrotomy that extended from the upper pole of the patella to the proximal end of the tibial tubercle [24,25]. A fixed-bearing-type implant with a metal-backed tibial tray (Tribrid UKA system; Kyocera Corp., Kyoto, Japan) was cemented into place. The operation was performed using the "tibia-cut first and spacer block" technique. First, the substitute AP line of the tibia [26] was drawn on the MTP to pass through the medial tibial eminence and the medial edge of the patellar tendon at the joint level. Subsequently, a vertical bone cut of the MTP with an oscillating saw was performed along the base of the medial tibial eminence along the AP line. In the study group, a special hook probe was placed in the AP direction on the medial second quarter of the MTP [21] (Fig. 1a). PTS was determined by setting a gauge inserted into the cutting slot parallel to the probe placed on the MTP (Fig. 1b). If large anterior and/or posterior osteophytes were observed on the preoperative lateral knee radiograph, preoperative MRI was checked to know whether the osteophyte(s) had a significant influence on the placement of the probe. However, there was no knee excluded from the study group due to this matter (Fig. 1c). In the control group, the surgeon set a gauge inserted into

Table 1
Demographic data of the control and study group.

Demographics	Control group (n = 50)		Study group (n = 55)		*P*
	Mean (SD)	Range	Mean (SD)	Range	
Age	74.0 (8.5)	45-90	74.7 (9.0)	48-89	.627
Height	156.3 (8.9)	140-174	155.8 (8.0)	143-172	.590
BMI	26.1 (3.8)	16.6-35.8	25.02 (3.7)	16.5-34.3	.130
Gender					
Male	19		16		.663
Female	31		39		
Disease					
OA (Osteoarthritis)	44		47		.976
SPONK (Spontaneous Osteonecrosis Of The Knee)	6		8		
OA grade (Kellgren-Lawrence)					
2	17		16		.988
3	27		29		
4	6		10		
Preoperative FTA	180.3 (3.1)	174-189	180.3 (3.1)	174-188	.159
Preoperative PTS	10.2 (3.1)	2.1-16.6	9.8 (2.9)	4.6-16.9	.198

BMI, body mass index; SD, standard deviation.

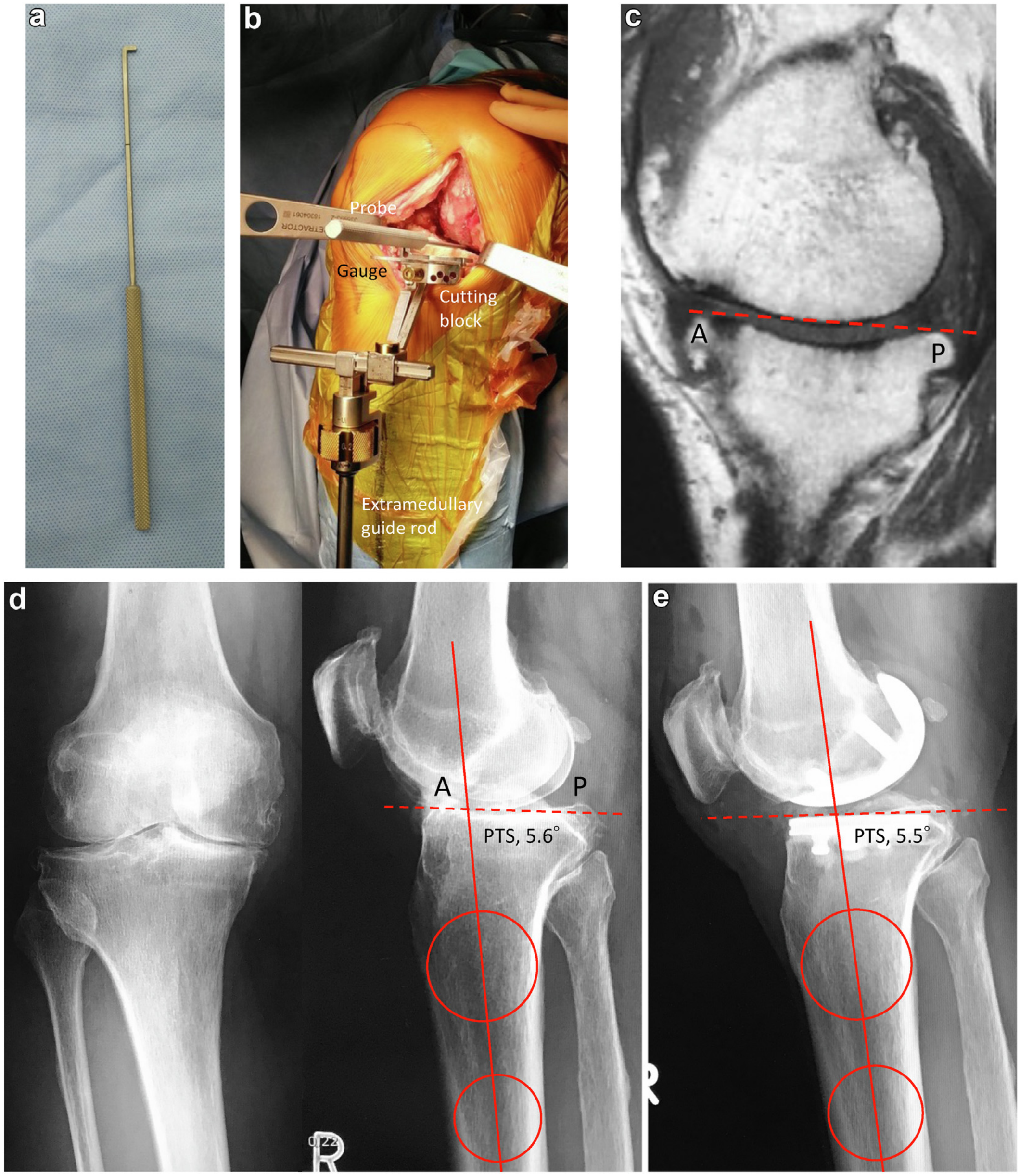

Figure 1. (a) A hook probe manufactured for the new referencing method to indicate the native posterior tibial slope (PTS) was placed on the medial second quarter of the medial tibial plateau (MTP) in the anteroposterior (AP) direction. (b) The PTS in the study group was determined by setting a gauge inserted into the cutting slot of the extramedullary guide parallel to the axis of the probe. (c) When large tibial marginal osteophytes were observed on the preoperative lateral knee radiograph, it was confirmed that the anterior (A) and/or posterior (P) osteophytes on the medial second quarter of the MTP did not disturb the placement of the probe using the preoperative magnetic resonance imaging (MRI). This case had the largest osteophytes in the study group. (d) Preoperative lateral knee radiographs showing anterior (A) and posterior (P) large osteophytes. The preoperative PTS was 5.6°. See the section "Angular measurements on the preoperative and postoperative lateral knee radiograph". (e) The postoperative PTS was accurately recreated with 5.5°.

the cutting slot parallel to the native MTP by visual observation while avoiding excessive PTS.

Angular measurements on the preoperative and postoperative lateral knee radiograph

PTS was defined as the posterior inclination of the plateau relative to the proximal anatomical axis of the tibia, and preoperative and postoperative PTS on a lateral knee radiograph were measured according to a previously reported method [27]. Briefly, a line passing through the center of 2 circles located over the AP width of the tibia was drawn, and the proximal anatomical axis was defined. The preoperative native PTS and postoperative tibial implant PTS were measured (Fig. 1d and e, respectively). The angle was measured to 1 decimal point using an image analysis software program (PACS system FABRICA Ver. 1.0.0.23; Cure Hope Corp., Osaka, Japan). Lateral knee radiographs that most closely matched the preoperative radiographs in terms of rotation were chosen for measurements. A positive value was given to the angle of the difference if the postoperative implant PTS was larger than the preoperative native PTS.

Statistical analysis

All angular measurements on lateral knee radiographs were independently performed twice, with an interval of more than

2 weeks, by 2 observers (M.A. and A.M.), and the mean of 4 measurements was considered a true value. The intraclass correlation coefficient (ICC) for intraobserver agreement with regard to the angle measurements of the PTS was determined. The ICCs of each observer in the control group were 0.964 and 0.975 for the preoperative PTS, respectively, indicating excellent agreement between the measurements. The ICC for interobserver agreement (Pearson correlation coefficient) between the 2 observers was 0.842. The results are presented as the mean ± standard deviation and were processed using Microsoft Excel 2016 (Microsoft Corp., Redmond, WA). Differences between the results were evaluated using unpaired or paired t-tests. An F-test was used to compare the variability of the 2 samples. A Pearson's correlation analysis was performed to analyze the relationship between the 2 angle measurements. The chi-squared test was used to compare categorical data. The root mean square (RMS) error was used to evaluate the accuracy of the 2 groups.

Results

In the study group, the mean angles of the preoperative and postoperative PTS were 9.8° ± 2.9° and 8.7° ± 2.7°, respectively. The mean angle of the postoperative PTS was significantly smaller than that of the preoperative PTS ($P < .0001$, n = 55). In the control group, the mean angles of the preoperative and postoperative PTS were 10.2° ± 3.1° and 7.2° ± 3.2°, respectively. The mean angle of the postoperative PTS was significantly smaller than that of the preoperative PTS ($P < .0001$, n = 50) (Fig. 2a). The correlation coefficient between the preoperative and postoperative PTS in the study group was larger than that of the control group (0.887 and 0.482, respectively; $P < .0005$) (Fig. 2b).

The absolute value of the mean implantation error of the postoperative PTS in the study group was smaller than that of the control group (−1.1° ± 1.3° and −3.0° ± 3.2°, respectively, $P < .0001$). The variance in the difference between the preoperative and postoperative PTS in the study group was smaller than that in the control group ($P < .0001$) (Fig. 3a). The percentage of knees within 2° of the implantation error of the PTS in the study group was significantly larger than that of the control group (73% vs 34%, $P < .0001$). The percentage of knees with more than 4° of error in the study group was significantly smaller than that of the control group (0% compared with 38%, $P < .0001$) (Fig. 3b). The RMS errors of the postoperative implant PTS relative to the preoperative PTS in the study and control groups were 1.7° and 4.3°, respectively.

Discussion

The PTS is an important anatomical feature that influences cruciate ligament function, sagittal plane stability of the knee, and knee kinematics [10,28-30]. Therefore, accurate recreation of the native anatomical morphology of the PTS with a tibial implant is important for postoperative knee function, knee kinematics, and longevity [13,31]. Different anatomical references on the lateral knee radiograph, including the sagittal mechanical axis and the proximal axis of the tibia and the anterior or posterior cortical line of the proximal tibia, have been used in relevant studies in order to measure PTS. Therefore, caution should be exercised regarding which radiological anatomical reference is used to measure the PTS in each study. For example, the PTS relative to the posterior cortical line of the tibia is 3° smaller on average than that to the sagittal mechanical axis or sagittal proximal axis of the tibia [32]. In the present study, the PTS was defined as the posterior inclination of the plateau relative to the sagittal proximal axis of the tibia on the lateral knee radiograph and was measured according to the method previously reported by Plancher et al. [27] because the PTS relative to the sagittal proximal axis of the tibia closely resembles that of the sagittal mechanical axis [32].

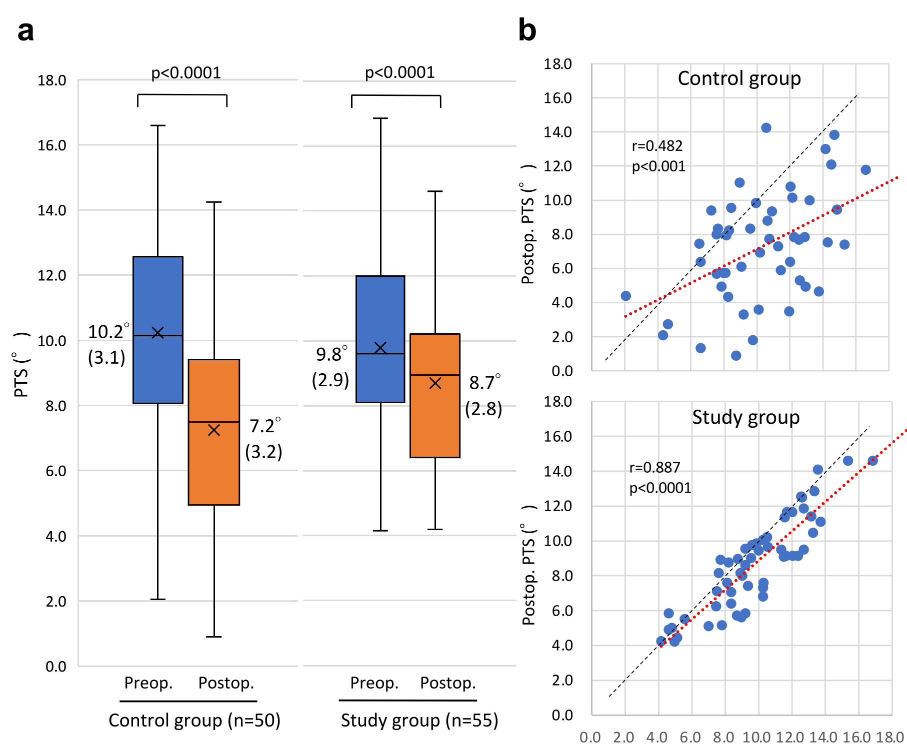

Figure 2. (a) Box plots of the preoperative and postoperative PTS in the control group (left) and in the study group (right). (b) Scatter plots showing correlation between the preoperative and postoperative PTS in the control group (upper) and in the study group (lower). A black line and a red dotted line mean y = x and linear regression, respectively.

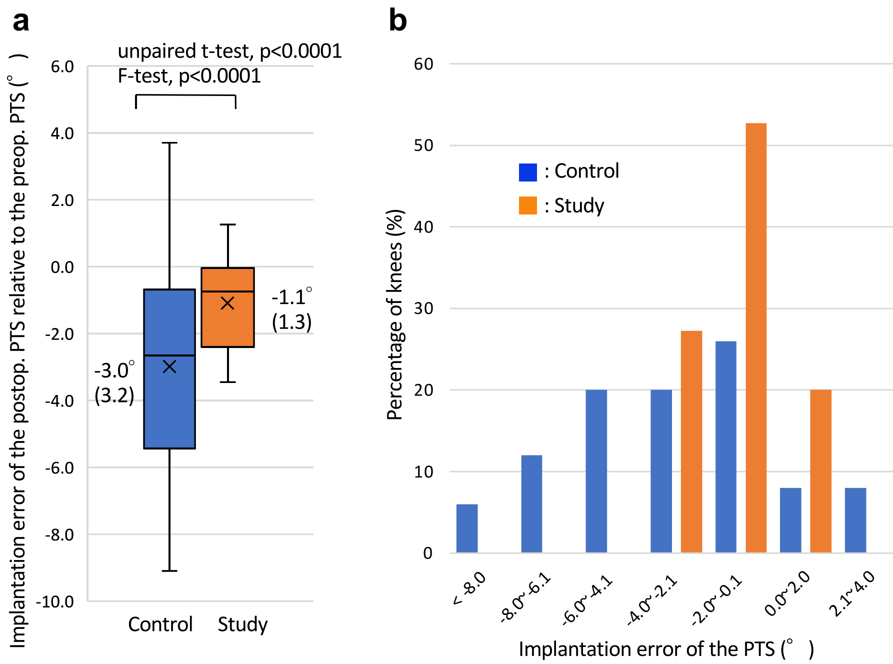

Figure 3. (a) Box plots of the implantation error in degrees on the postoperative PTS relative to the preoperative PTS in the control group (left) and in the study group (right). (b) Distribution of implantation error of the PTS in the control group (blue bar) and in the study group (orange bar).

Additionally, wide variations in PTS for both normal and arthritic knees have been reported. Faschingbauer et al. reported a PTS of 8.5° ± 3.2° (range: 1.0°-16.7°) on lateral knee radiographs [33]. Using preoperative 3-dimensional CT data, Nunley et al. reported that the medial PTS relative to the mechanical axis was 6.8° ± 3.3° (range: −9.8° to 16.8°) and demonstrated that routinely targeting a 5°-7° PTS in UKAs will create a PTS less than that in a patient's native anatomy in 47% of patients [34]. Ho et al. reported a medial PTS of 11.3° ± 3.2° (range: 2.7°-19.7°) using CT data [35]. In the current study, the mean preoperative medial PTS in all knees in both groups was 10.0° ± 3.0° (range: 2.1°-16.9°, n = 105), which resembles those in other publications [34-36]. To achieve physiological knee function, the tibial implant should be aligned to recreate a patient's native PTS. However, there is still no consensus on how to address the large variability in the preoperative native PTS although Chatellard et al. proposed that the implant PTS relative to the posterior tibial cortical line should not exceed 5° and the change in the PTS should not be >2° relative to the native value [11]. In this study, we set the target postoperative PTS to the preoperative native PTS, regardless of the variability in the individual PTS, and investigated the accuracy of the new referencing method.

The correlation coefficient between the preoperative and postoperative PTS in the study group was significantly larger than that of the control group. Furthermore, the inclination of linear regression was closer to 1.0 in the study group than that in the control group (0.843 and 0.494, respectively). These results indicate that the reproducibility of the preoperative PTS with the new referencing method was better than that of the conventional method. The percentages of knees with implantation errors over 2.0° and 4.0° in the study group were significantly lower than those in the control group. Bell et al. reported that the percentage of knees within 2° of the native PTS was 22% through the conventional method, while our study showed 34% [17]. The percentage of knees within 2° of the native PTS in the study group was 73%, which is almost equivalent to those reported in robot-assisted surgeries [17]. The RMS error of the postoperative PTS has been reported to be 3.1° to 4.6° in conventional methods [7,17,37], and ours was 4.3° for the control group, indicating that the surgical skill of the senior surgeon is comparable to that of others. Contrarily, the RMS error was 1.7° in the study group, which was within the range when a robot-assisted surgery was performed (range of the RMS error: 1.6° to 1.9°) [7,17,31,37,38] and slightly larger than that when the conventional method was used by an experienced high-volume surgeon (the RMS error: 1.5°) [13]. These results indicate that the axis of the hook probe placed on the medial second quarter of the MTP accurately reflects the preoperative native PTS and that surgeons can accurately reproduce the native PTS by referencing the hook probe in medial UKAs. Furthermore, if the surgeon wants to modify the PTS, they can use the probe axis as a standard to indicate the native PTS.

The mean postoperative PTS significantly decreased compared to the mean preoperative PTS in both the control and study groups. A postoperative increase in PTS is not preferred because it may place excessive loads on the anterior cruciate ligament and decrease the bone stock of the posteromedial condyle of the tibia, which can compromise the longevity of the tibial implant [10,11]. The mean postoperative decrease in the PTS of the study group was smaller than that of the control group. Additionally, the mean implantation error of the postoperative PTS relative to the preoperative PTS and the variability of the error in the study group were significantly smaller than those in the control group. The hook probe placed on the MTP can determine the PTS of the tibial implant without leading to an excessive postoperative PTS.

This study had some limitations. First, there was no follow-up study on the clinical results because of the recent adoption of this method in our institute. Fifteen knees (27.3%) in the study group had a postoperative PTS >10°. It is necessary to determine whether the recreation of the native PTS in patients with a large PTS (>10°) will result in good knee function without compromising longevity. Second, we did not determine the reproducibility of angle measurements on lateral knee radiographs in terms of rotation. However, we believe that there was acceptable consistency in the angle measurements and that our interpretation and conclusions were not impaired. Third, caution should be exercised regarding the probe's flexibility. If the probe is thin and flexible, the axis of the probe cannot indicate the native PTS. We used a hook probe manufactured exclusively for our use (Fig. 1a). Fourth, the indication of a medial UKA for all patients was determined by the senior surgeon. Caution is needed for selection bias although the patient selection followed the recent criteria [22]. Finally, the study population was small, and the effects of sex differences were not evaluated. In addition, it is desirable to perform a direct comparison of this new referencing technique to either robotically assisted or other enabling technologies for confirming its accuracy.

Conclusion

This study indicates that the new referencing method with a hook probe placed on the medial second quarter of the MTP could reduce outliers and improve the accuracy of the PTS of the tibial implant, even for a minimally invasive approach. The accuracy of the postoperative PTS with this method may be comparable to that of the robot-assisted surgery and the conventional method in experienced high-volume surgeons. The hook probe could serve as a direct anatomical reference, indicating the native PTS in medial UKAs. Future midterm and long-term follow-up studies on the clinical results with this new method are needed.

Ethical review committee statement

Approvals for this study were obtained from the institutional review boards in our institutes (23-087, 02-007).

Conflicts of interest

M. Akagi is a paid consultant for Kyocera Medical Corp. and Smith & Nephew Japan and receives research support as a principal investigator from Kyocera Medical Corp., Zimmer Japan, and Smith & Nephew Japan. The other authors declare no potential conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2022.08.017.

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