The Knee 26 (2019) 459–465

Contents lists available at ScienceDirect

The Knee

Rotational position of the tibial component can decrease bony coverage of the tibial component in Oxford mobile-bearing unicompartmental knee arthroplasty

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ARTICLE INFO

Article history:
Received 10 August 2018
Received in revised form 2 November 2018
Accepted 8 January 2019

Keywords:
Oxford knee
Tibial component
Tibial coverage
Unicompartmental knee arthroplasty

ABSTRACT

Background: This study examined how coverage of the tibial component changes when the tibia vertical cut is externally or internally rotated in Oxford mobile-bearing unicompartmental knee arthroplasty.

Materials and methods: Fifty patients scheduled for primary Oxford medial unicompartmental knee arthroplasty (UKA) at the current hospital were included in this study. This study was a computed tomography (CT) simulation study. The anteroposterior (AP) and mediolateral (ML) length as well as the ML/AP ratio of the tibial cut surfaces were calculated when the vertical cut was performed parallel (base line), five degrees externally rotated (ER5), 10° externally rotated (ER10), five degrees internally rotated (IR5), or 10° internally rotated (IR10) relative to the tibial AP line using pre-operative CT. The tibial AP line connecting the middle of the posterior collateral ligament to the medial border of the patellar tendon attachment is a reproducible and reliable line because it is perpendicular to the SEA. These parameters among three lines were compared using a repeated measures ANOVA.

Results: The mean ML/AP ratios were statistically significantly lower in ER5 (0.53 ± 0.04) than base line (0.56 ± 0.04) ($P < 0.01$). The ER10 (0.48 ± 0.03) also exhibited lower mean ML/AP ratios than ER5 (0.53 ± 0.04) ($P < 0.01$). The mean ML/AP ratios were higher in IR5 (0.59 ± 0.04) than base line (0.56 ± 0.04) ($P < 0.01$). The IR10 (0.63 ± 0.06) also showed a higher mean ML/AP ratio than IR5 (0.59 ± 0.04) ($P < 0.01$).

Conclusion: Rotational malalignment of tibial vertical cuts can affect tibial coverage in Oxford mobile-bearing unicompartmental knee arthroplasty.

1. Introduction

Rotational alignment of the tibial component is important in both unicompartmental knee arthroplasty (UKA) and total knee arthroplasty. The tibial anteroposterior (AP) line connecting the middle of the posterior cruciate ligament (PCL) to the medial edge of the patellar tendon attachment has been proposed for this alignment in total knee arthroplasty [1]. However, it can be difficult to identify the tibial AP line in modern mini-incision UKA because the PCL is barely visible or accessible in a small operating field [2].

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https://doi.org/10.1016/j.knee.2019.01.003
0968-0160/

There are few reports that recommend any alternative useful tibial AP rotational references of the tibial AP line. Kawahara et al. reported that the medial wall of the intercondylar notch is one of the recommended useful tibial AP rotational landmarks for UKA because it was found to be almost parallel to the tibial AP line in their magnetic resonance imaging (MRI) study using normal healthy knees [3]. However, degeneration and osteophytes of the intercondylar wall may change the positional relationship of these landmarks and reduce accuracy in knees with osteoarthritis. Thus, there is still room for argument about ideal landmarks for tibial component rotation in medial UKA.

In some reports, tibial component rotation tends to be externally rotated relative to the tibia AP line, and has wide variation because of the lack of a useful landmark for the tibial sagittal saw cut [4,5]. This wide variation is also caused by degenerative changes and removing osteophytes in the notch to avoid saw blade misguidance. Therefore, the current institution makes a tibial vertical cut just medial to the apex of the tibial spine through the edge of the anterior cruciate ligament (ACL) insertion with the blade directed at the anterior superior iliac spine (ASIS), outside of the operating field, according to the Oxford partial knee surgical technique. However, wide variation has also been observed even with this method using the ASIS as a landmark of tibial rotation [5,6]. In addition, several authors have reported that clinical outcomes tend to worsen with external rotation of the tibial component [6,7]. It has not been clearly addressed as to why rotation of the tibial component negatively affects clinical outcomes.

Regarding the tibial component coverage in UKA, several authors reported that underhang or overhang of the tibial component led to poorer clinical outcomes due to subsequent impingement of the surrounding soft tissues [8]. Additionally, edge loading on the tibial polyethylene and insufficient bony support of the tibial component led to a lower Oxford Knee Score (OKS) and pain score [9–11]. Size and proportion of respective implants are the main determinants of good coverage. Tsukamoto et al. pointed out the possibility that rotation of the tibial cut surface affects tibial component coverage [2]. However, no study has yet described, with sufficient evidence, the effect of tibial component rotation on component coverage.

Medial tibial plateau fracture after Oxford mobile-bearing UKA is recognized as a serious complication of surgery. The risk of fracture has been reported to be increased with a short distance between the keel and posterior cortex due to a sagittal tibial cut that is too medial and deep [12,13]. Therefore, a sagittal cut should be made just medial to the apex of the medial tibial spine. However, the effect of rotational errors on the distance of the keel and cortex has not been fully investigated.

Based on the above-mentioned issues, it was hypothesized that rotational errors of the tibial sagittal cut would affect tibial coverage and the distance between the keel and cortex. This study simulated how coverage of the tibial component and the keel line distance change when the tibia vertical cut is externally or internally rotated using pre-operative computed tomography (CT).

2. Materials and methods

Computed tomography data that were obtained from routine pre-operative planning from 50 lower limbs in 50 Japanese patients were reviewed (with approval from the hospital Institutional Review Board). The patients comprised 32 women and 18 men (age 71.7 ± 6.9 years, body mass index 25.3 ± 3.6 kg/m^2). Among these patients, the average pre-operative coronal plane alignment on standard weight-bearing AP radiographs was 7.3 ± 5.3° in varus. Patients were scheduled for consecutive primary UKA at the current hospital between 2013 and 2014; all were diagnosed with anteromedial osteoarthritis. Flexion contracture of the knee was <10°, and the hip-knee-ankle angle was <10° in all knees.

2.1. Imaging technique

Computed tomography scans were performed using a 64-row multi-slice CT system at the current hospital. Patients were positioned on the CT table in a supine position. Scans of 1.25-mm slices were performed from the hip joint to the ankle joint with the patient in a knee-extended position with the patella facing upward. The obtained image datasets were imported into 3D software (Aquarius Net; Tera Recon, San Mateo, CA, USA). In the software, the operating window is comprised of three multiplanar reformation viewers in the frontal, sagittal, and axial planes. Each reconstructed image can be simultaneously rotated, cut, and measured arbitrarily in all three operating windows. Three investigators performed all radiographic assessments and used the software to measure the angles and lengths on a virtually cut surface of the proximal tibia.

2.1.1. Measurement of the anteroposterior rotational reference and tibial cut surface

The tibial mechanical axis (TMA) passes through the center of the tibial eminence and the center of the talar dome. The tibial AP line connects the middle of the PCL and the medial border of the patellar tendon attachment to the tibial tubercle [1]. The tibia was raised along the TMA and moved forward along the tibial AP line. The proximal tibial articular surface was cut perpendicular to the TMA with a posterior inclination of seven degrees and two millimeters below the medial joint lines. The base line was defined as the line parallel to the tibia AP line through the medial brink of Parsons' knob (MBP) (Figure 1a). Parsons' knob is the anterior border of the ACL tibial insertion [14,15]. The MBP is visible or accessible even in the small operating field used in medial UKA [16].

The AP and mediolateral (ML) length were evaluated and the ML/AP ratio of the tibial cut surfaces was calculated when the sagittal cuts of the tibia were performed parallel to the tibial AP line through the MBP (base line, Cut 1), five degrees externally rotated relative to the base line through the MBP (ER5, Cut 2), 10° externally rotated relative to the base line through the MBP (ER10, Cut 3), five degrees internally rotated relative to the base line through the MBP (IR5, Cut 4), and 10° internally rotated relative to the base line through the MBP (IR10, Cut 5) (Figure 1a and b). The keel line (KL) was defined as the line nine

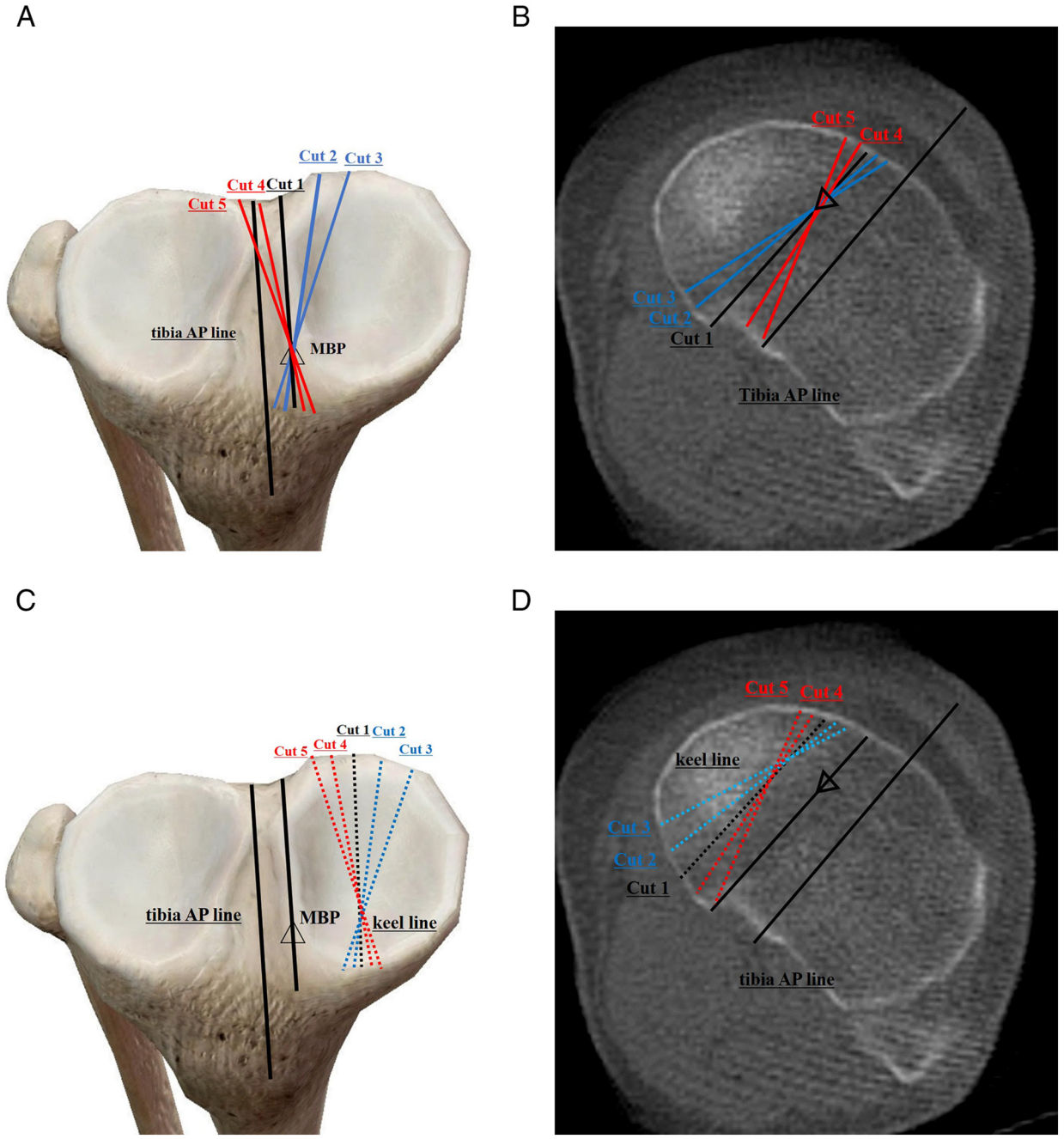

Figure 1. a. Image showing bony landmark (medial brink of Parson's knob) cutting lines. b. Image showing AP referencing lines and cutting lines on tibial cut surface. c. Image showing bony landmark (medial brink of Parson's knob) keel line. d. Image showing AP referencing lines and keel line on tibial cut surface. AP, Anteroposterior; MBP, medial brink of Parsons' knob Cut 1: parallel to tibia AP line through MBP (base line) Cut 2: five degrees externally rotated relative to base line through MBP Cut 3: 10° externally rotated relative to base line through MBP Cut 4: five degrees internally rotated relative to base line through MBP Cut 5: 10° internally rotated relative to base line through MBP.

millimeters medial and parallel to each cutting line, on which the keel cut would be made. The KL length and KL/AP ratio of each cutting line were also evaluated (Figure 1c and d).

Finally, sizing was simulated using tibial component data in the Oxford partial knee (Zimmer Biomet, Warsaw, IN, USA), assuming that a medial underhang or overhang <2 mm could be allowed with the sagittal tibial cut (Table 1). The optimal implant size was chosen based on the AP length. The proportion of cases with an underhang or overhang >2 mm in each cutting line was examined. Simulation was also made assuming that the size of the tibial component was selected according to the ML length. There was often a small area anteriorly that was uncovered by the tibial component when the optimal implant size

Table 1
Sizes and mediolateral/anteroposterior ratios of tibial components in Oxford knee.

Size	AP	ML	ML/AP
AA	45.2	24.0	0.531
A	45.2	26.0	0.575
B	48.6	26.2	0.539
C	51.8	28.0	0.541
D	55.0	29.8	0.542
E	58.2	31.6	0.543

AP and ML sizes are reported in mm.
AP, anteroposterior; ML, mediolateral.

was selected based on the ML length, and so the tibial component was placed as far posteriorly as possible. The number of cases were investigated where overhang >2 mm occurred, even if the smallest size was selected, and the number of cases where underhang occurred, even if the largest size was selected. The AP distance of the uncovered area was also selected. Negative value showed the amount of anterior overhang instead of no uncovered area.

2.2. Statistical analysis

Intraclass and interclass correlation coefficients were calculated to examine the reproducibility of measurements. All measurements were performed, three times by one surgeon and once by another two examiners, on 10 knees randomly selected from the study group. The intraclass correlation coefficients between the three measurements made by the same observer were: 0.87, 0.89, 0.91, 0.84, and 0.83 for measurements of AP length in Cuts 1–5; 0.85, 0.87, 0.88, 0.86, and 0.82 for measurement of ML length in Cuts 1–5; and 0.84, 0.81, 0.84, 0.81, and 0.80 for measurement of KL length in Cuts 1–5, respectively. The interclass correlation coefficient was calculated from the mean of the three measurements of the investigator and the measurements of another investigator. The coefficients were 0.86, 0.83, 0.91, 0.86, and 0.82 for measurements of AP length in Cuts 1–5; 0.81, 0.82, 0.87, 0.86, and 0.84 for measurement of ML length in Cuts 1–5; and 0.82, 0.82, 0.86, 0.82, and 0.83 for measurement of KL length in Cuts 1–5, respectively.

All values were reported as mean ± standard deviation (SD). Results were analyzed using StatView 5.0 (Abacus Concepts Inc., Berkeley, CA, USA). Differences in the ML/AP ratios and KL/AP ratios of each cutting line in case of external rotation (ER5, ER10) or internal rotation (IR5, IR10) were compared with the base line using repeated measures ANOVA ($P < 0.01$). The proportion of cases with an overhang >2 mm were compared among each cutting line using the Cochran Q test with Bonferroni correction ($P < 0.01$). The AP distance of the uncovered area was compared among all cutting lines using Friedman's test ($P < 0.01$).

3. Results

3.1. Measurement date when cutting two millimeters below the joint line

Table 2 reports all measurement data when cutting two millimeters below the joint line. The mean ML/AP and KL/AP ratios were significantly lower in ER5 (0.53 ± 0.04, 0.89 ± 0.06) than base line (0.56 ± 0.04, 0.93 ± 0.06) ($P < 0.01$). The ER10 (0.48 ± 0.03, 0.87 ± 0.04) also exhibited significantly lower mean ML/AP and KL/AP ratios than ER5 ($P < 0.01$). The mean ML/AP and KL/AP ratios were significantly higher in IR5 (0.59 ± 0.04, 0.95 ± 0.06) than base line (0.56 ± 0.04, 0.93 ± 0.06) ($P < 0.01$). The IR10 (0.63 ± 0.06, 0.96 ± 0.06) also showed a significantly higher mean ML/AP ratio than IR5 ($P < 0.01$).

3.2. Simulation of sizing using Oxford UKA

In the simulation of sizing using the Oxford UKA system, significantly higher rates of overhang >2 mm in ER10 were found compared to the two cutting lines (base line, ER5) at 2 mm below the joint line (Tables 3 and 4) ($P < 0.01$ after Bonferroni correction). However, IR10 also exhibited a significantly higher rate of underhang >2 mm compared to two cutting lines (base line, IR5) at 2 mm below the joint line (Tables 5 and 6) ($P < 0.01$ after Bonferroni correction).

Table 2
Assessment of tibial coverage (anteroposterior and mediolateral length, mediolateral/anteroposterior ratio, keel line length of tibial cut surface) when cut at each line.

	AP length (mm)	ML length (mm)	ML/AP ratio	KL length (mm)	KL/AP ratio
IR10	46.0 ± 3.4	28.9 ± 2.3	0.63 ± 0.05	44.4 ± 4.0	0.96 ± 0.06
IR5	46.8 ± 3.5	27.6 ± 2.2	0.59 ± 0.04	44.5 ± 3.9	0.95 ± 0.06
Base line	47.7 ± 3.8	26.9 ± 2.1	0.56 ± 0.04	44.7 ± 4.0	0.93 ± 0.06
ER5	48.3 ± 3.6	25.7 ± 2.2	0.53 ± 0.04	43.3 ± 3.7	0.89 ± 0.05
ER10	49.8 ± 3.5	23.9 ± 2.2	0.48 ± 0.03	41.4 ± 3.6	0.87 ± 0.04

AP, anteroposterior; ML, mediolateral; KL, keel line; ER10, 10° externally rotated; ER5, five degrees externally rotated; IR5, five degrees internally rotated; IR10, 10° internally rotated.

Table 3
Proportion of cases with >2-mm overhang in each cutting line.

Size	ER10	ER5	Base line	IR5	IR10
A or AA	7/14	1/19	0/21	0/24	0/25
B	14/16	2/15	0/18	0/15	0/15
C	10/12	2/13	1/6	0/9	0/9
D	5/7	1/6	0/4	0/2	0/1
E	1/1	0/1	0/1	0/0	0/0
Total	37/50 (74%)	6/50 (12%)	1/50 (2%)	0/50 (10%)	0/50 (0%)

ER10, 10° externally rotated; ER5, five degrees externally rotated; IR5, five degrees internally rotated; IR10, 10° internally rotated.

Table 4
Comparison of the proportion of overhang between the three cutting lines on Cochran's Q test.

Size	*P*	Bonferroni correction
Base line vs. ER5	0.03	0.09
Base line vs. ER10	<0.01	<0.01
ER5 vs. ER10	<0.01	<0.01

ER10, 10° externally rotated; ER5, five degrees externally rotated.

Table 5
Proportion of cases of with >2-mm underhang in each cutting line.

Size	ER10	ER5	Base line	IR5	IR10
A or AA (<46.9)	0/14	1/19	1/21	6/24	12/25
B (<50.2)	0/16	1/15	3/18	7/15	12/15
C (<53.4)	0/12	2/13	0/6	1/9	7/9
D (<56.6)	0/7	0/6	1/4	1/2	0/1
E (≥56.6)	0/1	0/1	0/1	0/0	0/0
Total	0/50 (0%)	4/50 (8%)	5/50 (10%)	15/50 (30%)	31/50 (62%)

ER10, 10° externally rotated; ER5, five degrees externally rotated; IR5, five degrees internally rotated; IR10, 10° internally rotated.

Table 6
Comparison of the proportion of underhang between the three cutting lines on Cochran's Q test.

Size	*P*	Bonferroni correction
Base line vs. IR5	<0.01	<0.01
Base line vs. IR10	<0.01	<0.01
IR5 vs. IR10	<0.01	<0.01

IR5, five degrees internally rotated; IR10, 10° internally rotated.

3.3. Simulation of sizing based on the mediolateral length using Oxford UKA

Table 7 shows the results of simulation based on mediolateral length. Ten overhang cases were found in ER10, even if the smallest size was selected, and a significantly larger distance of uncovered area compared to two cutting lines (base line, ER5) ($P < 0.01$). Five underhang cases were found in IR10, even if the largest size was selected, and a significantly smaller distance of uncovered area compared to two cutting lines (base line, IR5) ($P < 0.01$).

Table 7
Simulation based on the mediolateral length.

	ER10	ER5	base line	IR5	IR10
Number of overhang cases	10	1	0	0	0
Number of underhang cases	0	0	0	1	5
Distance of uncovered area (mm)	3.5 ± 3.3	0.8 ± 3.2	−0.9 ± 2.6	−1.3 ± 2.8	−2.8 ± 3.0

ER10, 10° externally rotated; ER5, five degrees externally rotated; IR5, five degrees internally rotated; IR10, 10° internally rotated.

4. Discussion

The main finding of this study was that rotational position of the tibial component can decrease the coverage of the tibial component in UKA. This implies that after UKA, the optimal tibial component rotation is extremely important for tibial coverage. It is believed that this is the first study to describe the effects of tibial sagittal cut rotation on tibial coverage for UKA.

The present study found that the ML/AP ratio was significantly lower when the cut was 10° externally rotated relative to the tibial AP line than when the cut was parallel to it. It also found a higher rate of overhang >2 mm when the cut was 10° externally rotated relative to the tibial AP line in the simulation of sizing using the Oxford knee. Furthermore, it proved that the uncovered area anteriorly becomes large in ER10, even if size selection is made based on the ML length in order to avoid overhang. These results suggest that external rotational errors can result in a smaller ML length of the tibial cut surface relative to the AP length, and lead to ML overhanging or AP incomplete bony coverage. Moreover, based on the findings of this study, excessive external rotation of the tibial component can cause deterioration of covering the component and ultimately lead to a poorer clinical outcome. This suggests that surgeons should control intraoperative tibial component rotation to avoid medial overhanging of the tibial component after Oxford medial UKA.

In contrast, a significantly higher ML/AP ratio and higher rates of underhang >2 mm were found when the cut was 10° internally rotated relative to the tibia AP line than when the cut was parallel to it. These findings suggest that an internal rotation error of approximately 10° may be a risk factor for underhang in Oxford UKA because the AP length becomes shorter due to the PCL fossa. This may increase the risk of PCL injury, due to an excessively internally rotated cut [5]. Underhang of the tibial cut surface could result in edge loading on the tibial polyethylene, leaving insufficient bony support for the tibial component on the cut surface [8].

Medial tibial plateau fracture after UKA has been described as a result of technical errors, such as creation of an improper pin site for fixation of the tibial cutting block [17,18], vertically overcutting the medial plateau [12,19], using excessive force with a heavy hammer [20], and breach of the posterior tibial cortex during preparation of the tibial plateau for the implant [13]. This study also found a shorter keel line when the cut was 10° externally rotated relative to the tibial AP line. This suggests that an excessive external rotational error of approximately 10° may decrease the bone mass supporting the tibial components where the body weight load is concentrated and, therefore, be a major risk factor for fracture in Oxford UKA.

This study had some limitations. First, the tibial AP line is not a suitable reference because it can not be intraoperatively identified in UKA. To show clinical relevance, it was thought that it was better to use CT of the knee in a flexion position to evaluate the lateral wall of the medial femoral condyle as a reference because the vertical tibial saw cut is performed lying against the lateral margin of the medial femoral condyle with the knee in a flexed position. However, Kawahara et al. reported that the medial wall of the intercondylar notch is one of the recommended useful tibial AP rotational landmarks for UKA because it was almost parallel to the tibial AP line with the knee in flexion in their MRI study [3]. In addition, the current study showed a trend toward poor outcomes when the tibial component was placed at a higher angle of external rotation relative to the tibial AP line [6]. Therefore, using the tibial AP line as a reference of tibial AP rotation in this type of research is meaningful for clinical practice. Moreover, it is believed that the tibial AP line brings high reproducibility in CT measurements, unlike the medial wall of the intercondylar notch, which is influenced by the positional relationship between the tibia and femur.

Second, unlike fixed-bearing UKA, rotation of the tibial component in Oxford UKA featuring the mobile meniscal bearing impacts both the coverage and bearing location. Malrotation of the tibial components in mobile meniscal bearing UKA may cause dissociation of the bearing from the lateral wall. This increases the risk of bearing spin-out and subsequent dislocation. The effects of rotation on bearing wall distance should therefore be evaluated.

Third, the study population was limited to Japanese patients undergoing UKA. As the shape of the tibia might be different in other populations, additional and larger studies are needed. The correlation between tibial component rotation and clinical outcome warrants clarification in future studies. Although the current results provide useful information about the effect of tibial component rotation on component coverage and support the idea that excessive external rotation of the tibial component becomes a risk factor for poor clinical outcomes, the greatest problem of how to manage tibial component rotation intraoperatively has yet to be solved.

5. Conclusions

External rotational error of tibial sagittal cuts can affect tibial coverage and keel line. An excessive external rotation error of approximately 10° may be a strong risk factor for fracture and overhang, and an internal rotation error of approximately 10° can increase the risk of underhang in Oxford mobile-bearing UKA.

Declarations of interest

None.

Acknowledgements

None.

Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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