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BASIC RESEARCH

Is the Medial Wall of the Intercondylar Notch Useful for Tibial Rotational Reference in Unicompartmental Knee Arthroplasty?

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Abstract

Background It is difficult to implant components in the correct rotational position in the narrow operating field in a unicompartmental knee arthroplasty. Although no rotational reference has been confirmed for unicompartmental knee arthroplasty, the AP axis of the tibia may serve as a reference for unicompartmental knee arthroplasty and TKA. However, it is difficult to identify the AP axis during unicompartmental knee arthroplasty, especially with the tibia first-cut technique.

Questions/purposes We explored whether the medial wall of the intercondylar notch could be useful for the tibial rotational reference as an alternative to the AP axis in unicompartmental knee arthroplasty.

Methods We scanned the knees of 24 healthy Asian patients (45 knees) at a flexion angle of 90° using open MRI, then measured the angle between the AP axis and the medial wall of the notch. We determined whether the origins of the ACL and PCL were located lateral to the line on the medial wall of the notch and whether the mediolateral dimension of the bone cut surface of the medial tibial plateau was wide enough relative to the AP dimension to use the commercially available unicompartmental knee arthroplasty tibial components when the tibia was cut parallel to the medial wall of the notch.

Results At 90° flexion the medial wall of the notch was externally rotated 0.1° ± 4.4° relative to the AP axis. In all knees, the ACL and PCL were located lateral to the line on the medial wall of the notch. The mediolateral dimension of the bone cut surface was wide enough to use the commercially available tibial components.

Conclusions At 90° flexion the medial wall of the intercondylar notch is almost parallel to the AP axis of the tibia at and we believe a reasonable candidate for a rotational reference of tibial placement in unicompartmental knee arthroplasty. This landmark would need to be confirmed in other populations and in patients with osteoarthritis.

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Each author certifies that his or her institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.
This work was performed at Department of Orthopaedic Surgery, Graduate School of Medical Sciences, Kyushu University.

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Introduction

Unicompartmental knee arthroplasty (UKA) relieves pain in most patients with localized osteoarthritis of the knee [4, 6, 7, 23, 28, 31]. Accuracy of implant positioning and reconstruction of the mechanical leg axis are major requirements for avoiding aseptic loosening and polyethylene wear [12, 17, 18, 24, 34]. However, compared with coronal and sagittal alignment of the knee, it is difficult to implant components in the correct rotational position in small operating fields, particularly with mini-incision surgery.

For TKA, some surgeons recommend rotationally aligning a femoral component with the surgical epicondylar axis (SEA, the line connecting the tip of the lateral epicondyle to the medial epicondylar sulcus) [5, 21, 35]. However, no rotational reference has been confirmed as accurate for UKA. The positional relationship between the femoral and tibial components would be the most important factor for rotational alignment in UKA. When the rotational alignment of the femoral component is aligned parallel to the tibial cut surface in flexion of the knee, one would expect the femoral component would be aligned to the SEA in UKAs and TKAs [2]. Given the femoral component is aligned to the SEA, the rotational alignment of the tibial component should be aligned to the SEA to avoid rotational mismatch with the femoral component in extension of the knee. However, the SEA cannot be readily identified in a small operating field, therefore, a reference perpendicular to the SEA would be useful for the rotational landmark of the tibia.

Tibial rotational alignment in UKA also is important in considering the direction of the sagittal cut of the tibia. Yoshioka et al. [35] suggested that the SEA is the functional transverse axis of the knee, and some authors have considered the coronal plane of the knee as the plane parallel to the SEA in their studies [9, 20]. The sagittal cut of the tibia should then be made perpendicular to the SEA when the coronal plane is considered as the plane parallel to the SEA.

There is no consensus regarding the correct rotational placement of the tibial component [11, 22, 27, 32]. We suggest the following requirements for correct placement: First, there must be no rotational mismatch with the femoral component in extension of the knee as described above. Second, the sagittal cut of the tibia should be made perpendicular to the coronal plane of the knee owing to its posterior slope if the tibial component is set neutral in the coronal alignment. If the tibial cutting guide is set externally rotated, a posteromedial slope (varus) will be produced, and vice versa [16]. Third, alignment of the tibial component should be just medial to the origins of the ACL and PCL to avoid damaging these fibers. Fourth, the tibial component should achieve sufficient coverage to obtain stability of the tibial component [26].

Given all the requirements for the tibial rotational reference in UKA, we suspected the AP axis of the tibia, described by Akagi et al. [1], can be used as a tibial rotational reference. The AP axis connecting the middle of the PCL to the medial border of the patellar tendon attachment is a reproducible and reliable line because it is perpendicular to the SEA. However, it is not easy to identify the middle of the PCL at the tibial attachment in the narrow operating field during a UKA, especially when surgeons make the tibial cut first. Consequently, anatomic references easily visible in the operating field are required as an alternative to the AP axis. We focus on the medial wall of the intercondylar notch since surgeons generally perform the sagittal tibial cut with a knee flexion angle of 90° [11] and can easily identify this reference during the procedure. However, it is unclear whether the medial wall of the intercondylar notch is useful as an alternative to the AP axis of the tibia in UKA.

We therefore addressed three questions: (1) is the medial wall of the notch parallel to the AP axis of the tibia at a 90°-flexion angle, (2) are the origins of the ACL and PCL located lateral to the line on the medial wall of the notch, and (3) is the mediolateral (ML) dimension of the bone cut surface of the medial tibial plateau wide enough relative to the AP dimension to use the commercially available UKA tibial components when the tibia is cut parallel to the medial wall of the notch?

Materials and Methods

We examined 45 knees in 24 healthy subjects who were recruited from the local community through direct advertisements based on a US Food and Drug Administration guide [33]. There were 15 men and nine women with a mean age of 32 years (range, 28–36 years). Twenty-two subjects were Japanese and two were Chinese. None had knee symptoms or history of injury. The clinical status and MRI for each subject showed no abnormalities in the menisci, cartilages, or ligaments. The subjects gave informed consent and agreed to participate in this study without payment. Our institutional review board approved this study.

The MRI system used in this study was an open MRI at 0.4 T (APERTO; Hitachi Medical Corporation, Tokyo, Japan). The MRI was open in the horizontal direction with a 38-cm vertical gap. The subject was placed on the table and asked to lie on the side of the knee being examined. To stabilize the trunk and leg during the procedure, we flexed the contralateral hip and knee over and anterior to the knee under examination (Fig. 1). We performed the procedure at a knee flexion angle of 90°. We chose this position so the subject felt a naturally flexed knee position without any feeling of internal or external rotation. We first measured the knee flexion angle using MR images in adjusting the knee position and finally measured the angle with MR images used in this study, and confirmed invariance of the knee position during testing. The knee then was scanned in the axial plane (TR/TE, 880 ms/19.0 ms; flip angle, 90°; field of volume, 200 mm; thickness, 2.0 mm), and MR images were taken as the DICOM data from the open MRI system server. An axial plane was defined perpendicular to the tibial mechanical axis. The MRI data were modified so

a computer program could be used (Real INTAGE V4.34; Cybernet Systems Co, Ltd, Tokyo, Japan).

We measured the angle between the AP axis of the tibia and the line on the medial wall of the intercondylar notch. We identified the medial border of the patellar tendon at the attachment level (Fig. 2A) and the middle of the PCL at the tibial attachment (Fig. 2B). The femoral condyle plane was the plane dividing the posterior femoral condylar surface and the center of the intercondylar notch in half (Fig. 3A). A line was drawn from the anterior edge of the wall to the posterior edge of the wall on the femoral condyle plane. The medial border of the patellar tendon and the middle of the PCL then were projected into the femoral condyle plane, and the angle between the AP axis and the line on the medial wall of the notch was measured (Fig. 3B). Additionally, we classified the contour of the medial wall of the notch on the femoral condyle plane as a flat, concave, or convex wall in relation to the line drawn from the anterior edge to the posterior edge of the wall.

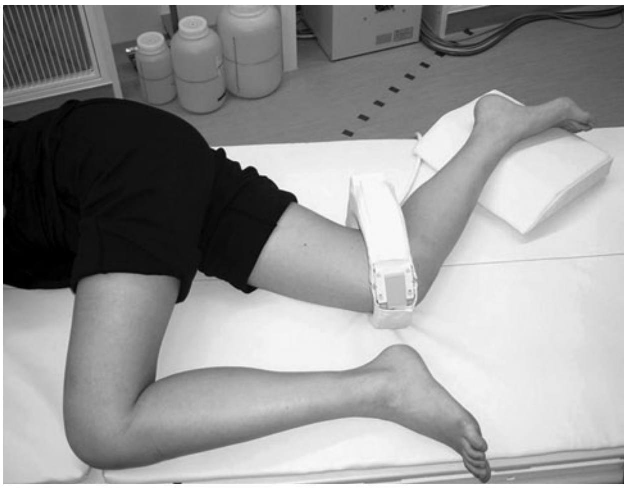

Fig. 1 The photograph shows how we scanned the knees at a knee flexion angle of 90°.

We evaluated the relationship between the origins of the ACL and PCL and the medial wall of the intercondylar notch. The medial borders of the ACL (Fig. 4) and PCL (Fig. 2B) were identified at the tibial attachment. The line on the medial wall of the notch was projected to the tibial plateau, which was defined as the tibial sagittal cut line. We examined whether the medial borders of the ACL (Fig. 4) and PCL (Fig. 5) at the tibial attachment were located lateral to this line.

We next assessed the extent of the medial tibial plateau, covered with the tibial component, when we cut the tibia along the line on the medial wall of the intercondylar notch. The tibial axial plane 8 mm distal to the surface plane of the tibial medial plateau was defined as the tibial cut plane [34] (Fig. 5). We projected the line on the medial wall of the notch to the tibial cut plane, and measured the

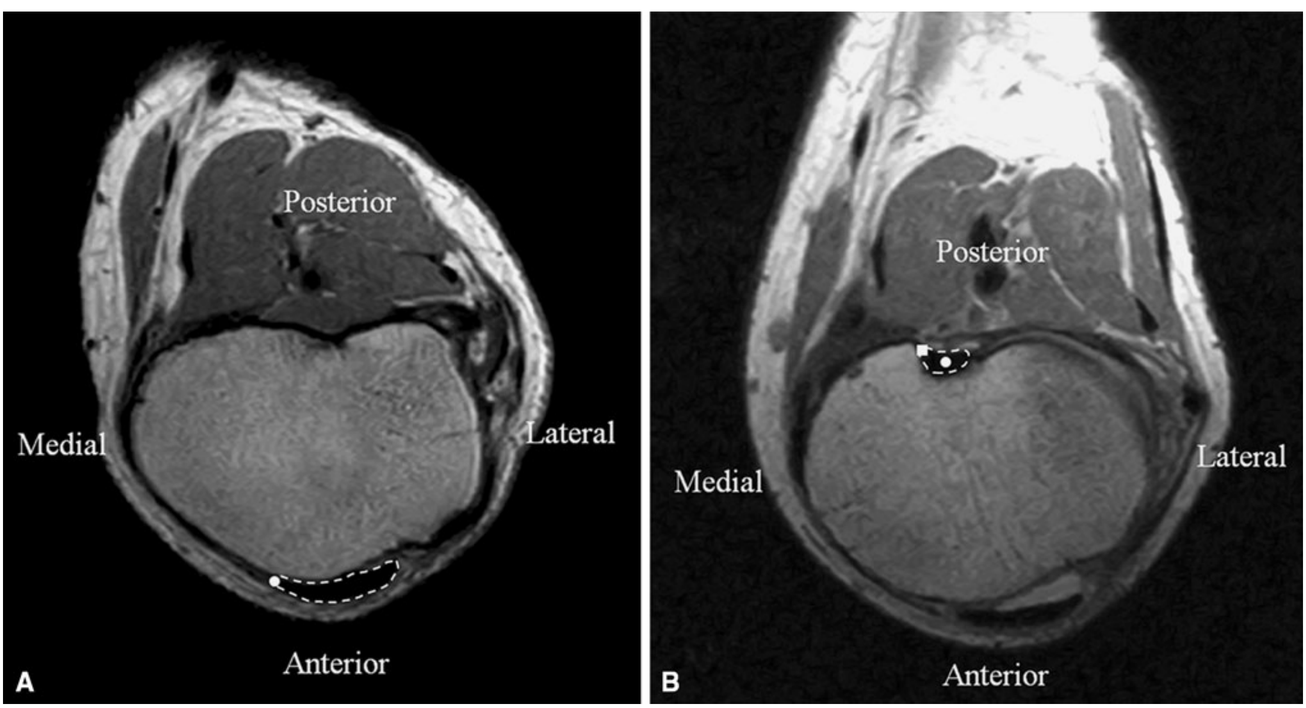

Fig. 2A–B MR images show (A) the medial border of the patellar tendon at the tibial attachment level (white circle) and (B) the middle (white circle) and medial borders (white rectangle) of the PCL at the tibial attachment.

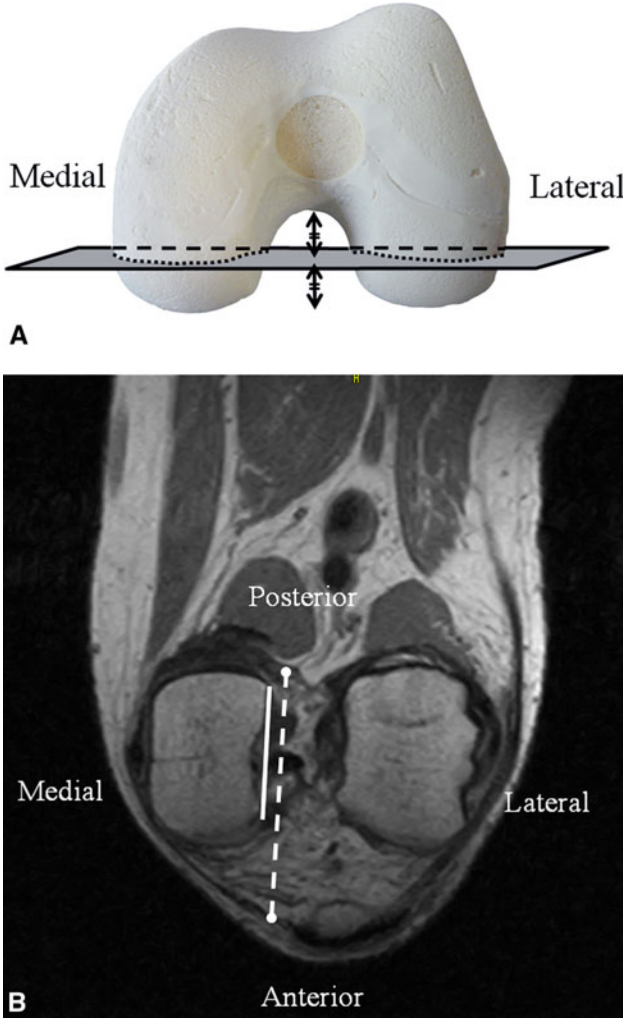

Fig. 3A–B (**A**) The photograph shows how we selected the femoral condyle plane (gray plane) as the plane dividing the posterior femoral condylar surface and the center of the intercondylar notch in half. (**B**) The MR image shows how the medial border of the patellar tendon and the middle of the PCL (two white circles, respectively) were projected into the femoral condyle plane. A line was drawn on the medial wall of the intercondylar notch (white solid line) and the AP axis of the tibia (broken line) and the angle between these lines was measured. The contour of the medial wall of the notch on the femoral condyle plane was classified as flat, concave, or convex in relation to the position of the line drawn from the anterior edge of the wall to the posterior edge of the wall.

AP and ML dimensions of the tibial cut plane using the image data processing software ImageJ (Open-source software; http://rsbweb.nih.gov/ij/; National Institutes of Health, Bethesda, MD, USA). The condylar aspect ratio (the ML dimension divided by the AP dimension × 100) [13, 30] was calculated and compared with that of the commercially available UKA tibial components (Table 1).

To confirm the reproducibility of the knee position during MRI scanning, we randomly selected five knees from the study group, scanned each three times, and measured the angles between the AP axis of the tibia and

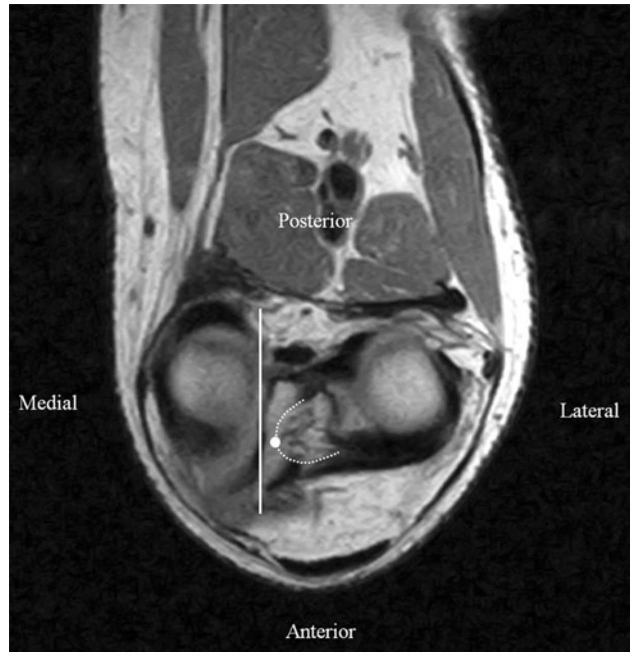

Fig. 4 The medial border of the ACL at the tibial attachment (white circle) is seen on this MR image. We projected the medial wall of the intercondylar notch to the tibial plateau (white solid line), then extended the line to determine if it intersected the medial border of the ACL.

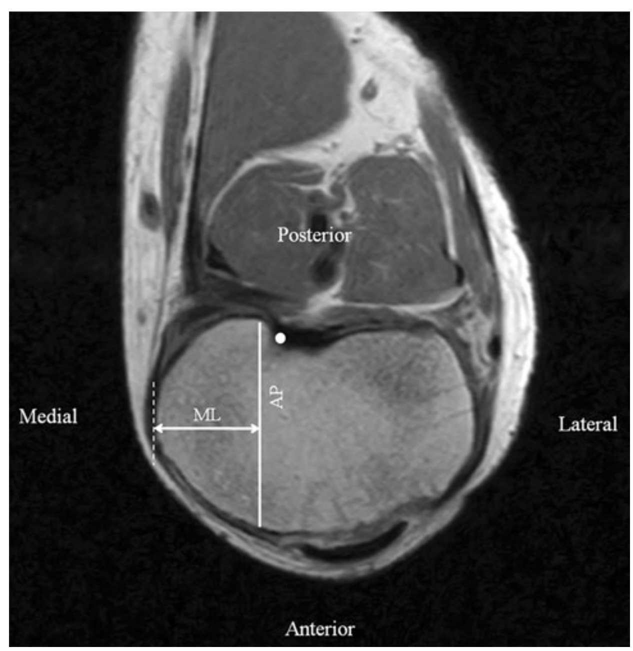

Fig. 5 The MR image shows how the medial border of the PCL at the tibial attachment and the medial wall of the intercondylar notch were projected to the tibial cut plane (white circle and white solid line, respectively). It then was determined if this line intersected the medial border of the PCL. The AP and ML dimensions of the tibial cut plane also were measured and the condylar aspect ratio (ML/AP × 100) was calculated.

Table 1. Conventionally available sizes* and condylar aspect ratio† of UKA tibial components

Oxford (Biomet)			Zimmer Unicompartmental (Zimmer)			Preservation (DePuy)		
AP (mm)	ML (mm)	ML/AP	AP (mm)	ML (mm)	ML/AP	AP (mm)	ML (mm)	ML/AP
45.2	24	53.1	41	23	56.1	41	20	48.8
45.4	26	57.3	44	25	56.8	45	23	51.1
48.6	26.2	53.9	47	27	57.4	49	26	53.1
51.8	28	54.1	50	29	58.0	53	29	54.7
55	29.8	54.2				57	32	56.1
58.2	31.6	54.3						

* AP and mediolateral (ML) dimensions; †ML/AP × 100; Biomet, Warsaw, IN, USA; Zimmer, Warsaw, IN, USA; DePuy, Warsaw, IN, USA.

the line on the medial wall of the intercondylar notch. A maximum difference between the angles of the same knee scans was less than 2°. To evaluate intraobserver and interobserver reproducibility, the measurement was performed three times by one examiner (SK) and once by two examiners (HN, SO) on the 10 knees randomly selected from the study group. An intraclass correlation coefficient and an interclass correlation coefficient were used to test the reproducibility. We performed an ANOVA under a general linear model procedure to calculate the intraclass and interclass correlation coefficients. The intraclass correlation coefficient among the three measurements conducted by the same observer (SK) was 0.92 for measurement of the angle between the AP axis and the line on the medial wall of the intercondylar notch. The interclass correlation coefficient was calculated from the data of the measurements of two of the observers (HN, SO) and the average of the three measurements of the other observer (SK), and 0.89 for measurement of the angle between the AP axis and the line on the medial wall of the intercondylar notch. Similarly, we also evaluated the intraobserver and interobserver reproducibility of the position of the AP axis. We measured the angle between the AP axis and the line fixed in the computer program window. The intraclass correlation coefficient was 0.95 and the interclass correlation coefficient was 0.90.

Results

The line on the medial wall of the intercondylar notch was almost parallel to the AP axis of the tibia. The line on the medial wall of the notch was 0.1° (± 4.4°) (range, 8°–9.1°) externally rotated relative to the AP axis (Fig. 6). The line on the medial wall of the notch was within 5° internal or external rotation relative to the AP axis in 33 of 45 knees (73.3%). The contour of the medial wall was located more medially from the line connecting the anterior and posterior edges of the wall in all the knees. Therefore, we classified all knees as concave.

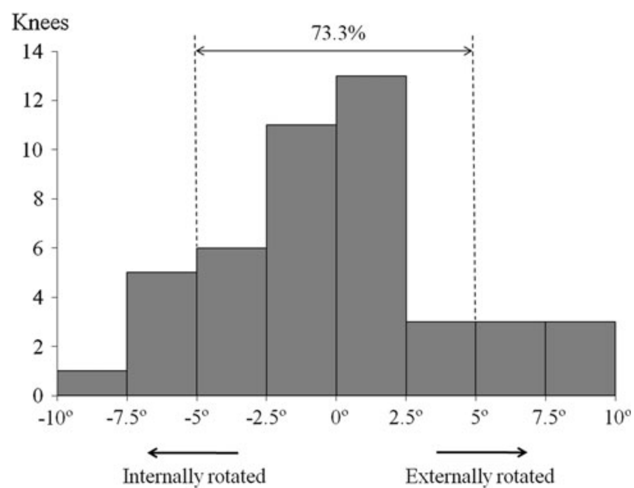

Fig. 6 A distribution histogram of the knees shows the amount of internal or external rotation of the medial wall of the intercondylar notch relative to the AP axis of the tibia.

The medial borders of the ACL and PCL at the tibial attachment were located lateral to the line projected from the medial wall of the intercondylar notch in all of the knees.

The condylar aspect ratio was 55.2% ± 3.6%, which was comparable to the commercially available market sizes of the UKA tibial components (Table 1); the ML dimension of the bone cut surface of the medial tibial plateau was wide enough to use the commercially available UKA tibial components.

Discussion

Accuracy of bone cutting and implant positioning based on anatomic references are major requirements for avoiding implant failure in TKA and UKA [12, 17, 18, 24, 34]. However, compared with coronal and sagittal alignment of the knee, there are no data for reliable rotational alignment of a UKA. Rotational alignment of the femoral component would be close to the SEA when it is adjusted to the tibial

cut surface with proper MCL tension [2]. Moreover, the SEA is a functional flexion-extension axis and considered an anatomic basis of the coronal plane of the knee reference [8, 9, 14, 20, 29], although the reliability of the SEA measurement has not been proven [3, 5]. We believe the AP axis of the tibia described by Akagi et al. [1] is the appropriate rotational reference of the tibia. Theoretically, there is no rotational mismatch between the femoral and tibial components in extension when surgeons use the AP axis as the rotational reference of the tibia. Additionally, the AP axis is perpendicular to the coronal plane of the knee when the coronal plane is considered as the plane parallel to the SEA [9, 20, 21, 35]. It is not easy to identify the AP axis during a UKA, especially when using the tibia first-cut technique. In the current study, we focused on the medial wall of the intercondylar notch, and examined the usefulness of the medial wall of the notch as an alternative to the AP axis of the tibia by answering three questions described above.

This study has some limitations. First, the study population was limited to Asian subjects. The data included in the current study might be typical for knees of Asian subjects, but there might be anatomic differences in other populations [15]. Therefore, one should interpret our findings with some caution when extrapolating to other populations and the observations would need to be confirmed. Second, the subjects in this study had normal healthy knees. However, in knees with medial unicompartmental osteoarthritis, the most common indication for UKA, the soft tissue components of the joint, especially the cruciate ligaments generally thought to help restore normal joint function and the articular surfaces of the lateral compartment, must be intact [10, 18, 19]. As UKA typically is indicated in patients with minimal deformity and osteophytes and nearly normal kinematics, we believe the measurements on healthy knees can be applied to most of these patients. Knees with substantial deformity would likely have much more variation in the medial wall and use in these patients would need to be confirmed in an appropriate study. Intercondylar osteophytes may be present in osteoarthritic knees. However, intraoperatively, surgeons can identify the medial wall of the intercondylar notch after resection of intercondylar osteophytes. Third, the leg position used in subjects in the current study might vary slightly from the actual leg position in UKA. In UKA, surgeons generally perform the tibial sagittal cut with the patient in the supine position with the knee flexed 90° [11]; however, we could not take MR images of the subjects in the supine position. In this study, open MRI was used to take images with the subjects' knees flexed 90° in the lateral position, and the repeated examination revealed no more than 2° difference between the tests. The positional relationship between the femur and tibia in the lateral leg position might differ slightly from that in the supine leg position.

The medial wall of the intercondylar notch was almost parallel to the AP axis of the tibia at midheight of the wall in our study subjects. The medial wall of the intercondylar notch was within 5° internal or external rotation relative to the AP axis in 73.3% of knees (33/45), and therefore we believe would be useful as an alternative to the AP axis for making the tibial sagittal cut. There has been no theoretical background for a reference of correct tibial rotation, although several methods have been proposed and used according to surgeons' preferences and experiences [11, 22, 27, 32]. Some suggest the sagittal cut on the tibia should be directed toward the center of the hip [11]; however, we are unaware of any published studies regarding the theoretical background of this technique, and the position of the center of the hip is difficult to locate intraoperatively. Some surgeons have recommended range-of-movement methods [22, 27, 32]. Manual flexion and extension, however, might cause varus, valgus, external, or internal rotation between the femur and the tibia with range-of-movement methods. A reliable and reproducible intraarticular anatomic reference parallel to the AP axis is still required, and our observations suggest the medial wall of the intercondylar notch is a candidate for an appropriate rotational reference of the tibia in UKA, although the accuracy of this technique was not compared with those of other techniques in our study. Additionally, one can draw the line on the medial wall easily because its contour is concave in all knees.

The medial borders of the ACL and PCL at the tibial attachment were located lateral to the line projected from the medial wall of the intercondylar notch in all of the knees, which fulfilled one of the important requirements for the tibial sagittal cut line. The PCL at the tibial attachment is not identified during a UKA in the narrow operating field; therefore, the medial wall of the intercondylar notch is useful as the reference that does not sacrifice the ACL and PCL.

A ML position of the tibial sagittal cut line is another important point for successful UKA when considering tibial component coverage [26]. Our data suggest the condylar aspect ratio of the tibial cut plane was 55.2% (± 3.6%), which is comparable to that for commercially available implants. The size of the tibial component generally is determined to fit the AP dimension of the bone cut surface of the medial tibial plateau, therefore, this means the ML dimension of the bone cut surface is wide enough to use the commercially available implants when surgeons use the medial wall of the intercondylar notch as the tibial sagittal cut line. Maximizing contact between the prosthesis and the bone helps widely distribute weightbearing forces to resist subsidence and loosening [25].

Our observations suggest the medial wall of the intercondylar notch is a reasonable candidate for aligning the tibial component rotation and an alternative to the AP axis of the tibia. The line on the medial wall was almost parallel to the AP axis, and the origins of the ACL and PCL were located lateral to the line on the medial wall of the intercondylar notch in all knees. The ML dimension of the tibial bone-cut surface is wide enough to use commercially available implants when surgeons use the medial wall of the intercondylar notch as the tibial sagittal cut line. This landmark would need to be confirmed in other populations and in patients with osteoarthritis.

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