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Anteroposterior Rotational References of the Tibia for Medial Unicompartmental Knee Arthroplasty in Japanese Patients

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ABSTRACT

Background: In unicompartmental knee arthroplasty (UKA), there is no consensus regarding how to determine the anteroposterior (AP) reference of the tibia. A number of surgeons in Japan perform the sagittal saw cut using the medial intercondylar ridge (MIR) of the tibia according to surgical manuals. However, there is no theoretical basis for this practice.
Methods: Preoperative computed tomography data from 32 lower limbs of 31 Japanese patients who received UKA were used. First, the angles between the surgical epicondylar axis and the MIR and the substitute AP (sAP) line connecting the medial border of the patellar tendon at the articular surface level and the medial intercondylar tubercle were measured. Next, the mediolateral (ML)/AP ratio of the tibial cut surface was measured when cut parallel to the MIR and sAP line. Finally, the ML/AP ratio of the tibial component was investigated in 4 contemporary UKA implants.
Results: The MIR and sAP line were externally rotated $94.9^\circ \pm 4.1^\circ$ and $90.4^\circ \pm 3.6^\circ$ relative to the surgical epicondylar axis, respectively. Compared with a cut parallel to the MIR, the mean ML/AP ratio of the cut surface was significantly larger, and the ML/AP ratio was closer to the ML/AP ratio of the components for a cut parallel to the sAP line.
Conclusion: Obtaining the tibial AP orientation is one of the key steps not only in total knee arthroplasty but also in UKA. The sagittal cut referencing the sAP line provides better AP rotation and fitting of the tibia in UKA than referencing the MIR.

Rotational alignment of the tibial component is important in both total knee arthroplasty (TKA) [1] and unicompartmental knee arthroplasty (UKA) [2,3]. The tibial anteroposterior (AP) line connecting the middle of the posterior cruciate ligament (PCL) to the medial edge of the patellar tendon (PT) attachment has been proposed for this alignment and is used in TKA [4,5]. However, it can be difficult to identify the tibial AP line in a modern mini-incision UKA because the PCL is barely visible or accessible in the small operating field. A manufacturer has suggested the medial intercondylar ridge (MIR) as an anatomical rotational reference of the tibial component, although without sufficient evidence [6–8]. According to these manuals, a number of surgeons in Japan including us perform the sagittal saw cut using the MIR as the tibial AP reference. To our knowledge, however, there is no theoretical basis for this practice. The MIR appears to be only one bony landmark for indicating the AP orientation on the tibial plateau, which can be identified as a linear peak connecting the medial intercondylar tubercle (MIT) and the medial brink of Parsons' knob [9,10] (Fig. 1A). However, it is not clear whether the MIR is perpendicular to the surgical epicondylar axis (SEA) or parallel to the tibial AP line [4,5].

In UKA, the tibial components must be sized and positioned properly so that the tibial cut surfaces are well covered without marked underhang or overhang and subsequent impingement of the surrounding soft tissues [11]. Rotational orientation of the

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Approval of institutional review board in our university hospital was obtained for this study (Approval No: 23-087).

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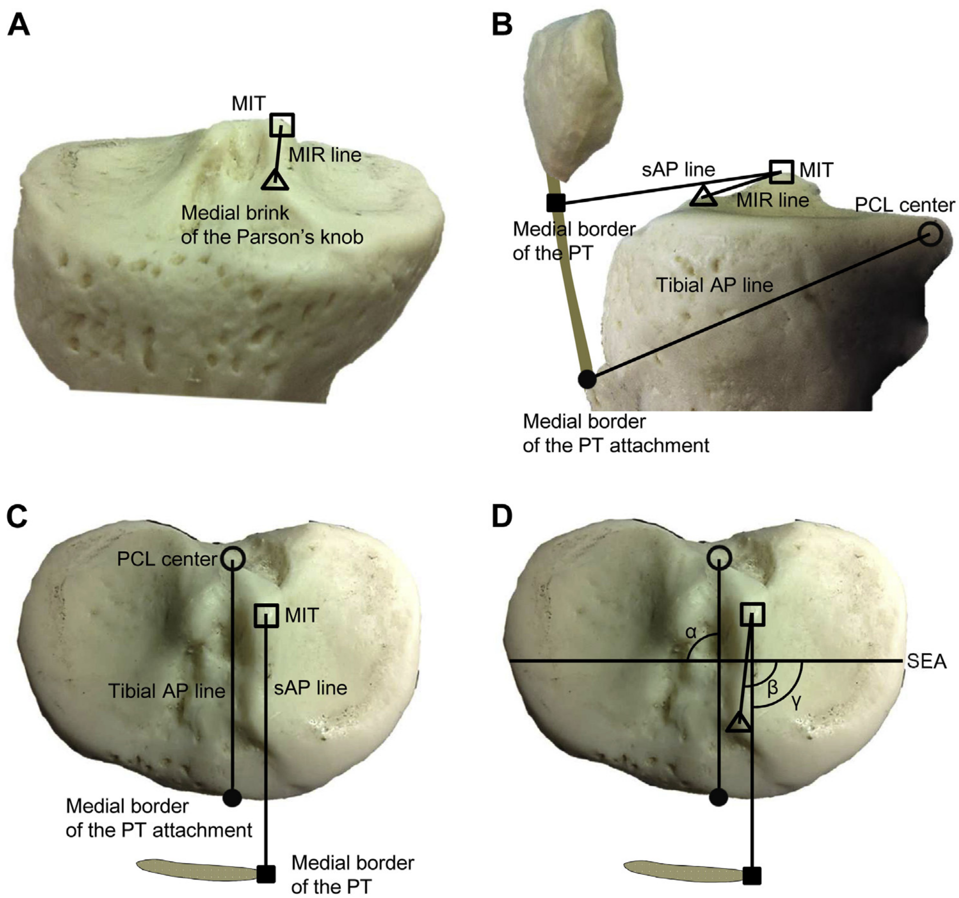

Fig. 1. Photographs showing the anatomical bony landmarks and the AP referencing lines on the tibial plateau. (A) Frontal view. The MIT, a medial brink of Parsons' knob, and the MIR line connecting the MIT and brink are shown. (B) Lateral view. The sAP line connecting the MIT and medial border of the PT at the articular surface level, the MIR line and tibial AP line connecting the PCL center and the medial border of the PT attachment to the tibia are shown. (C) Axial view. The tibial AP line and sAP line are shown. (D) The external rotation angle of the tibial AP line (α), MIR line (β), and sAP line (γ) relative to the SEA are shown. Open squares (□), MIT; triangles (△), brink of Parsons' knob; filled squares (■), medial border of the patellar tendon at the articular surface level; open circles (○), PCL center; filled circles (●), medial border of the patellar tendon attachment. AP, anteroposterior; MIR, medial intercondylar; MIT, medial intercondylar tubercle; PCL, posterior cruciate ligament; PT, patellar tendon; sAP, substitute AP; SEA, surgical epicondylar axis.

sagittal cut of the tibia can affect the coverage of the cut surface because external or internal rotational errors can result in a smaller mediolateral (ML) length of the tibial cut surface relative to the AP length. Underhang of the tibial cut surface may result in edge loading on the tibial polyethylene and insufficient bony support of the tibial component on the cut surface [12]. By contrast, medial overhang of the tibial component of 3 mm or more can significantly worsen the Oxford Knee Score and pain score [13]. A cadaveric study showed that a medial overhang of more than 2 mm increases the load to the medial collateral ligament, which is one possible cause of pain [14]. Actually, we have sometimes experienced medial overhang of the tibial component when the sagittal bone cut was performed parallel to the MIR.

In this study, we investigated whether the MIR is an appropriate reference for determining the AP orientation of the tibia in a medial UKA and, if not, whether there is an alternative AP reference of the tibia that is better than the MIR. First, we searched anterior anatomical landmarks to find alternative AP references when the MIT is used as a posterior landmark. After screening, we chose the medial border of the PT at the articular surface level as a good candidate for the anterior landmark and called this line made by these landmarks a substitute AP (sAP) line (Fig. 1B and C). We then compared the MIR and sAP line in terms of their angles relative to the SEA (Fig. 1D). We also examined whether the MIR or sAP line is a better AP reference for avoiding medial overhang.

Materials and Methods

Study Population

After obtaining approval from our institutional review board, we reviewed computed tomography (CT) data obtained for routine preoperative planning from 32 lower limbs in 31 Japanese patients. These patients were scheduled for consecutive primary UKA in our hospital between January 2015 and November 2015. All patients gave informed consent to allow use of their medical information for this retrospective study. The mean age of the patients was 73 years (range 59–87 years), and 10 knees were in men and 22 knees were in women. Twenty-eight knees were diagnosed with primary medial osteoarthritis (OA) and 4 knees with spontaneous osteonecrosis of the medial femoral condyle. In the radiographic assessment, the severity of OA according to the Kellgren–Lawrence classification [15] was grade 2 in 19 knees and grade 3 in the other 9 knees. Flexion contracture of the knee was less than 10°, and the hip–knee–ankle angle was less than 10° in all knees.

Image Technique

The CT scans were performed using a 64-row multislice CT system (LightSpeed VCT; GE Healthcare, Chalfont St. Giles, UK) in our hospital. The patients were positioned on the CT table in a

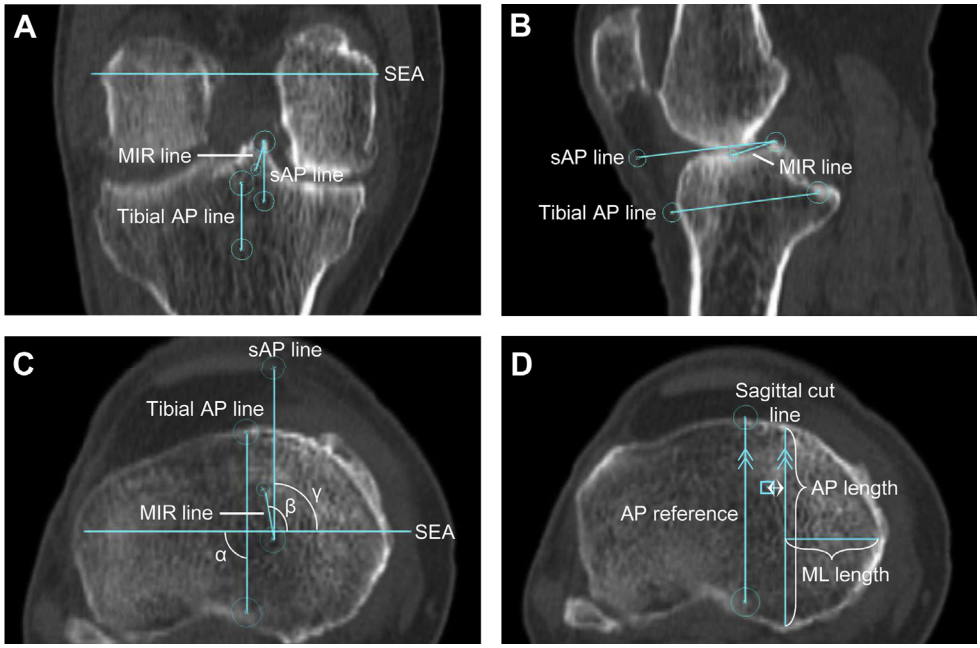

Fig. 2. Multiplanar reformation images used for determining the SEA, tibial AP line, MIR line, sAP line, and AP and ML lengths of the tibial cut surface. The SEA, PCL center, medial border of the PT attachment to the tibia, MIT, medial brink of Parsons' knob, and medial border of the PT at the articular surface level were identified using frontal (A), sagittal (B), and axial (C) multiplanar reformation views. (C) The SEA, tibial AP line, MIR line, and sAP line were projected onto the virtual tibial plateau, which was perpendicular to the tibial mechanical axis (TMA). The external rotation angle of the tibial AP line (α), MIR line (β), and sAP line (γ) relative to the SEA were measured. (D) The proximal tibia was cut 8 mm below the tibial plateau center cortex with a 3° medial slope and 7° posterior slope to the TMA. The sagittal cut line was set at a point 3 mm (arrow) medial from the brink of the knob (square) and parallel to each AP reference. The AP and ML lengths of the cut surface were then measured. ML, mediolateral.

supine position. Scans of 1.25-mm slices were performed from the hip joint to the ankle joint with the patient in the knee-extended position with the patella facing upward. The obtained DICOM datasets were imported into the 3-dimensional (3-D) preoperative planning software for TKA and UKA (3-D template for TKA and UKA; KYOCERA Medical Corporation, Osaka, Japan). In the software, the operating window comprises 3 multiplanar reformation viewers in the frontal, sagittal, and axial planes. Each reconstructed image can be simultaneously rotated, cut, and measured arbitrarily in all 3 operating windows. Three investigators performed all radiographic assessments and operated the software to measure the angles and lengths on a virtually cut surface of the proximal tibia.

Measurement of the AP Rotational Reference and the Tibial Cut Surface

The tibial mechanical axis (TMA), which passes through the center of the tibial eminence and the center of the talar dome, and the tibial AP line, which connects the middle of the PCL and the medial border of the PT attachment to the tibial tubercle [5], were defined (Figs. 1B, C and 2A-C). The tibia was verticalized along the TMA and frontalized along the tibial AP line. The line connecting the MIT and the medial brink of Parsons' knob was defined and designated as the MIR line (Figs. 1A, B and 2A-C). Parsons' knob is the anterior border of the anterior cruciate ligament tibial insertion [9,10]. The medial brink of Parsons' knob and the MIT just medial to the anterolateral bundle of the PCL are visible or accessible even in the small operating field used in medial UKA [16,17]. Next, the sAP line was devised to connect the medial border of the PT at the articular surface level and the MIT (Figs. 1B, C and 2A-C). The SEA connecting the tip of the lateral epicondyle and the medial epicondylar sulcus was defined according to the description of Berger et al [18]. The tibial AP line, MIR line, sAP line, and SEA were projected onto the virtual tibial cut surface, which was perpendicular to the TMA, and the angles made by these 4 lines were measured (Fig. 2C).

The proximal tibia was cut 8 mm below the tibial plateau center cortex with a 3° medial slope and 7° posterior slope to the TMA [19]. The tibial AP line, MIR line, and sAP line were projected onto the virtual tibial cut surface (Fig. 2D). The virtual sagittal cut of the tibia was performed so that the cut line passed at a point 3 mm medial from the medial brink of Parsons' knob and (1) parallel to the tibial AP line, (2) parallel to the MIR line, and (3) parallel to the sAP line (Fig. 2D). The ML and AP length of the tibial cut surface were measured by the software (Fig. 2D). The ML/AP ratio of the tibial cut surfaces was calculated when the sagittal cuts of the tibia were performed (1) parallel to the tibial AP line, (2) parallel to the MIR line, and (3) parallel to the sAP line. Any gender dimorphism of the ML/AP ratio for each item measured was assessed statistically. We recalculated the ML/AP ratios of the cut surface when the medial length of the tibial cut surface in each knee was elongated by 2 mm, assuming that a medial overhang up to 2 mm could be allowed.

Finally, we compared the ML/AP ratios of tibial components in the 4 contemporary UKA implants available in Japan: the Oxford knee (Zimmer Biomet, Warsaw, IN), Preservation (DePuy, Warsaw, IN), TRIBRID (KYOCERA Medical), and Zimmer Uni (Zimmer Biomet). We assessed the relationships between the ML/AP ratio of the tibial cut surfaces in the subjects in this study with those of the tibial components in the 4 implants.

Statistical Analysis

Intraclass and interclass correlation coefficients were calculated to examine the reproducibility of measurements. The angles made by the tibial AP line, MIR line, sAP line, and SEA, and all lengths on the virtual cut surface of the tibial plateau were measured 3 times

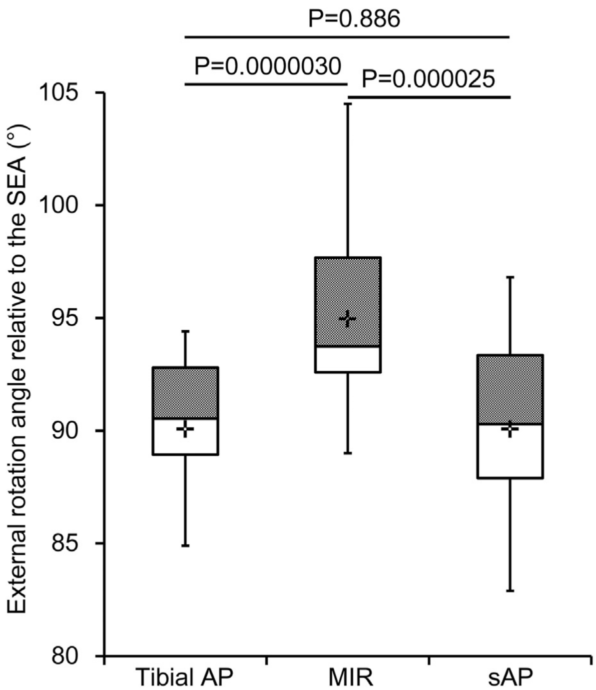

Fig. 3. Box plots showing external rotation angles of the tibial AP line, MIR line, and sAP line relative to the SEA. The mean external rotation angles of the tibial AP line and the MIR line were 90.3° ± 2.7° and 94.9° ± 4.1°, respectively. The MIR line was externally rotated by around 5° relative to the tibial AP line, and this difference was significant ($P < .0001$). The mean external rotation angle of the sAP line was 90.4° ± 3.6°. There was no difference between mean external rotation angles of the tibial AP line and the sAP line relative to the SEA ($P = .886$).

by 1 investigator and once by 2 investigators on the 10 knees randomly selected from the study subjects. The intraclass correlation coefficients between the 3 measurements made by the same observer were 0.98, 0.99, 0.98, 0.94, and 0.98 for measurement of the angle between the SEA and tibial AP line, the SEA and MIR line, and the SEA and sAP line and ML and AP length of the cut surface, respectively. The interclass correlation coefficient was calculated from the measurements of 2 of the investigators and the mean of the 3 measurements of the other observer. The coefficients of the angle and dimension were 0.97, 0.90, 0.97, 0.98, and 0.99, respectively. The interclass correlation coefficient was calculated from the measurements of 2 of the investigators and the mean of the 3 measurements of the other observer. The coefficients of the angle and dimension were 0.97, 0.90, 0.97, 0.98, and 0.99, respectively.

The results are presented as the mean ± SD and were processed using Microsoft Excel 2010 (Microsoft Corp, Redmond, WA) and 2 statistical calculating add-ins (Statcel 4; OMS Ltd, Saitama, Japan and Real Statistics Resource Pack software (Release 4.3); Copyright (2013-15) Charles Zaiontz; www.real-statistics.com). Differences between results were evaluated using a Student paired *t* test or Welch *t* test.

Results

The mean external rotation angles relative to the SEA of the tibial AP line, MIR line, and sAP line were 90.3° ± 2.7° (range 84.9°-93.5°), 94.9° ± 4.1° (range 89.5°-104.5°), and 90.4° ± 3.6° (range 82.9°-96.8°), respectively. The MIR line was significantly externally rotated by around 5° relative to the tibial AP line ($P < .0001$). There was no difference between the mean rotation external angles of the tibial AP line and the sAP line relative to the SEA ($P = .886$, Fig. 3).

The MIR lines that were externally rotated within 85°-95° accounted for 18 of 32 knees. The sAP lines that were externally rotated within 85°-95° accounted for 24 of 32 knees. There was no significant gender dimorphism between the mean angles between the tibial AP line and SEA, the MIR and SEA, and the sAP and SEA ($P = .59$, $P = .53$, and $P = .80$, respectively).

The mean ML/AP ratio of the tibial cut surface was 0.54 ± 0.048 (range 0.45-0.64) when cut parallel to the tibial AP line, 0.50 ± 0.043 (range 0.39-0.58) when parallel to the MIR line, and 0.54 ± 0.048 (range 0.45-0.64) when parallel to the sAP line (Fig. 4A). The mean ML/AP ratio was significantly larger when parallel to the tibial AP line and the sAP line than when parallel to the MIR line ($P < .001$ and $P < .001$, respectively).

There was no significant gender dimorphism of the ML/AP ratio when cut parallel to the tibial AP line, MIR line, or sAP line ($P = .58$, .50, and .54, respectively; Fig. 4B).

We investigated the ML/AP ratios of tibial components in 4 contemporary UKA implants. The ML/AP ratios ranged from 0.488-0.585 and tended to increase slightly as the AP dimension increased in all 4 implants (Table 1).

A scatter diagram of the ML/AP ratios of the tibial cut surface showed that the regression lines of the ratios when cut parallel to the tibial AP line and sAP line were located above the regression line of the ratios when cut parallel to the MIR line. The distribution of the tibial ML/AP ratios of the 4 implants were closer to the regression line when cut parallel to the tibial AP line and sAP line than when cut parallel to the MIR line (Fig. 5A).

When the medial length of the tibial cut surface in each knee was elongated by 2 mm assuming that a 2-mm medial overhang could be allowed, all tibial ML/AP ratios of the 4 implants were on or under the regression lines when the tibia was cut parallel to the tibial AP line and sAP line. By contrast, many of the ML/AP ratios of the tibial components were above the regression line when cut parallel to the MIR line (Fig. 5B).

Discussion

We acknowledge some limitations in the present study. The medial border of the PT at the articular surface level is subject to change because of internal rotation of the tibia with knee flexion (so-called medial pivot motion of the knee) because the CT scan in this study is performed in full knee extension. Although 1°-2° internal rotation of the sAP line is expected with knee flexion under non–weight-bearing condition [20,21], we believe that this angular error is small enough in our clinical practice. However, we recommend avoiding deep knee flexion and passive internal rotation of the tibia when using this rotational reference in UKA. In addition, the study population was limited to Japanese patients undergoing UKA. The angles between the MIR line and SEA, and the sAP line and SEA, and thus the relevant data obtained, might be different in other populations. We detected no gender dimorphism in this study, but this could be attributable to the small study population. Further studies in different and larger populations would be needed.

Although there is no consensus regarding how to determine the rotational alignment of the tibia, obtaining the correct AP orientation of the tibia is one of the key steps in the UKA surgical technique. Rotational alignment of the tibia can affect the varus and/or valgus alignment and the posterior slope of the tibia because the tibial proximal cut is performed using the extramedullary guide with a posterior slope. Inappropriate tibial rotation would increase risks of polyethylene bearing spinning out in the mobile-bearing UKA and excessive internal rotation of the sagittal saw cut can result in PCL fossa involvement with iatrogenic PCL injury [8]. If the femoral component is aligned to the SEA

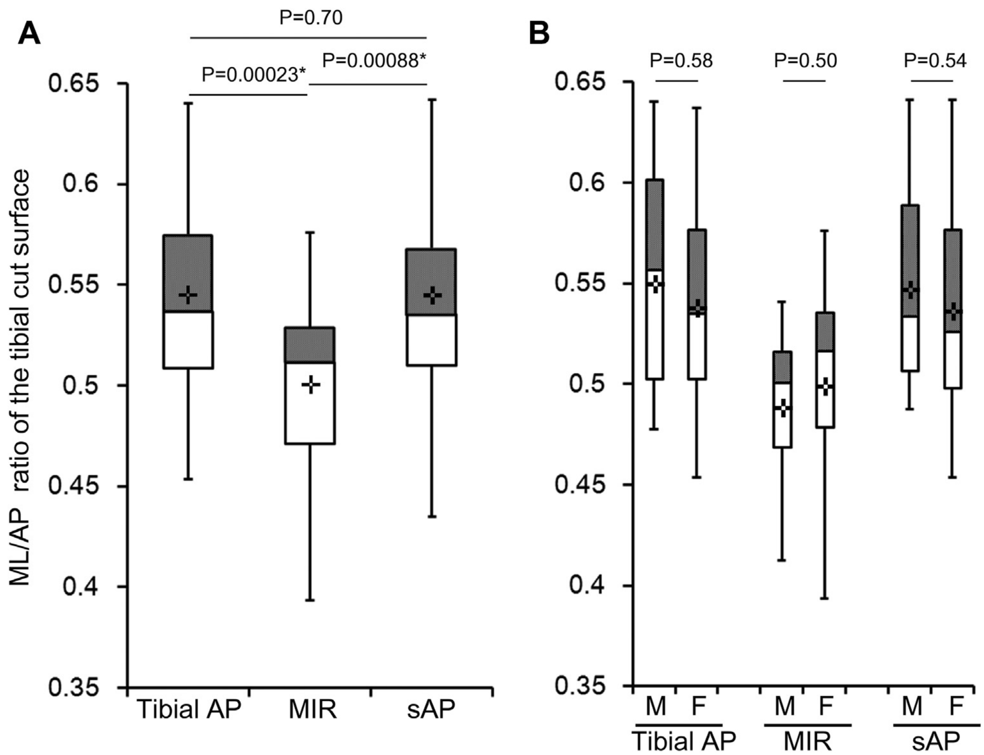

Fig. 4. Box plots showing the ML/AP ratios of the tibial cut surface when the sagittal cut was parallel to the tibial AP line, MIR line, and sAP line. (A) The ratio was significantly larger when parallel to the tibial AP line and sAP line than when parallel to the MIR line ($P < .001$ and $P < .001$, respectively). There was no significant difference between the ratios when cut parallel to the tibial AP line and the sAP line ($P = .70$). (B) There was no significant difference in the ML/AP ratio between men and women. M, male; F, female.

and the tibia is aligned vertical to the SEA, rotational mismatch between the components would be minimized and contact points between the components would be optimized in full range of the knee motion, which are considered to make longevity of the UKA better avoiding polyethylene edge loading [22]. Furthermore, correct rotational alignment would improve the component fitting to the tibial cut surface minimizing risks of MCL impingement [14] and subsidence of the tibial component [12].

In this study, we noted that the MIR line was not perpendicular to the SEA and that the MIR line was rotated externally 94.9° ± 4.1° (range 89.5°-104.5°) relative to the SEA. This finding indicates that the MIR in the subjects of this study may be significantly externally rotated by around 5° relative to the anatomical AP line. This finding supports the clinical observation that the sagittal cut of the tibia referencing the MIR causes the tibial component to be externally rotated relative to the tibial AP line [23–25].

Therefore, we devised an alternative AP reference (the sAP line) connecting the medial border of the PT at the articular surface level and the MIT, and found that the sAP line was almost perpendicular (90.4° ± 3.6°, range 82.9°-96.8°) relative to the SEA. There was a significant difference between the mean angles of the MIR line and sAP line relative to the SEA ($P < .0001$), and there was no difference between mean angles of the tibial AP line and the sAP line relative to the SEA ($P = .886$). This finding suggests that the tibial component could be placed more closely perpendicular to the SEA, if the sagittal tibial bone cut is performed parallel to the sAP line. Furthermore, the sAP line could provide a more correct rotational orientation in the operation field than the MIR line because the sAP line is about 3 times longer than the MIR line. In addition, the sAP line would be useful for 3-D preoperative planning with computer simulation software and intraoperative navigation systems because the medial border of the PT and the MIT can be identified on CT scans and in the operation field.

The mean ML/AP ratios when cut parallel to the tibial AP line and sAP line were significantly larger than the mean ratio when cut parallel to the MIR line ($P < .001$ and $P < .001$, respectively). There was no significant difference between the mean ML/AP ratios when cut parallel to the tibial AP line and sAP line. These results suggest

Table 1
Sizes and ML/AP Ratios of Tibial Components in Four Contemporary UKA Implants.

Oxford Knee (Zimmer Biomet)			Preservation (DePuy)			TRIBRID (KYOCERA Medical)			Zimmer Uni (Zimmer Biomet)		
AP	ML	ML/AP	AP	ML	ML/AP	AP	ML	ML/AP	AP	ML	ML/AP
45.2	24.0	0.531	41.0	20.0	0.488	40.0	21.0	0.525	41.0	23.0	0.561
45.4	26.0	0.573	45.0	23.0	0.511	44.0	23.0	0.523	44.0	25.0	0.568
48.6	26.2	0.539	49.0	26.0	0.531	46.0	25.0	0.543	47.0	27.1	0.575
51.8	28.0	0.541	53.0	29.0	0.547	49.0	27.0	0.551	50.0	29.0	0.580
55.0	29.8	0.542	57.0	32.0	0.561	53.0	30.0	0.566	53.0	26.5	0.585
58.2	31.6	0.543									

AP and ML sizes are presented as millimeter.
AP, anteroposterior; ML, mediolateral; UKA, unicompartmental knee arthroplasty.

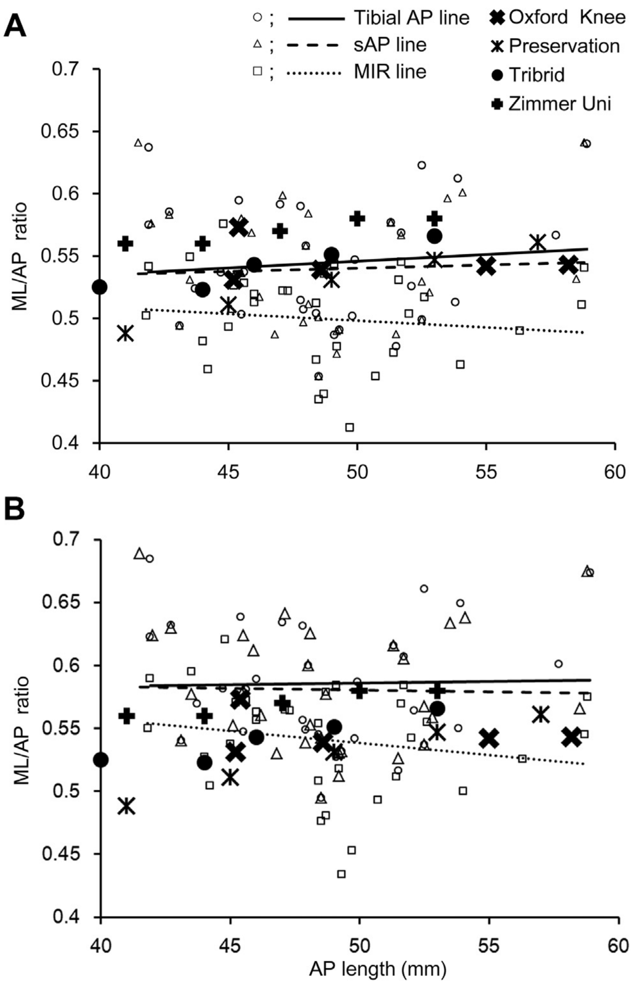

Fig. 5. Scatter diagrams showing the ML/AP ratios of the tibial cut surface in each knee (A) and those when the medial length was elongated by 2 mm (B) when cut parallel to the tibial AP line, MIR line, and sAP line. (A) The distributions of the ratios of the four implants were closer to the regression lines when cut parallel to the tibial AP line and sAP line. (B) All ML/AP ratios of the 4 implants were on or under the regression lines when the tibia was cut parallel to the tibial AP line and sAP line.

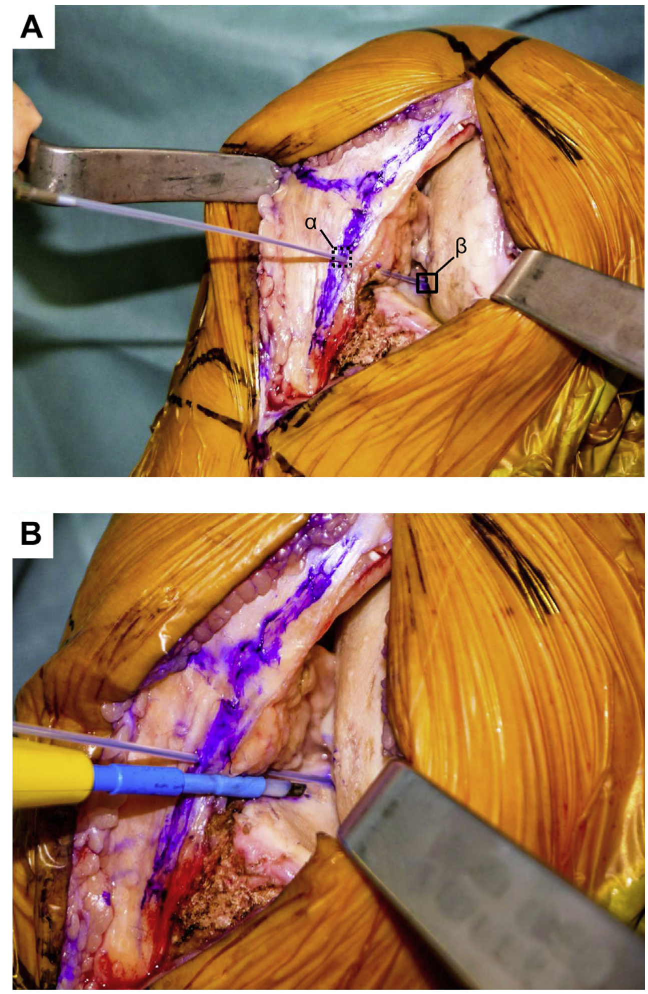

Fig. 6. Photographs showing the identification of the sAP line in an actual operating field. (A) A long 16-gauge needle is shown penetrating the medial border of the patellar tendon at the articular surface level (α) and extending toward the MIT (β). (B) The sAP line is drawn on the tibial plateau using a coagulator parallel to the needle.

that a sagittal cut parallel to the sAP line may be advantageous for avoiding medial overhang and that the sAP line may be a good substitute for the tibial AP line.

Several other AP references of the tibia have been proposed and currently used in UKA. Goodfellow JW and O'Connor [26] have recommended that the sagittal cut of the tibia should be directed toward the femoral head. However, detection of the femoral head center may be difficult in actual operating fields [23,27], and any theoretical basis on this method has not been shown. Shakespeare et al has recommended the range-of-movement method for determining the AP orientation of the tibia [28,29]. This method seems to be affected by how to hold the foot and knee during the manual flexion and extension of the knee because the knee has some freedom in an axial plane. The operating manual for the Oxford Partial Knee system with Microplasty Instrumentation (Zimmer Biomet, Warsaw, IN) recommends aiming the reciprocating saw toward the anterior superior iliac spine (ASIS) during sagittal tibial resection [30]. Recently, however, it has been reported that the ASIS cannot be recommended for the AP guidance because of the wide variation and inherent difficulty of identifying the ASIS during the operation [8]. Furthermore, Kawahara et al recommends the sagittal tibial resection along the medial wall of the intercondylar notch because the wall is almost parallel to the tibial AP line [2,5]. However, changes in rotational position between the femur and the tibia may make some errors in this method. The benefits of using the sAP line instead of the Kawahara's line include the following. The first, variability of the sAP line would be smaller in OA knees than that of the Kawahara's line. The subjects in their study were normal healthy knees and the accuracy of their line can be affected by rotational deformity in the femorotibial joint [31] and osteophyte formation in the intercondylar notch in medial OA knees. The second, the sAP line is length around 2 times as long as the Kawahara's line. The longer line could provide a better orientation in the operation field. The third, the sAP line is hardly subject to the rotational position between the femur and tibia because the MIT is on the tibia itself and the length of the PT from the tibial tuberosity to the articular surface level is relatively short.

Finally, we investigated the relationships between the ML/AP ratios of the tibial cut surface in this study population and those of 4 contemporary tibial components to determine which line provides a better fitting of the tibial components to the cut surface. Compared with the values when cut parallel to the MIR line, the regression lines of the ML/AP ratios when the tibia was cut parallel to the tibial AP line and the sAP line were closer to the tibial ML/AP ratios of the 4 contemporary implants. If a 2-mm medial overhang is allowed, all the tibial ML/AP ratios for the 4 implants were on or under the regression lines when the tibia was cut parallel to the tibial AP line and sAP line. These results suggest that the sAP line may be advantageous for obtaining a better fitting of the tibial components to the tibial cut surface compared with the MIR. However, our data also suggest that some of the patients would have had an overhang of more than 2 mm even if the tibial sagittal cut was performed parallel to the sAP line. In such cases, the component may need to be downsized to reduce the AP underhang, and a bare lateral shift of the components may be needed to avoid cruciate ligament damage.

In conclusion, we propose that the sAP line connecting the medial border of the PT at the articular surface level and the MIT can be an alternative tibial AP reference for better component alignment and fitting of the tibial component in UKA. We now are using the sAP line as the AP reference of the tibia during UKAs. The medial border of the PT can be identified by palpation in the operation field because the thickness of the PT is substantially different from that of the medial retinaculum. The line can be easily drawn on the tibial articular surface using a long needle to penetrate the medial border of the PT and extend to the MIT (Fig. 6).

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