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Original

Correlation of External Rotational Alignment of the Tibial Component with 2-Year Clinical Outcomes after Guided-Motion Total Knee Arthroplasty

Tatsunori Kataoka[1], Norishige Iizawa[2], Tokifumi Majima[3] and Makoto Hirao[3]

[1]Department of Orthopaedic Surgery, Nippon Medical School Chiba Hokusoh Hospital, Chiba, Japan
[2]Department of Orthopaedic Surgery, Heisei Tateishi Hospital, Tokyo, Japan
[3]Department of Orthopaedic Surgery, Nippon Medical School Hospital, Tokyo, Japan

Background: Proper rotational alignment of the femoral and tibial components is critical for successful total knee arthroplasty (TKA). However, few studies have focused on the effect of external rotation of the tibial component on patient-reported outcomes after guided-motion TKA. This study assessed the association between tibial rotational alignment and patient-reported outcomes in patients with neutral alignment in all other planes.

Methods: This retrospective cohort study at a regional institutional hospital analyzed data from patients who underwent primary TKA for knee osteoarthritis and had no postoperative coronal malalignment, malrotation of the femoral component, internal tibial rotation, or component rotational mismatch. Rotational alignment of the tibial component was evaluated using computed tomography, and its association with postoperative 2011 Knee Society Score was evaluated using Spearman correlation analysis.

Results: The study included 32 knees from 32 patients. The tibial component was 4.8°±6.2° externally rotated postoperatively. An externally rotated tibial component was associated with a smaller flexion angle (at 6 months: $r=0.37$, $p=0.04$; at 2 years: $r=0.43$ $p=0.02$), lower objective score (at 2 years: $r=0.32$, $p=0.02$), symptoms (at 6 months: $r=0.50$, $p=0.003$), and satisfaction (at 6 months: $r=0.37$, $p=0.04$).

Conclusions: Tibial rotational alignment may affect flexion angle and clinical outcomes of TKA. Excessive external rotation should be avoided in guided-motion prostheses. Future studies should attempt to identify thresholds for rotational alignment of the tibial component.

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Keywords: total knee arthroplasty, rotational alignment, patient reported outcomes

Introduction

Total knee arthroplasty (TKA), the gold-standard treatment for advanced knee osteoarthritis, results in excellent long-term survival[1]. However, patient satisfaction with TKA is low and worse after TKA than after total hip arthroplasty[2]. Many factors contribute to patient dissatisfaction after TKA, including unmet expectations, postoperative pain, and malalignment[3,4].

Regarding rotational alignment, femoral component orientation is referenced to the posterior condylar axis, midtrochlear line (Whiteside's line), and transepicondylar axis[5,6]. For tibial rotational alignment, Akagi's line, tibial tuberosity, and the second metatarsal have been reported as landmarks[7,8]. Inadequate rotational alignment causes polyethylene wear, patellofemoral disorders, and anterior knee pain, all of which contribute to dissatisfaction[9–11]. Internal rotation of the femoral and tibial components should be specifically avoided. Conversely, external rotation of the tibial component did not affect patient-reported outcomes[12]. However, previous studies of the as-

Correspondence to Tatsunori Kataoka, 1109tk1986@nms.ac.jp
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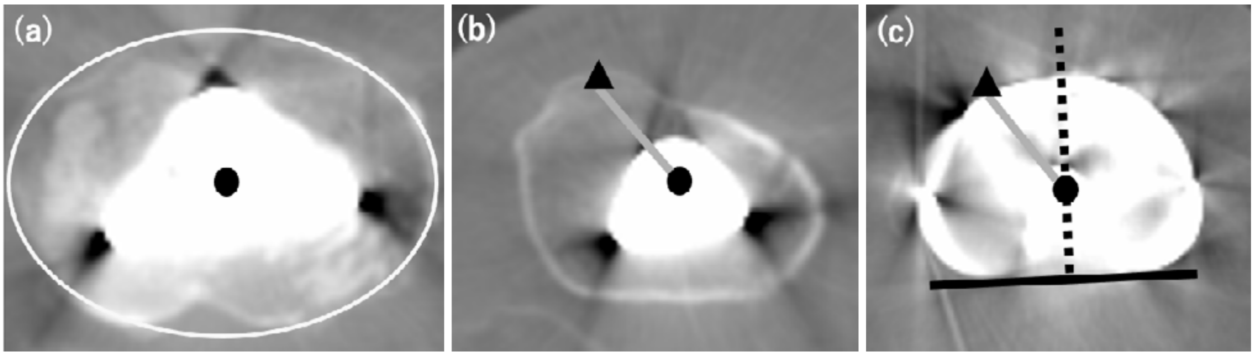

Figure 1 Berger method applied to the asymmetric tibial component
(a) The geometric center of the proximal tibia (black circle) is identified in the slice immediately distal to the component by drawing the best fit oval (white oval). (b) The tip of the tibial tubercle (black triangle) is identified on the slice in which the tubercle is most protruded. The two points are connected, and the resulting line represents the anatomical axis of the tibia (gray solid line). (c) The posterior surface of the component (solid line) is identified by connecting the medial and lateral posterior margins of the component, and a line perpendicular to the posterior surface (dotted line) is drawn.

sociation between malrotation and patient-reported outcomes did not account for the mutual relationship of each component. Furthermore, no study evaluated the influence of rotational alignment of the tibial component on patient-reported outcomes for guided-motion TKA, where the tibia is forced to internally rotate during knee flexion to reproduce the medial pivot motion. When internal rotation is excessive, the iliotibial band may become taut, resulting in knee pain[13].

We hypothesized that excessive external rotational alignment of the tibial component in guided-motion TKA would result in worse clinical outcomes. We assessed the relationship between rotational alignment of the external tibial component and patient-reported outcomes in a group of patients with neutral alignment in all other planes.

Materials and Methods

This retrospective study was performed at Nippon Medical School Chiba Hokusoh Hospital and approved by the Institutional Review Board of Nippon Medical School Chiba Hokusoh Hospital (approval number: 878). All patients provided informed consent using an opt-out method. Data were collected for patients who underwent primary TKA for knee osteoarthritis between April 2020 and March 2022. All patients had an asymmetric tibial component and available postoperative computed tomography (CT) scans, and all procedures were performed by the same fellowship-trained orthopedic surgeon with over 10 years of experience. The exclusion criteria included revision TKA or TKA with augmentation, osteoarthritis of the knee secondary to rheumatoid arthritis, infection, trauma, and a history of surgery in the vicinity of the knee, including around-the-knee osteotomy. To exclude the effects of postoperative alignment factors other than tibial external rotation, patients were not included in the analysis if they had postoperative coronal malalignment, malrotation of the femoral component, internal rotation of the tibial component, and component rotational mismatch.

Coronal alignment was evaluated using femoral tibial angle via standing anteroposterior (AP) whole-leg radiographs, defined as the lateral angle between the anatomical axes of the femur and tibia. Patients with varus alignment were excluded[4]. Rotational alignment was measured on CT images obtained using a helical two-dimensional scanner (Scenaria, Hitachi, Ltd., Tokyo, Japan) operating at 120 kV with a slice thickness of 2.5 mm. Images were loaded and measured using OsiriX software version 11.0 (Pixmeo SARL, Bernez, Switzerland). For the femoral component, rotational alignment was defined by measuring the angle between the surgical epicondylar axis (SEA) of the femur and the line connecting the posterior surface of the femoral component. Patients with >3° of internal rotation were excluded[14].

Postoperative tibial rotational angle was also measured on CT images. First, the geometric center of the proximal tibia was identified in the slice distal to the component by drawing a best-fit oval (**Figure 1a**). Next, the tip of the tibial tubercle was identified on the slice in which the tubercle was most protruded (**Figure 1b**). The two points were connected, and the resulting line represented the anatomical axis of the tibia. Finally, the posterior surface of the tibial component was identified by connecting the medial and lateral posterior margins of the component, and a perpendicular line of the posterior surface was drawn (**Figure 1c**). This process is identical to the Berger method[10] and has been used in recent studies of tibial rotational alignment[15,16]. However, this method is applicable only for symmetric tibial components, where the AP axis and posterior surface of the component are perpendicular.

Because the tibial components implanted in this study were asymmetrical, to evaluate the angle between the anatomical axis of the tibia and the AP axis of the component, 8° of the angle between the AP axis and the perpendicular line of the posterior surface of the implanted component confirmed by the manufacturer was subtracted from the angle between the anatomical axis of the tibia and the perpendicular line of the posterior surface (**Figure 2**). Subsequently, 18° was subtracted, in accordance with the method of Berger et al.[10]. The value is negative when the tibial component is externally rotated. Three observers evaluated interobserver and intraobserver reliability, 0.92 and 0.78, respectively. Patients with internal tibial rotation of >4.3° were excluded[12].

In total, 47 knees from 42 patients were considered; we excluded two knees from two patients owing to health problems not related to the operation, two knees from two patients owing to coronal malalignment, five knees from five patients owing to tibial internal rotation, and one knee from one patient owing to the patient's relocation. Furthermore, only the initial knee was included in bilateral cases, which led to exclusion of five knees from five patients. After applying the exclusion criteria, data for 32 knees from 32 patients were analyzed. The mean patient age was 71.5±5.6 (61–84) years, and the study sample included three knees from three men and 29 knees from 29 women. The Evolution cruciate-substituting (CS) TKA (MicroPort Orthopedics, Arlington, TN, USA) implant was used.

TKA was performed after midline skin incision and medial parapatellar arthrotomy. Cruciate ligaments, meniscus, and bony spurs were subsequently removed, and distal femoral and proximal tibial cuts were performed perpendicular to the mechanical axis. The posterior tibial slope was targeted as 3°, in accordance with the manufacturer's recommendation. The posterior femur was cut parallel to the SEA. After completing the bone cuts, stepwise medial soft tissue releases were performed when required. The extension and flexion gaps were measured with a spring-loaded ligament balancer (Umihira Co. Ltd., Kyoto, Japan)[17]. The tibial and femoral components were fixed, according to Akagi's line and the bone cut surface, respectively, and the polyethylene surface was

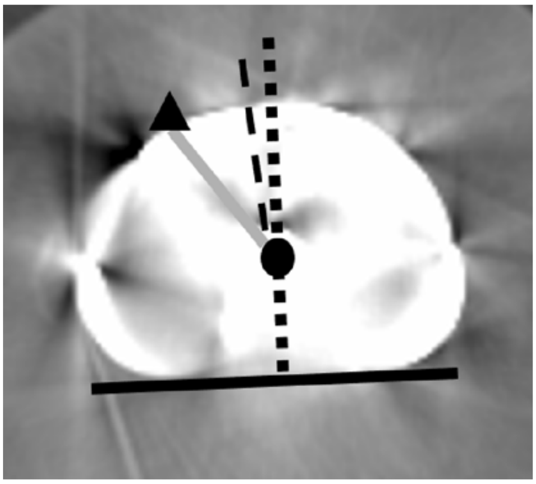

Figure 2 Final calculation to determine rotational alignment in the asymmetric tibial component
The angle between the anatomical axis of the tibia (gray line) and the anteroposterior (AP) axis of the component (black dashed line) is determined by subtracting the angle between the AP axis and the line perpendicular to the posterior surface (black dotted line), namely, 8°, from the angle between the anatomical axis of the tibia and the line perpendicular to the posterior surface.

then inserted according to the gap measured by the ligament balancer and spacer block.

The correlation of the tibial rotational alignment with each subscale of the 2011 Knee Society Score was evaluated at 6 months and 1 and 2 years postoperatively.

Statistical Analysis

All statistical analyses were performed using SPSS version 27.0 (IBM Corp., Armonk, NY, USA). For power analysis, the power level was set as 80% with a 0.05 significance level, and the effect size was set at 0.5. The analysis indicated a requirement of 30 knees. The correlation between tibial rotational alignment and outcomes was analyzed using Spearman correlation analysis. Statistical significance was set at $p<0.05$.

Results

The exclusion criteria resulted in no patients with malalignment and malrotation, and the tibial component was externally rotated by 4.8°±6.2° (**Table 1**). The extension angle, objective scores, symptoms, walking and standing, standard activities, advanced activities, discretionary activities, and satisfaction subscales significantly improved (**Table 2**). In contrast, expectations significantly worsened (**Table 2**). Tibial rotational alignment was significantly positively correlated with flexion angle (6 months: r=0.37, p=0.04; 2 years: r=0.43 p=0.02), objective score (2 years: r=0.32, p=0.02), symptoms (6 months: r=0.50, p=0.003), and satisfaction (6 months: r=0.37, p=0.04), confirming that tibial external rotation had an adverse effect (**Table 3** and **Figures 3–5**). Conversely, tibial rotational alignment was significantly negatively correlated with walking and standing (1 year: r=0.52, p=0.002; 2 years: r=0.41, p=0.04) and expectation (2 years: r=0.46, p=0.02), indicating the positive effect of tibial external rotation (**Table 3**).

Table 1 Preoperative and postoperative coronal alignment and postoperative femoral and tibial rotational alignment

Parameter	Mean ± SD
Femoral tibial angle	
Preoperative	184.6°±6.2°
Postoperative	175.7°±2.9°
Postoperative rotational alignment	
Femoral component	–0.3°±1.5°
Tibial component	–4.8°±6.2°

Negative values represent external rotation.

Discussion

Our findings confirm that externally rotated tibial components resulted in smaller flexion angles, lower objective scores, better symptom scores, and greater satisfaction at 6 months and a smaller flexion angle at 2 years in patients with neutral alignment in all other planes. To our knowledge, this is the first study to clarify the correlation between tibial external rotation and 2-year outcomes for guided-motion TKA.

In a study of patient-reported outcomes and tibial rotational alignment, Barrack et al.[11] found a significant dif-

Table 2 Preoperative and postoperative extension angle, flexion angle, and 2011 Knee Society Score

		Postoperative			
	Preoperative	6 months	1 year	2 years	p-value
Extension angle	10.3°±5.1°	2.2°±3.8°	1.6°±3.2°	1.3°±2.8°	*<0.05*
Flexion angle	118.9°±10.6°	119.4°±9.0°	120.8°±8.8°	121.4°±6.7°	0.09
2011 Knee Society Score					
Knee score					
Objective score	34.4±16.6	64.0±16.4	64.3±15.1	68.8±12.7	*<0.05*
Symptoms	8.5±5.3	19.8±4.3	22.0±2.6	22.0±3.5	*<0.05*
Function score					
Walking/standing	15.6±6.9	22.0±7.4	23.7±7.3	24.7±6.7	*<0.05*
Standard activities	17.1±5.2	24.4±4.5	25.3±3.7	25.6±3.5	*<0.05*
Advanced activities	7.2±3.6	9.6±6.1	12.3±5.3	12.0±5.6	*<0.05*
Discretionary activities	5.8±3.9	7.3±4.8	8.9±4.3	8.3±5.1	*0.03*
Satisfaction	14.5±5.4	27.6±6.5	29.2±6.6	31.0±6.4	*<0.05*
Expectation	13.6±1.7	10.0±2.5	10.1±2.5	11.3±2.6	*<0.05*

Table 3 Correlation between tibial rotational alignment and postoperative outcomes

	6 months		1 year		2 years	
	r	p	r	p	r	p
Extension angle	–0.13	0.47	–0.07	0.72	0.15	0.43
Flexion angle	0.37	0.04	0.24	0.22	0.43	0.02
2011 Knee Society Score						
Knee score						
Objective scores	0.17	0.34	0.02	0.91	0.32	0.02
Symptoms	0.50	0.03	0.09	0.95	0.23	0.25
Function score						
Walking/standing	–0.29	0.11	–0.52	0.002	–0.41	0.04
Standard activities	0.15	0.42	0.05	0.80	0.05	0.73
Advanced activities	–0.05	0.80	0.05	0.77	0.03	0.89
Discretionary activities	0.02	0.92	0.10	0.59	0.13	0.51
Satisfaction	0.37	0.04	0.01	0.95	0.30	0.14
Expectation	0.02	0.92	0.02	0.92	–0.46	0.02

r: correlation coefficient, p: p-value.

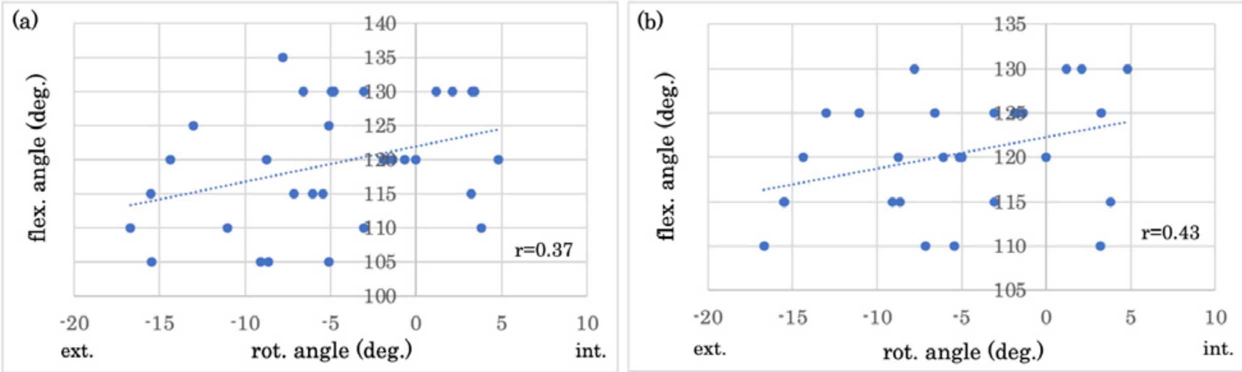

Figure 3 Scatterplot of the association between (a) 6-month and (b) 2-year knee flexion angle and rotational alignment of the tibial component
Negative values for rotational angle indicate that the tibial component is externally rotated.

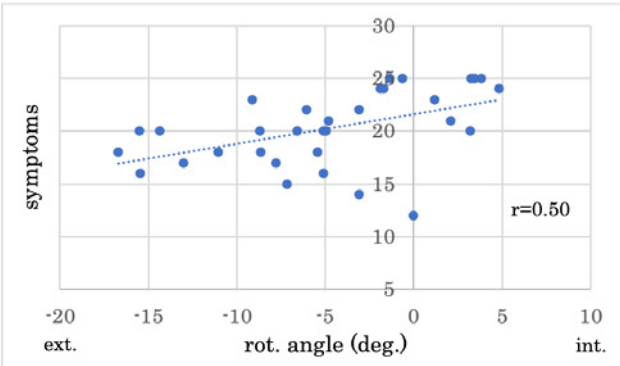

Figure 4 Scatterplot of 6-month 2011 Knee Society Score (KSS) symptom scores and rotational alignment of the tibial component
Negative values for rotational angle indicate that the tibial component is externally rotated.

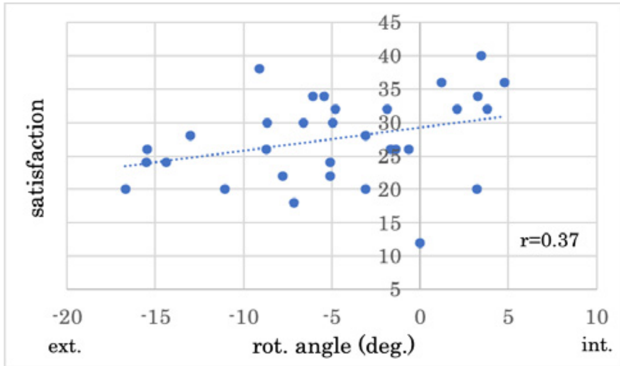

Figure 5 Scatterplot of 6-month 2011 Knee Society Score (KSS) satisfaction scores and rotational alignment of the tibial component
Negative values for rotational angle indicate that the tibial component is externally rotated.

ference in tibial component rotation between patients with anterior knee pain and an asymptomatic control group, while Bell et al.[18] identified internal rotation as an important factor in pain after TKA in a comparison of patients experiencing pain after TKA with a matched control cohort of pain-free patients. Nicoll and Rowley[12] found that 4.3° of internal rotation was associated with knee pain and observed a threshold value of >9° of internal rotation that resulted in pain. A systematic review[15] reported that excessive internal rotation of the tibial component is a risk factor for worse functional outcomes. Therefore, we excluded patients with internal rotational alignment. Consequently, we could not draw a conclusion about internal tibial rotation and patient-reported outcomes in the current study.

External rotation of the tibial component has not been reported to influence patient-reported outcomes. In the current study, when the tibial component was externally rotated, the flexion angle was smaller and patient-reported outcomes were worse, perhaps because of stretching of the iliotibial band, a lateral thickening of the fascia lata in the thigh that passes over the lateral femoral epicondyle and attaches to Gerdy's tubercle on the anterolateral aspect of the tibia. Tibial internal rotation is primarily restricted by the iliotibial band[19], and increased tension of this band results in external tibial rotation during flexion[20]. The current study involved guided-motion TKA, with the implant causing the tibia to internally rotate during knee flexion. Therefore, when the tibial component is externally implanted, the iliotibial band is further stretched in flexion, possibly resulting in lateral knee pain[13]. This could result in decreased knee flexion and worse patient-reported outcomes. Therefore, excessive external rotation should be avoided in a guided-motion implant.

External rotation was positively correlated with the walking/standing and expectations domains, in contrast to the negative correlation for flexion angle, which may be due to the ceiling effect, a statistical construct that describes clustering of patient score towards the upper limit of a scale. If present, variance in the outcome is insufficiently measured above a certain level. Terwee et al.[21] suggested that a ceiling is present when 15% or more of respondents receive the maximum score[21–23]. As half of the present patients had maximum scores for the walking/standing category, and 16% of the patients had maximum scores for the expectations category, the ceiling effect may have influenced the results.

This study has some limitations. First, because clinical outcomes were assessed for only one type of prosthesis, the present results may not be applicable to other implants. Second, the threshold for external rotation was not investigated. In future studies, the threshold of rotational alignment of the tibial component should be clarified. Third, most patients in this study were women. However, because most patients undergoing TKA in East Asia are women, the present study reflects the actual clinical situation. Finally, the patient population was restricted and patients with external rotation of the tibial component were included. However, this was reasonable because the study objective was to evaluate the influence of external tibial rotation in patients with neutral alignment in all other planes. Despite these limitations, we believe that our study yielded clinically important information regarding tibial rotational alignment in TKA.

Conclusions

Tibial rotational alignment may affect 2-year knee flexion angle after guided-motion TKA. Excessive external rotation should be avoided in guided-motion prostheses. Thresholds of rotational alignment of the tibial component should be clarified in future investigations.

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