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Difference in Rotational Alignment of the Tibial Component, as Determined by the Range-of-Motion Technique and Akagi's Line, is Influenced by Tibial Varus Deformity: A Cross-Sectional Study

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Background: Anatomical landmarks and range-of-motion (ROM) techniques are commonly used to rotationally align the tibial component in total knee arthroplasty (TKA). This study investigated; 1) the difference in tibial rotational alignment between the ROM technique and Akagi's line, 2) the influence of preoperative deformity and intraoperative gaps on this difference, and 3) intraoperative tibial rotational kinematics associated with these 2 techniques.

Methods: Patients who underwent cruciate-substituting (CS) TKA (Evolution, Microport Orthopedics) for knee osteoarthritis were enrolled. Intraoperatively, the rotational alignment of the tibial component was determined with the ROM technique and recorded. The difference from the value determined using Akagi's line was evaluated. Correlations among preoperative coronal deformity, postoperative coronal alignment, and intraoperative gaps between the femur and tibia were evaluated. Differences in knee kinematics (rotational movement of the tibia against the femur) between the 2 techniques were compared.

Results: This study included 34 knees from 34 patients. The rotational alignment of the tibial component using the ROM technique was 2.5±6.4° externally rotated in relation to that determined using Akagi's line ($p=0.029$), which was increased in knees with a smaller preoperative medial proximal tibial angle ($r=0.45$). Tibial rotational kinematics did not significantly differ between the 2 techniques.

Conclusions: The ROM technique and Akagi's line yielded significantly different values for the rotational alignment of the tibial component. Orthopedic surgeons using Evolution (CS) should be reminded that in knees with proximal tibial varus deformity, the ROM technique will result in external rotation of the tibial component in relation to Akagi's line. (J Nippon Med Sch 2024; 91: 480–487)

Key words: tibial rotation, varus deformity, medial proximal tibial angle, knee kinematics

Introduction

Accurate rotational alignment in total knee arthroplasty (TKA) is essential for achieving good outcomes; whereas inaccurate rotational alignment causes polyethylene wear, patellofemoral disorders, and anterior knee pain, leading to patient dissatisfaction[1-3].

The rotational alignment of the femoral component has been extensively studied, and the posterior condylar axis, midtrochlear line (Whiteside's line), and transepicondylar axis have been reported as useful intraoperative references[4,5].

The rotational alignment of the tibial component has received less attention. Currently, there are multiple intraoperative techniques, none of which has proven superior. One popular technique relies on anatomical landmarks such as the tibial tuberosity, patella tendon, anterior line of the tibia plateau, and second metatarsal[6,7]. Another technique, the range-of-motion (ROM) technique, involves putting the knee through flexion to extension, allowing the tibial component to set itself in the best po-

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sition of fit relative to the femoral component.

Several studies have reported a relatively small discrepancy in the rotational alignment of the tibial component achieved using the ROM technique and that achieved using Akagi's line, a popular anatomic landmark for aligning the tibial component[8–10]. Notably, Tao et al.[11] reported that 5% of patients demonstrated >10° difference in the rotational alignment of the tibial component between the ROM technique and Akagi's line; however, the effects of preoperative deformity, postoperative alignment, and intraoperative gaps have not been carefully studied.

Medial soft tissue release is often required in knees with increased preoperative varus deformity due to tightness of the medial soft tissues[12], with excessive release leading to rotational instability[13]. Furthermore, the intraoperative joint gap affects postoperative rotational kinematics[14]. Therefore, we hypothesized that an greater preoperative varus deformity or unbalanced intraoperative gap would lead to a larger discrepancy in the tibial rotational alignment between the 2 techniques. To test the hypothesis, we investigated 1) the difference in tibial rotational alignment determined by using the ROM technique and Akagi's line, 2) the influence of preoperative deformity and intraoperative gaps on this difference, and 3) intraoperative tibial rotational kinematics associated with these 2 techniques in the same knee.

Materials and Methods

This single-center, cross-sectional study included consecutive patients who underwent TKA for medial compartment knee osteoarthritis with a cruciate-substituting (CS) prosthesis (Evolution; Microport Orthopedics, Arlington, TN, USA) performed by a single orthopedic surgeon between April 2020 and June 2022. The exclusion criteria were as follows: lateral compartment knee osteoarthritis, revision TKA or TKA with tibial augmentation, knee osteoarthritis secondary to rheumatoid arthritis, infection, trauma, and history of surgery around the knee, including fracture and around-the-knee osteotomy, because the kinematics of such knees are reported to differ from those of varus knees[15]. Patients with missing data were also excluded. The study protocol was approved by the relevant institutional review board (approval number : H-2022-021), and informed consent was obtained from all the patients.

Preoperatively, the lateral femoral-tibial angle (FTA), hip-knee-ankle (HKA) angle, lateral distal femoral angle (LDFA), and medial proximal tibial angle (MPTA) were evaluated using standing anteroposterior (AP) whole-leg radiographs (**Fig. 1**). The FTA was defined as the lateral angle between the anatomical axes of the femur and tibia, and the HKA angle was defined as the angle between the mechanical axes of the femur and tibia, with a positive value indicateing valgus alignment[16]. The LDFA was defined as the lateral angle between the mechanical axis of the femur and the joint line of the distal femur, and the MPTA was defined as the medial angle between the mechanical axis of the tibia and the joint line of the proximal tibia[16]. In addition, the condylar twist angle of the femur, ie, the angle between the posterior condylar axis (PCA) and the surgical epicondylar axis (SEA), was evaluated using plain computed tomography by projecting both lines into onto 1 transverse plane (**Fig. 2**). A positive value was obtained when the SEA was externally rotated in relation to the PCA[5].

All knees were implanted with a CS-guided motion prosthesis (Evolution; Microport Orthopedics) without resurfacing the patella. Rotational knee kinematics were recorded intraoperatively with a navigation system (Stryker Knee Navigation System version 4.0; Stryker Leibinger, Freiburg, Germany). Active infrared sensor built-in trackers were attached to the femur and tibia, and the tourniquet was then inflated. A midline skin incision and a medial parapatellar arthrotomy were performed. The required landmarks were subsequently recorded in the navigation system. The AP axis of the proximal tibia was determined by placing the tip of the pointer at the center of the posterior cruciate ligament (PCL) and aligning it with the medial insertion of the patellar tendon, which corresponds to Akagi's line[6]. This axis was recorded in the navigation system as 0° rotation. Preoperative tibial rotation throughout knee flexion was recorded in the navigation system at 10° increments; positive values indicated that the tibia was internally rotated in relation to the femur. The 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 to be 3°, in accordance with the manufacturer's recommendation, and the posterior femur was cut parallel to the SEA. After completing the bone cuts, stepwise medial soft tissue releases were performed when required[17], and the extension and flexion gaps were then measured with a spring-loaded ligament balancer (Umihira Co. Ltd., Kyoto, Japan)[18]. The femoral trial component was fixed, and the tibial component and trial surface were then inserted according to the gap measured

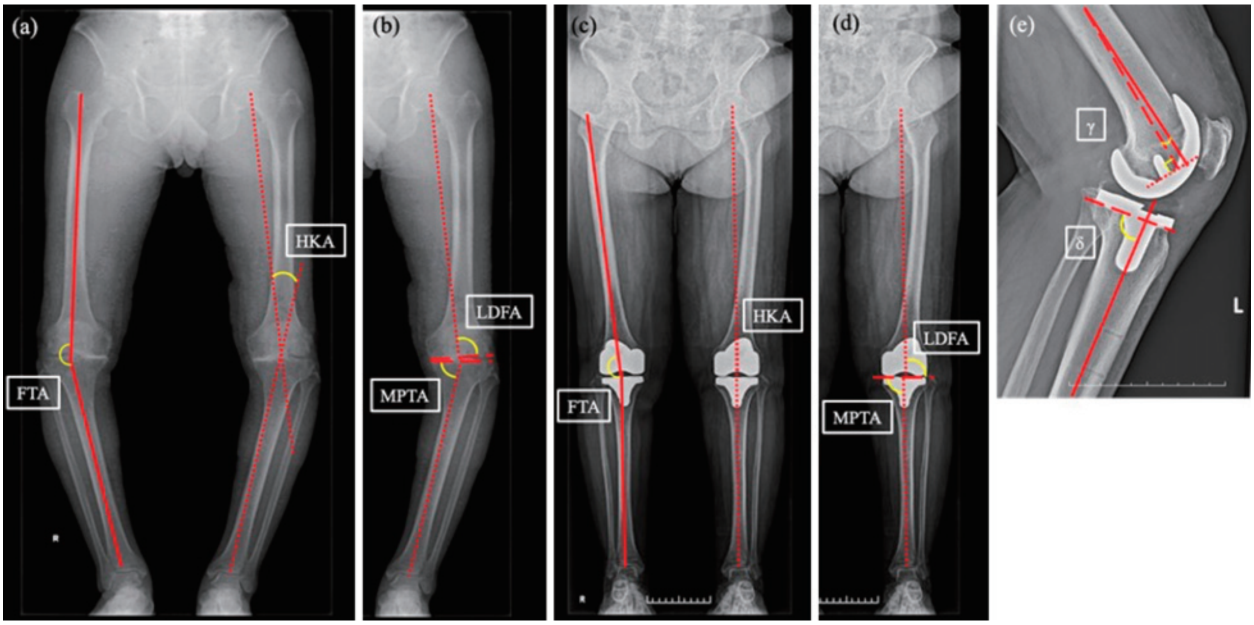

Fig. 1 (a) Femoral-tibial angle (FTA) was defined as the lateral angle between the anatomical axes of the femur and tibia (solid line). Hip-knee-ankle (HKA) angle was defined as the angle between the mechanical axes of the femur and tibia (dotted line), and a positive value indicates valgus alignment. (b) Lateral distal femoral angle (LDFA) was defined as the lateral angle between the mechanical axis of the femur (dotted line) and the joint line of the distal femur (dashed line). Medial proximal tibial angle (MPTA) was defined as the medial angle between the mechanical axis of the tibia (dotted line) and the joint line of the proximal tibia (dashed line). (c), (d) FTA, HKA angle, LDFA and MPTA were evaluated in the same manner as preoperative evaluation. (e) Sagittal alignment of the femoral (γ) and tibial (δ) implants was evaluated according to the knee society evaluating system.

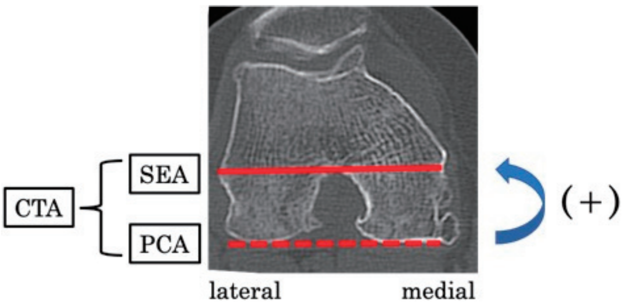

Fig. 2 Condylar twist angle (CTA) of the femur, which is the angle between the posterior condylar axis (PCA) and the surgical epicondylar axis (SEA), was evaluated on plain computed tomography. A positive value was given when the SEA was externally rotated in relation to the PCA.

by the ligament balancer and spacer block. The navigation tracker was connected to a handle of the trial tibial tray. Later, in accordance with the ROM technique, the knee was subjected to 5 full flexion-extension cycles without varus/valgus stress. The rotational alignment of the tibial component was recorded in the navigation system when the knee was in maximal extension after 5 cycles, and the difference from that achieved using Akagi's line was evaluated and defined as ROM-rot. Akagi's line was regarded as the reference and recorded as 0° rotation; thus, the rotational alignment of the tibial component determined by the ROM technique was equal to the difference between the 2 techniques (ROM-rot.). Positive values indicated that the tibial component achieved using the ROM technique was internally rotated in relation to the value recorded using Akagi's line.

Subsequently, the trial tibial tray was locked with a pin in the rotational alignment using the ROM technique. Then, the knee was flexed to the maximal angle from the maximal extension, with the operator supporting the thigh and heel with an open palm to avoid any rotational force on the leg, to record tibial rotation in the navigation system[19]. Next, the implant was rotated and locked with a pin according to Akagi's line, and tibial rotation was recorded similarly. Subsequently, we evaluated the angular difference between tibial rotation at maximal extension and that at each angle for knee kinematic assessment. The final tibial component was then implanted according to Akagi's line, and the insert thickness was decided using the trial insert. Thereafter, FTA, HKA angle, LDFA, and MPTA were evaluated postoperatively. In addition, sagittal alignment (γ and δ) of the femoral and tibial components was evaluated using plain

Table 1 Means of the preoperative and postoperative alignments and the intraoperative gap and their correlation with the difference in rotational alignment of the tibial component between the two techniques (ROM-rot.)

Variables	Mean±SD (range)	95% CI	Correlation with ROM-rot.	
			r	p-value
Pre-operative alignment				
FTA (°)	183.8±5.0 (172.1-190.9)	178.8-188.9	−0.144	0.418
HKA angle (°)	−9.1±4.1 (−17.7-−1.9)	−13.2-−5.0	0.162	0.361
LDFA (°)	1.3±2.1 (−2.31-6.59)	−0.8-3.5	0.091	0.609
MPTA (°)	83.4±2.7 (79.3-89.7)	80.7-86.1	0.45	*0.007*
CTA (°)	−3.3±1.5 (−7.2-−0.1)	−4.8-−1.7	0.10	0.566
Post-operative alignment				
FTA (°)	174.4±3.3 (170.5-184.2)	171.1-177.7	−0.139	0.434
HKA angle (°)	−1.1±2.5 (−6.2-0.6)	−3.5-1.4	0.061	0.731
LDFA (°)	−0.3±1.8 (−4.2-3.0)	−2.1-1.5	−0.24	0.164
MPTA (°)	89.2±1.9 (86.9-92.5)	87.3-91.0	−0.039	0.825
γ (°)	2.9±4.0 (−3.4-9.5)	−1.1-6.9	0.19	0.281
δ (°)	2.9±2.3 (−2.0-8.8)	0.6-5.2	−0.067	0.705
Intraoperative gap				
Extension gap (mm)	21.0±2.5 (15-25.5)	18.5-23.5	0.066	0.709
Flexion gap (mm)	22.6±3.8 (15-28)	18.8-26.4	0.23	0.189

FTA, femoral-tibial-angle; HKA angle, hip-knee-ankle angle; LDFA, lateral distal femoral angle; MPTA, medial proximal tibial angle; CTA, condylar twist angle; ROM, range of motion.

radiographs according to the Knee Society Evaluating System[20](**Fig. 1**).

The primary outcome was the difference in rotational alignment of the tibial component, as determined by the ROM technique and Akagi's line. The secondary outcome was the influence of preoperative varus deformity and intraoperative gap on the tibial rotational alignment and the differences in postoperative tibial rotational kinematics associated with the 2 techniques in the same knee.

Statistical Analysis

Before this study, 10 consecutive TKAs were performed, and the mean difference and standard deviation (SD) were evaluated. In total, 34 participants were required to achieve 80% power to detect a 3° difference, an SD of 6°, and a significance level of 0.05. The difference in the rotational alignment of the tibial component between the 2 techniques was evaluated with the paired t-test. Correlations of ROM-rot. with preoperative/postoperative radiographic parameters and intraoperative extension and flexion gaps were evaluated using Spearman's test. Furthermore, differences in knee kinematics between the 2 techniques at 10° increments were evaluated with the paired t-test. All statistical analyses were performed using SPSS (version 25.0; IBM Corp., Armonk, NY, USA), and statistical significance was set at $p<0.05$.

Results

Data were available for 38 patients, 10 of whom underwent bilateral TKA. In the bilateral TKA cases, only data for the first operated knee were analyzed, resulting in 38 knees (from 3 men and 35 women). Two knees were excluded because of incomplete kinematic data, and 2 knees were excluded because osteoarthritis was due to rheumatoid arthritis. Ultimately, data for 34 knees from 34 patients (3 men and 31 women) were analyzed. The mean patient age was 72.1±5.6 (64-82) years.

Postoperatively, varus alignment was corrected to neutral alignment and the intraoperative gap was adequate (**Table 1**). The deep medial collateral ligament (dMCL) was released in 22 knees (65%), all of which had a preoperative MPTA less than 87°.

The rotational alignment of the tibial component achieved using the 2 techniques differed by −2.5±6.4° (−14° to 12°), which was significant (p=0.03). The rotational alignment achieved using the ROM technique was externally rotated in 23 knees and internally rotated in 11 knees. Notably, 23 knees (68%) demonstrated a difference of >3°, including 6 knees (18%) that demonstrated a difference of >10° (**Fig. 3**).

ROM-rot. was weakly positively correlated with preoperative MPTA (**Fig. 4**). However, no correlations were found between ROM-rot. and the other parameters (**Ta-**

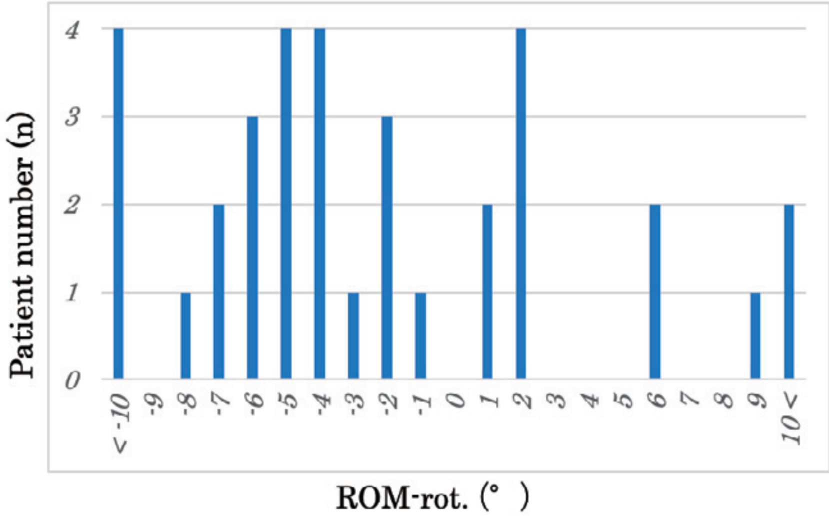

Fig. 3 Difference in tibial rotational alignment between the anteroposterior axis and range-of-motion technique (ROM-rot.). A positive value indicates that the rotational alignment of the ROM technique is internally rotated in relation to Akagi's line.

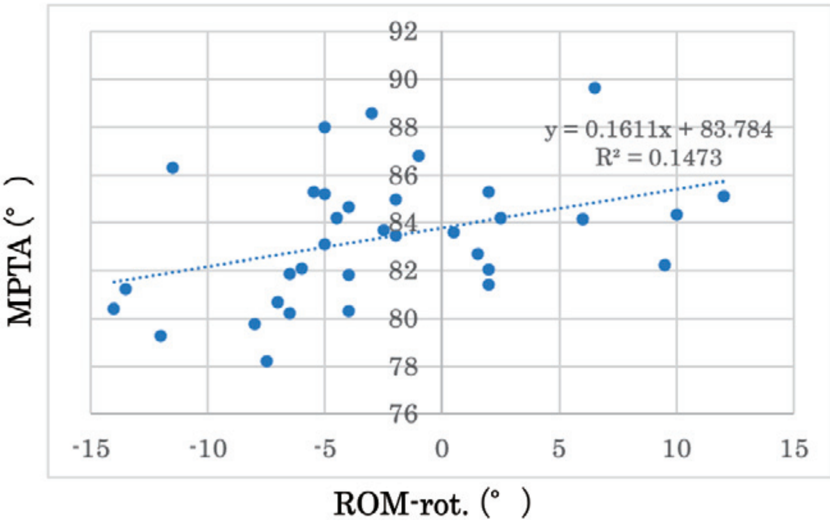

Fig. 4 Scatterplot of the difference in the rotational alignment of the tibial component achieved using the 2 techniques (ROM-rot.) against the medial proximal tibial angle (MPTA). Positive values for ROM-rot. indicate that the rotational alignment achieved using the ROM technique is internally rotated in relation to the anteroposterior axis. ROM-rot. and the MPTA were positively correlated.

ble 1).

Tibial rotational kinematics did not differ between the 2 techniques throughout flexion; the tibia internally rotated from maximal extension to 10°, externally rotated until 50° afterward, and subsequently internally rotated continuously to maximal flexion (**Fig. 5**).

Discussion

The first finding of this study is that the rotational alignment of the tibial component achieved using the ROM technique was significantly externally rotated in relation to the value achieved using Akagi's line; in 18% of the patients, the difference was greater than 10°.

Excessive internal rotation of the tibial component is associated with postoperative pain; 6.2° internal rotation of the tibial component is associated with anterior knee pain[3]. In another study, the threshold that produced pain was >9° internal rotation[21]. In addition, excessive external

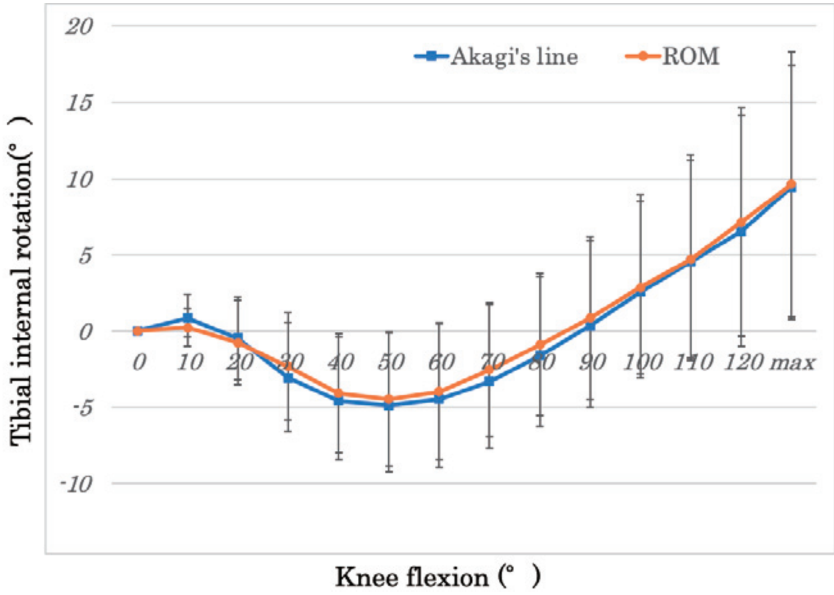

Fig. 5 Means of postoperative tibial rotational kinematics. Tibial rotation was similar between the 2 techniques. The tibia was internally rotated from full flexion to 10°, externally rotated until 50° afterward, and internally rotated continuously until maximal flexion.

rotation decreases postoperative satisfaction[22] and increases the failure rate[23]. Therefore, these problems may occur in many cases if tibial rotational alignment is determined by using the ROM technique only.

The present result is consistent with those reported by Rossi et al.[8] and Feczko et al.[9], who found that the tibial component was externally rotated by 0.35° and 4.6°, respectively, when the values for the ROM technique and Akagi's line were compared. However, the present result contradicts the findings of Ikeuchi et al.[10], who reported that the tibial component achieved using the ROM technique was internally rotated by 1.6°. The reason for this discrepancy may be the PCL status; the present study used CS implants, and Rossi et al.[8] and Feczko et al.[9] used posterior substituting implants that resected the PCL. In contrast, Ikeuchi et al.[10] used cruciate-retaining implants that retained the PCL. Ishida et al.[24] reported that the tibia internally rotates after PCL resection. The tibial component was not fixed to the tibial surface during the ROM technique; therefore, the tibial trial component may have been relatively externally rotated on the tibial surface.

The average degree difference between the 2 techniques was small; however, when accounting for absolute values, the difference increased to 5.7°, and 6 knees (18%) demonstrated a >10° difference between the 2 techniques. This proportion is larger than that reported by Tao et al.[11], who reported that 5% of knees demonstrated a difference >10°. This may be because they locked the tibial component on the tibia and used a mobile-bearing implant where the tibial insert rotated at the center of the implant. In this case, the rotational movement of the tibial implant may be less than that obtained by placing the component on the tibial surface without stabilization.

The second finding of the present study is that ROM-rot. was positively correlated with preoperative MPTA. Preoperative coronal alignment was reported to influence rotational alignment of the tibial component achieved using the ROM technique, and as compared with valgus knees, varus knees exhibit an externally rotated tibial component[25]. However, the present study did not find a correlation of rotational alignment with the FTA or HKA angle, perhaps because valgus knees were not included. In contrast, we found a positive correlation between ROM-rot. and the MPTA. Because of increased preoperative varus deformity of the proximal tibia, the ROM technique increases the external rotation of the tibial component in relation to Akagi's line, possibly because medial soft tissue release is required in knees with a small MPTA[26]. In the present study, 71% (22/31) of patients with an MPTA <87° underwent the dMCL release, whereas no patients with an MPTA >87° underwent the dMCL release. Release of the dMCL leads to rotatory instability in TKA[13] and may have influenced rotational alignment of the tibial component as determined by the ROM technique. Orthopedic surgeons should be reminded that in knees with increased preoperative varus deformity of the proximal tibia, the ROM technique may result in external rotation of the tibial component in relation to Akagi's line because of the release of medial soft tissues.

The intraoperative gap may also influence rotational alignment of the tibial component achieved using the ROM technique. With a tight medial or lateral gap, movement of the tibial component may be restricted to the tight compartment and may affect its rotational alignment. However, no correlation was observed between rotational alignment achieved using the ROM technique and the intraoperative gap, perhaps because the intraoperative gap was adequate and the difference between the included cases was small.

Rotational alignment of the tibial component affects the kinematics (the rotational relationship between the femur and tibia during flexion) of the knee joint[27,28]. Knee flexion and patient satisfaction after TKA are affected by postoperative knee kinematics[29]; therefore, we evaluated intraoperative kinematics by measuring the angular difference between the tibial rotational position at maximal extension and that at each angle. Intraoperatively, the tibia internally rotated, subsequently externally, rotated and then internally rotated again until maximal flexion. Knees with external tibial rotation in the early flexion phase are abnormal, perhaps because of the resected anterior cruciate ligament and symmetrical shape of the femoral component; however, further research is necessary to confirm this. Furthermore, as compared with the ROM technique, no difference in intraoperative kinematics was observed when the tibial component was implanted according to Akagi's line. This may be because the implant used in the present study was a guided motion medial pivot prosthesis, which causes each knee to rotate similarly when the tibial component was aligned within 10° from Akagi's line, which most of knees achieved. However, because the present study included only 6 knees with large differences between the 2 techniques, further studies are required in order to compare kinematics in a larger number of knees.

This study had several limitations. First, we only used 1 type of implant; therefore, no conclusion about the effects of other prostheses can be inferred. A similar study using different types of implants is ongoing. Second, each implant was fixed according to Akagi's line, and no conclusion could be derived regarding the superiority of a technique. Third, most patients in this study were women. However, most patients undergoing TKA in East Asia are women; therefore, the present study reflects the actual clinical situation. Finally, selective bias may have occurred because of the exclusion of valgus knees and knees with secondary osteoarthritis. However, excluding these knees is justifiable because their kinematics differ from those of varus knees[15]. Despite these limitations, we believe that our study has yielded clinically important information on tibial rotational alignment in TKA.

Conclusions

The mean difference in rotational alignment of the tibial component between Akagi's line and ROM technique was small; however, 18% of the knees demonstrated a difference of > 10°. Orthopedic surgeons should be reminded that in knees with a smaller preoperative MPTA the ROM technique will result in a larger external rotation of the tibial component, as compared with Akagi's line when using a CS-guided motion implant.

Data availability: The data supporting this study's findings are available from the corresponding author, TK, upon request.

Author contributions: TK performed all the operations, collected the data and drafted the manuscript. NI, YO, and TM participated in and helped to draft the manuscript. All authors read and approved the final manuscript.

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Conflict of Interest: None.

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