Original Article
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Self-aligned Technique for Tibial Component Placement in Total Knee Arthroplasty Lessening Rotational Malalignment in Measured Resection and Gap-Balancing Techniques

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Background: Femorotibial rotational mismatch can occur when there is a rotational malalignment in either the tibial or femoral component. Self-aligned technique was proposed for orienting the tibial component in relation to the femoral prosthesis to reduce rotational malalignment between components. Therefore, we aimed to compare the rotational angle of the femoral and tibial components, as well as the femorotibial rotational mismatch, between the measured resection (MR) and gap-balancing (GB) techniques when combined with a self-aligned technique.

Methods: We conducted a nonrandomized, experimental study with 50 patients in each group. The femoral rotation was set to 3° external rotation relative to the posterior condylar axis in the MR group, whereas the femur was resected to obtain an optimal rectangular flexion gap in the GB group. The self-aligned method was used to set the tibial rotation in both groups. Femoral and tibial rotational alignments were evaluated compared to a surgical transepicondylar axis of the femur using computed tomography. Rotational mismatch was defined as a difference between the femoral and tibial rotational alignments. A positive value indicated that the component was externally rotated relative to the reference line.

Results: The femoral component of the GB group was more externally rotated than that of the MR group (1.52° ± 1.31° vs 0.28° ± 1.16°, $p < 0.001$). However, the tibial rotational angle was not statistically significantly different between the MR and GB groups (1.28° ± 3.17° vs. 1.86° ± 2.81°, $p = 0.220$), and the rotational mismatch was 1.00° ± 3.28° and 0.34° ± 2.71°, respectively ($p = 0.306$).

Conclusions: Although the femoral component of the GB group had a greater degree of external rotation than that of the MR group, the use of a self-aligned technique for tibial component placement resulted in no significant difference in tibial rotational alignment or rotational mismatch. This technique helps align the tibial component with the femoral component and lessen the degree of rotational malalignment in both the MR and GB techniques.

Keywords: *Femur, Tibia, Tomography, Total knee arthroplasty*

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Femoral and tibial rotational alignment is crucial for good functional outcomes after total knee arthroplasty (TKA)[1] and for determining the longevity of knee prostheses.[2] Therefore, strategies for aligning the component rotation to ensure proper femorotibial kinematics after TKA are usually implemented using a stepwise approach. Generally, measured resection (MR) and the gap-balancing (GB) techniques are used to perform TKA. Although the rotational axis of the femur has been well demonstrated in biomechanical studies to be parallel to the surgical transepicondylar axis (sTEA) throughout knee flexion-extension,[3,4] the technique best suited to place this component parallel to the sTEA remains unclear.[5,6)]

For the MR technique, the rotation of the femoral component according to the posterior condyle of the femur can simply be determined by surgeons. However, the posterior condyle axis (PCA) has been reported to range from 1.3° internally rotated to 10.4° externally rotated relative to the sTEA.[7] Aglietti et al.[7] demonstrated a correlation between the PCA and deformity in the coronal plane and suggested that the PCA may not be reliable depending on the degree of deformity. On the other hand, the femoral rotation is set to create the rectangular flexion gap in the GB technique, regardless of anatomical landmarks.[8] Moon et al.[9] revealed that the femoral component is usually more externally rotated than the sTEA in the GB technique.

Additionally, to date, there has been no standard technique to precisely determine the rotation of tibial prosthesis. Various anatomical landmarks, for instance, the medial one third of the tibial tubercle,[10] Akagi line,[11] and posterior tibial condylar line,[12] are used to determine the rotational alignment of the tibial component. Despite the less difficulty in determining these landmarks intraoperatively, there can be conflicts between the tibial and femoral sides if each rotational axis is independently established.[13] Previous studies have demonstrated that a mismatch between the rotational alignment of the tibial and femoral components may result in residual pain, stiffness, wear-out of the polyethylene insert, and patellofemoral complications, leading to a requirement for early revision.[2,14,15] While it is still unclear what anatomical technique is better than the others, the self-aligned technique, which allows the tibial component to find its proper place relative to the femoral component rotation, may be an alternative option for reducing the rotational mismatch.

Hence, the objectives of this study were to compare (1) the rotational angle of the femoral component, (2) the rotational alignment of the tibial components, and (3) the femorotibial rotational mismatch between the MR and GB techniques when combined with the self-aligned technique. We hypothesized that the femoral component of the GB group may have a greater degree of external rotation than that of the MR group. The reason behind this assumption was that a tight medial flexion gap could lead to excessive femoral resection in external rotation to create the rectangular flexion gap when using the GB technique especially in knee osteoarthritis (OA) with varus deformity.[16] We also hypothesized that the use of a self-aligned technique for tibial component placement may result in no significant difference in tibial rotational alignment or rotational mismatch due to the effect of the self-aligned technique that allows the tibial component to rotate at a suitable angle, reducing the femorotibial mismatch and ensuring optimal knee kinematics, regardless the femoral cutting technique used.

METHODS

This study was approved by the Research Ethics Committee of the Phra Nakhon Si Ayutthaya Hospital, Phra Nakhon Si Ayutthaya, Thailand (No. 030/2019) and was performed in accordance with the tenets of the Declaration of Helsinki. Informed consent was obtained from all patients. All procedures in studies involving human participants were performed in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

From February 2019 to December 2020, 111 patients with primary OA scheduled for unilateral TKA were enrolled in the study. Patients who had valgus knee or mechanical axis deviation of more than 15° of varus were excluded. Patients with secondary knee OA, a history of knee surgery, or infection on the operated side were also excluded. Subsequently, there were 50 patients each in the MR and GB groups (Fig. 1). All TKAs were performed with identical knee implants by a single surgeon who had more than 20 years of experience (AP). In all cases, a symmetric posterior-stabilized total knee prosthesis with fixed-bearing polyethylene inserts (Vega prosthesis; B. Braun-Aesculap, Melsungen, Germany) was implanted without patellar resurfacing. The preoperative mechanical axis of the limb was measured using radiography, and varus alignment was recorded in positive values.

Surgical Technique

All TKAs were performed through the medial parapatellar approach after inflating the air tourniquet to 300 mmHg. Since a posterior-stabilized total knee prosthesis was used,

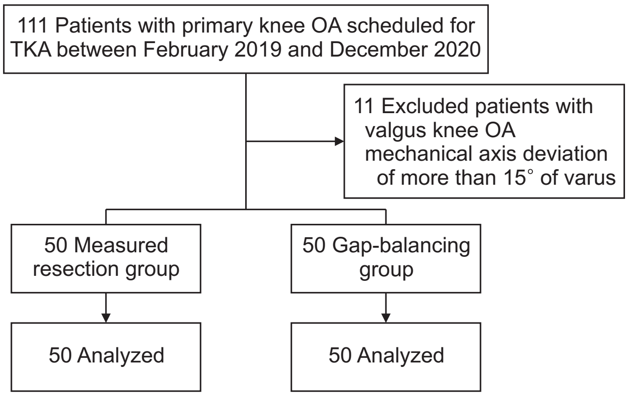

Fig. 1. Flowchart of the patient recruitment process. OA: osteoarthritis, TKA: total knee arthroplasty.

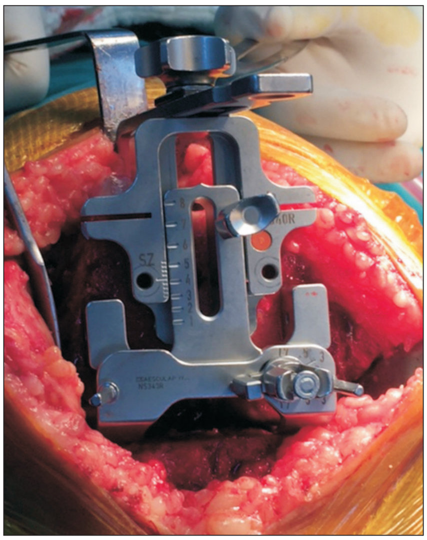

Fig. 2. In the measured resection group, the femoral component rotation was set to 3° of external rotation relative to the posterior condylar axis of the femur.

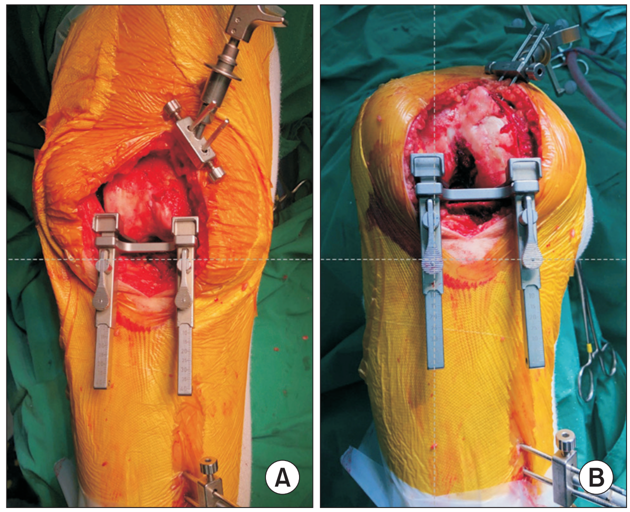

Fig. 3. The collateral ligaments were set at an equal tension using the tensor device in full extension (A) and 90° of knee flexion (B) to evaluate the joint gap sizes and plan for bone resection.

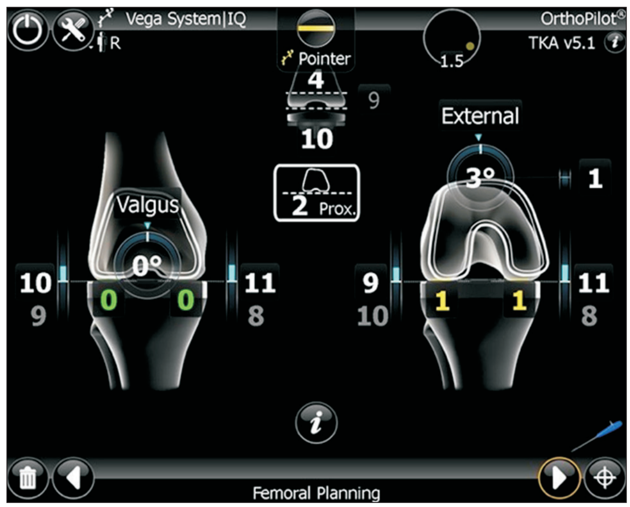

Fig. 4. The distal femur was cut perpendicular to the femoral mechanical axis on the screen of the navigation system. The anterior and posterior femurs were subsequently resected according to the rotation of the femoral component, guided by the navigation system, to obtain an optimal rectangular flexion gap. TKA: total knee arthroplasty.

we resected both the anterior and posterior cruciate ligaments. In the MR group, the tibia was first cut with an extramedullary cutting guide, perpendicular to the tibial mechanical axis. The distal femur was then resected using the intramedullary guide. After removal of osteophytes from the femoral and tibial sides, the medial ligament was released in extension. The femoral rotation was routinely set to 3° of external rotation relative to the posterior condylar axis of the femur, and then the anterior and posterior femurs were resected as shown in Fig. 2.

In the GB group, we used computed tomography (CT)-free navigation system (Orthopilot 4.2, B. Braun-Aesculap) to improve the precision of the proximal tibial and distal femoral bone cuts relative to the mechanical axis. After registration of all anatomical landmarks, we performed the tibial cut perpendicular to the tibial mechanical axis using this navigation system to set both coronal and sagittal alignments. When necessary, osteophytes on both tibial and femoral sides were removed, and the medial ligament was released in extension to equalize the extension gap. The collateral ligaments were then equally tensioned using the tensor device at 90° of knee flexion to evaluate the joint gap sizes (Fig. 3). With the help of navigation system, the distal femur was cut perpendicular to the femoral mechanical axis (Fig. 4). The anterior and posterior femurs were subsequently resected in order to obtain an optimal rectangular flexion gap, guided by the navigation system.

The self-aligned method was used to set the alignment of the trial tibial component in both groups.[3,17] After finishing the bone cut, the trial femoral and tibial components were placed, and the patella was reduced to allow proper patellofemoral tracking. The surgeon performed five cycles of full knee flexion and extension while maintaining the patellofemoral articulation. The rotational alignment of the trial tibial component was marked at the anterior tibial cortex. All prostheses were implanted with cement, along with a polyethylene insert.

All the patients received identical peri- and postoperative care, including fluid management, pain control, and rehabilitation. Femoral and tibial rotational alignments were evaluated 30 days after surgery using CT. The CT images were acquired in the supine position with the knee fully extended and were interpreted using Synapse software (Fujifilm, Tokyo, Japan). The CT images were taken with a slice thickness cut of 1 mm, perpendicular to the long axis of the leg; they were then evaluated by a consultant orthopedic surgeon (NK and AL) who was blinded to the techniques used. Rotational alignment of the femoral and tibial components was determined by a line projected parallel to the posterior edge of each component, as shown in Fig. 5. The alignment was then superimposed on the CT images. All reference lines were compared with the sTEA of the femur since it has been reported to approximate the knee joint flexion-extension axis.[3] Subsequently, we calculated the mean value of the femoral and tibial rotational angles, either internally or externally, relative to the sTEA in each group. A positive value indicated that the component was externally rotated relative to the sTEA. Femorotibial rotational mismatch was described as a disparity (in degrees) between the femoral and tibial rotational alignments. A positive value indicated that the tibial component was externally rotated relative to the femoral component. Therefore, we compared the rotational angle of the femoral and tibial components and the femorotibial rotational mismatch between the MR and GB groups. Rotational angles of either the femoral or tibial component that deviated > 3° from the sTEA and > 10° of rotational mismatch were considered to be outliers.[18]

Data Analysis

Data analyses were performed using SPSS ver. 18 (SPSS Inc., Chicago, IL, USA). The normality of data distribution among groups was assessed by the Kolmogorov-Smirnov test. An independent sample *t*-test was used to compare the femoral rotation, tibial rotation, and femorotibial rotational mismatch between the two groups. The number of outliers between the two groups was compared and assessed using Pearson's chi-square test (a sample size of at least 50 patients in each group was required to detect a mean difference of 1° with a standard deviation of 1.75°), using a power of 0.8 and an α value of 0.05. The authors measured all radiographic parameters twice at least 2 weeks after surgery. Intra- and interclass correlation coefficients were used to assess intra- and interobserver reliabilities, respectively.

RESULTS

One hundred and eleven patients with primary OA were enrolled in the study. We excluded 5 patients with valgus knee deformity and 6 patients with varus knee deformity, in whom the mechanical axis of the lower limb deviated more than 15º. Therefore, 100 patients were finally included in the study (Fig. 1). The mean age of the participants was 66.8 years (range, 52–82 years), and most patients were women (86.0) (Table 1). Fifty patients (50.0) had a

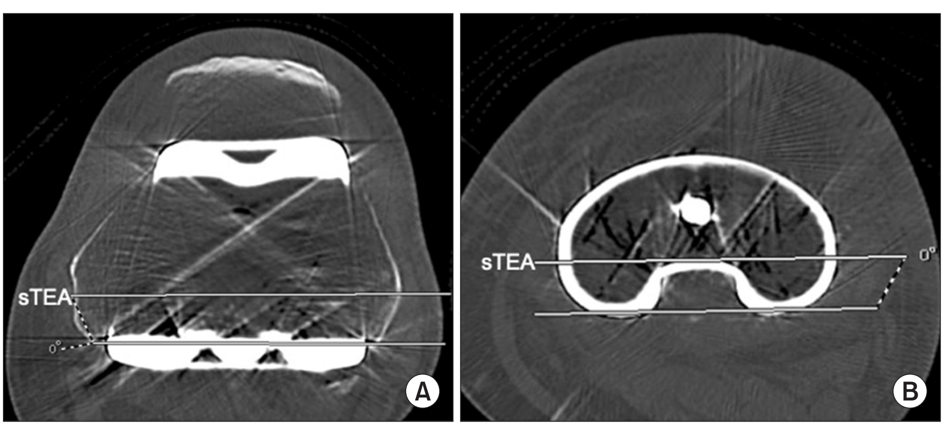

Fig. 5. Rotational alignment of the femoral (A) and tibial (B) components was defined as a line projected parallel to the posterior edge of each component. All reference lines were compared with the surgical transepicondylar axis (sTEA).

Table 1. Patient Demographics and Clinical Characteristics

Patient characteristics	Total (n = 100)	MR group (n = 50)	GB group (n = 50)	*p*-value
Age (yr)	66.8 ± 6.8	65.6 ± 7.0	68.0 ± 6.5	0.082
Female	86 (86.0)	43 (86.0)	43 (86.0)	1.000
Body mass index (kg/m^2)	27.1 ± 4.2	27.4 ± 4.5	26.8 ± 3.9	0.496
Charlson comorbidity index				0.726
1	13 (13.0)	7 (14.0)	6 (12.0)	
2	37 (37.0)	20 (40.0)	17 (34.0)	
≥ 3	50 (50.0)	23 (46.0)	27 (54.0)	
Preoperative alignment				-
Neutral	0	0	0	
Valgus	0	0	0	
Varus	100 (100.0)	50 (100.0)	50 (100.0)	
Degree of deformity				0.969
0–5	33 (33.0)	16 (32.0)	17 (34.0)	
6–10	36 (36.0)	18 (36.0)	18 (36.0)	
11–15	31 (31.0)	16 (32.0)	15 (30.0)	

Values are presented as mean ± standard deviation or number (%). A *p*-value of < 0.05 indicates statistical significance.
MR: measured resection, GB: gap-balancing.

Table 2. Comparison of Femoral Component Rotation, Tibial Component Rotation, and Femorotibial Rotational Mismatch

Outcome measure	Total (n = 100)	MR group (n = 50)	GB group (n = 50)	*p*-value
Femoral component rotation (°)	0.90 ± 1.38 (–3 to 4)	0.28 ± 1.16 (–3 to 2)	1.52 ± 1.31 (–1 to +4)	< 0.001
Outlier				
Total	4 (4.0)	0	4 (8.0)	0.117
> 3° IR	0	0	0	-
> 3° ER	4 (4.0)	0	4 (8.0)	0.117
Tibial component rotation (°)	1.57 ± 3.00 (–6 to 12)	1.28 ± 3.17 (–6 to 12)	1.86 ± 2.81 (–3 to 8)	0.220
Outlier				
Total	24 (24.0)	11 (22.0)	13 (26.0)	0.815
> 3° IR	1 (1.0)	1 (2.0)	0	1.000
> 3° ER	23 (23.0)	10 (20.0)	13 (26.0)	0.635
Femorotibial rotational mismatch (°)	0.67 ± 3.01 (–8 to 10)	1.00 ± 3.28 (–8 to 10)	0.34 ± 2.71 (–5 to 7)	0.306
Femorotibial rotational mismatch > 10°	0	0	0	-

Values are presented as mean ± standard deviation (range) or number (%). A *p*-value of < 0.05 indicates statistical significance.
MR: measured resection, GB: gap-balancing, IR: internal rotation, ER: external rotation.

Table 3. Incidence of Rotational Outlier of Knee Prostheses

Variable	MR group (n = 50)	GB group (n = 50)	*p*-value
Outlier of femoral component	0	4	0.117
Outlier of tibial component	11	13	0.815
p-value	0.001	0.017	

A *p*-value of < 0.05 indicates statistical significance.
MR: measured resection, GB: gap-balancing.

Charlson Comorbidity Index of ≥ 3. All patients had preoperative varus alignment. There was no significant difference in age, sex, body mass index, Charlson Comorbidity Index, or degree of preoperative deformity between the groups.

There was a significant difference between the MR and GB groups with respect to the rotational angle of the femoral component (0.28° ± 1.16° vs. 1.52° ± 1.31°, $p < 0.001$), but the rotational angle of the tibial component was not significantly different between the two groups (1.28° ± 3.17° vs. 1.86° ± 2.81°, $p = 0.220$) (Table 2). The average femorotibial rotational mismatch in the MR and GB groups was 1.00° ± 3.28° and 0.34° ± 2.71°, respectively, without significant difference ($p = 0.306$). No patient had a femorotibial mismatch of > 10°.

There were 11 outliers in the MR group and 13 in the GB group (Table 3). There were fewer outliers in the MR group than in the GB group (femoral component: 0 vs. 4, $p = 0.117$; tibial component: 11 vs. 13, $p = 0.815$). In the MR group, 1 tibial component had > 3° internal rotation and 10 tibial components had > 3° external rotation. In the GB group, 4 femoral components had > 3° external rotation and 13 tibial components had > 3° external rotation. Compared to the femoral component, the tibial component was associated with a higher incidence of outliers deviating from the sTEA in both the MR and GB groups. Intra- and interclass correlation coefficients for all parameters were considered excellent.

DISCUSSION

In this study, we found that the femoral components of the GB group were more externally rotated than those of the MR group. The GB group also tended to have a higher incidence of rotational outliers of the femoral components (deviating > 3° from sTEA). However, the mean angle of tibial rotation, the incidence of outliers deviating from the sTEA, and the rotational mismatch were not significantly different between the two groups.

Achieving correct rotational alignment of both the femur and tibia is critical to success after TKA. The sTEA has been reported to approximate the knee joint flexion-extension axis[3] and has been used as a reference for rotational placement of both the femoral and tibial prostheses in TKA.[4] Strategies to determine the rotational alignment of the femur with reference to the PCA have been reported to be variable among patients and can range from 1.3° internally rotated to 10.4° externally rotated relative to the sTEA.[7] Also, the degree of posterior condylar erosion was a major concern.[19] Therefore, it could be deceptive to use only the PCA as the sole reference to set the rotational alignment of the femoral component without considering other factors, such as coronal deformity.[7] However, we demonstrated that the MR group (using the PCA as anatomical reference) achieved an average femoral rotation that was closer to being parallel to the sTEA than did the GB group. This is consistent with the findings of Nagamine et al.,[20] which showed a consistent relationship between the PCA and epicondylar axis, particularly in knees with medial tibiofemoral arthritis. The epicondylar axis is also reliable when the posterior condyles show bony erosion.[21] For the GB technique, rotational resection of the femur relies on an accurate proximal tibial resection and tension of the collateral ligaments.[16,22] Thus, these factors may cause an inappropriate rotational resection of the femur. For instance, a varus tibial cut could cause the femoral component to be more internally rotated, whereas a tight medial flexion gap could lead to excessive femoral resection in external rotation.[16] To overcome this potential error, we used computer navigation to confirm the alignment of the proximal tibial cut and appropriate tension of the collateral ligaments. Despite this, we still observed 1.2° greater external rotation of the femoral component in the GB group than in the MR group, and this finding is similar to the results demonstrated in a recent meta-analysis.[9] Additionally, the number of outliers with an external rotation of > 3° was higher in the GB group, implying that it is more difficult to reproduce a consistent rotation of the femoral component with this technique. Nevertheless, there were no outliers with internal rotation of the femoral component in the GB group, and the outcomes of TKA with an externally rotated femoral component were more favorable than those with internal rotation.[23]

Currently, there is no established consensus regarding the method for achieving the precise rotational alignment of the tibial prosthesis, and rotational malalignment of the tibial component is considered a key factor in rotational mismatch.[14] While various historically used anatomical landmarks have resulted in high variability of tibial component positioning,[24] the self-aligned or range of movement technique, which allows the tibial component to rotate freely with respect to the femoral component during cycles of knee flexion and extension, was introduced to determine the tibial component rotation. Despite the GB group showing significantly greater external rotation of the femoral component in the present study, we found that the rotational angle of the tibial component and femorotibial rotational mismatch were not significantly different between the MR and GB groups. Additionally, we found the rotational alignment of the tibial component had a significantly higher incidence of outliers deviating from sTEA than that of the femoral component in both groups. This means that the rotationally malaligned femoral implant can eventually lead to a malaligned tibial rotational placement. The polyethylene insert's survival may be jeopardized by rotational incongruity that is caused by severe malrotation of the tibial component. Theoretically, the precise rotation of the femoral component and soft-tissue balancing are required for the self-aligned procedure to work and maintain proper kinematics. The tibial component tended to have slightly greater external rotation in the GB group than in the MR group as a result of a greater external rotation of the femoral component, although there was no significant difference. Therefore, the outcome of this method can be influenced by improper femoral component rotation. We have to admit that the reason more outliers were seen in the tibial prostheses is one of the potential drawbacks of the self-aligned technique but this may not have any effect on clinical outcomes because there was no patient who had > 10° of rotational mismatch, which would theoretically increase strain on the tibial cortex after TKA.[18] The reason for these findings may be because the self-aligned technique is influenced not only by the femoral component rotation but also by femorotibial kinematics, patellar tracking, and soft-tissue tension.[12,17,25] Both MR and GB groups in our study had the soft tissue and collateral ligaments balanced to preserve knee kinematics and this can be a crucial factor to determine the final tibial component rotation and mismatch between the femoral and tibial components. Hence, our findings may emphasize that the self-aligned technique could accommodate the tibial component into appropriately rotational angle, lessen the femorotibial rotational mismatch, and ensure optimal kinematics of the knee joint regardless of the femoral cutting technique performed.

Our study has some limitations. First, it may not be possible to generalize our findings to other types of knee prostheses. While sacrificing the posterior cruciate ligament in a posterior-stabilized TKA might help balance the tight medial flexion gap and reduce the need to increase external rotation of the femoral component in the GB group, Heesterbeek et al.[26] demonstrated a mean rotation of the femoral component ranging from 5° to 12° of external rotation relative to the posterior condyles when performing cruciate-retaining TKA. Secondly, the rotational alignment of the tibial component in the present study was determined by CT only in the extension position. Currently, three-dimensional CT has become increasingly popular as it can mitigate several factors, including lower limb position and joint contracture, which may influence the accuracy and reliability of conventional two-dimensional CT imaging.[27,28] Lastly, our study included predominantly female patients (n = 86), which may be associated with different femoral geometry compared to male patients. Koh et al.[29] demonstrated gender differences in both medial and lateral posterior condyle morphology, and this could contribute to variation in the PCA between men and women. The femoral component of the GB group was associated with a 1.2° greater degree of external rotation when compared to the MR group. Despite this, by using a self-aligned technique for tibial component placement, there was no significant difference between the GB and MR groups regarding the rotational angle of the tibial component and femorotibial rotational mismatch.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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