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Association between femorotibial rotational mismatch and early clinical outcomes after bi-cruciate retaining total knee arthroplasty

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Abstract

Background Bi-cruciate retaining (BCR) total knee arthroplasty (TKA) is considered to provide improved clinical function and kinematics compared with conventional TKA, but it is unclear which factors affect clinical outcomes after BCR TKA. This study aimed to investigate whether rotational alignment of the femoral and tibial components and rotational mismatch between the femoral and tibial components affected early clinical outcomes after BCR TKA, according to the 2011 version of the Knee Society Score (2011KSS).

Methods This retrospective cohort study included 39 knees that underwent BCR TKA. Rotational alignment of the femoral and tibial components and rotational mismatch between the components were measured by computed tomography based three-dimensional evaluation software. 2011KSS was obtained at 3, 6, and 12 months postoperatively. The relationship of each of rotational alignment and rotational mismatch with 2011KSS was analyzed.

Results Rotational alignment of the femoral and tibial components was not correlated with symptoms, patient satisfaction, patient expectations, or functional activities at 3, 6, or 12 months postoperatively. Rotational mismatch was negatively correlated with symptoms, patient satisfaction and functional activities at 3 months; negatively correlated with symptoms and functional activities at 6 months; and negatively correlated with symptoms, patient satisfaction, patient expectations and functional activities at 12 months postoperatively.

Conclusions Rotational mismatch between the femoral and tibial components was negatively correlated with 2011KSS, whereas no relationship of rotational alignment of the femoral and tibial components with 2011KSS was observed. Excessive external rotation of the tibial component relative to the femoral component resulted in worse early clinical outcomes.

Keywords Rotational mismatch, Rotational alignment, Clinical outcomes, Bi-cruciate retaining, Total knee arthroplasty

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Background

Conventional total knee arthroplasty (TKA), as cruciate retaining (CR) or posterior stabilized (PS) designs, offer good long-term results in terms of survival and clinical outcomes [1, 2]. However, patient-reported outcome measures indicate that many patients remain dissatisfied after TKA [3, 4]. Simultaneous medial and lateral tibiofemoral osteoarthritis could be treated with bi-cruciate retaining (BCR) TKA and bi-unicompartmental knee arthroplasty (Bi UKA) as an alternative to total knee arthroplasty (TKA) [5–7]. BCR TKA is an alternative technique for TKA [8]. Its design enables preservation of both the anterior and posterior cruciate ligaments, with the aims of restoring joint kinematics to near normal, restoring posterior femoral rollback, preserving normal proprioception, and reproducing medial pivot rotation [9–12]. Several studies have reported patient preference for BCR TKA over the conventional TKA designs [13, 14]. However, there are concerns regarding technical difficulties, risks of complications, long term survival, and functional outcomes [15, 16].

Rotational malalignment of components is reportedly associated with inferior outcome, severe knee stiffness, knee pain, abnormal gait patterns, and early revision arthroplasty in conventional TKA [17–24]. Alternatively, in BCR TKA, both the anterior and posterior cruciate ligaments are retained and it is unclear whether femorotibial rotational parameters are associated with clinical outcomes. The authors hypothesized that rotational mismatch between the femoral and tibial components was associated with inferior clinical outcome after BCR TKA. The aim of this study was to investigate whether rotational alignment of the femoral and tibial components and rotational mismatch between the femoral and tibial components after BCR TKA were correlated with the new 2011 version of the Knee Society Scoring System (2011KSS).

Methods

Patient selection

This retrospective case series was approved by the ethics committee of our institution (No.H2018-083) and the 1964 Helsinki Declaration and its later amendments [25]. Our institution performed consecutive TKAs between April 2017 and February 2019. The inclusion criteria were knees with primary varus osteoarthritis and with both cruciate ligaments intact and functional. The retention of both cruciate ligaments were confirmed by magnetic resonance imaging and visualized intraoperatively. The exclusion criteria were knees with flexion contracture ≥ 20°, valgus deformity, and revision TKA. Ultimately, the study analyzed 39 consecutive knees of 33 patients who underwent primary BCR TKA (Vanguard XP Total Knee System; Biomet, Warsaw, IN). All preoperative and postoperative evaluations were performed by the author (ST) and all operations were performed by a senior surgeon (MH).

Radiological analysis

All patients underwent pre- and postoperative computed tomography (CT) for assessment of component alignment. Postoperative CT was performed 2 weeks after surgery. Helical CT was performed from the hip to the ankle with a 1-mm slice interval in all cases. Pre- and postoperative CT data were imported into Zed Knee System (LEXI Co., Tokyo, Japan), a validated CT-based three-dimensional (3D) preoperative planning and postoperative evaluation software program for TKA [26–29]. On preoperative CT, seven reference points were plotted on the femur to define the mechanical axis in the sagittal and coronal planes, the surgical epicondylar axis (SEA), and the posterior epicondylar axis. Twelve reference points were then plotted on the tibia to define the mechanical axis in the sagittal and coronal planes, as well as the anteroposterior axis (from the medial third of the patellar tendon attachment to the middle of the posterior cruciate ligament). Reference points defined on preoperative CT were then transferred to the postoperative CT by matching the preoperative and postoperative CT images. Therefore, the component positions and rotations could be evaluated using common perioperative reference points.

Baselines of the femoral and tibial components were defined in the coronal and sagittal planes relative to the mechanical axis; and those of rotational alignment were defined relative to the SEA of the femur and anteroposterior axis of the tibia. Postoperative rotational alignment of each of the femoral and tibial components was measured as the angle relative to baseline (Fig. 1a, b). Postoperative rotational mismatch was measured as the angle of the tibial component relative to the femoral component (Fig. 1c). A positive alignment value indicated valgus alignment with the component in the coronal plane, flexion, or posterior tilt in the sagittal plane. A positive rotational alignment value indicated an externally rotated position of the femoral or tibial component relative to baseline. A positive value of rotational mismatch indicated an externally rotated position of the tibial component relative to the femoral component.

Surgical procedure

The Vanguard XP system used in this study is a recently developed TKA with a U-shaped symmetrical tibial component that retains the anterior and posterior cruciate ligaments. The anterior portion of the tibial component consists of a broad bar to provide sufficient rotating-beam fatigue strength. The femoral component

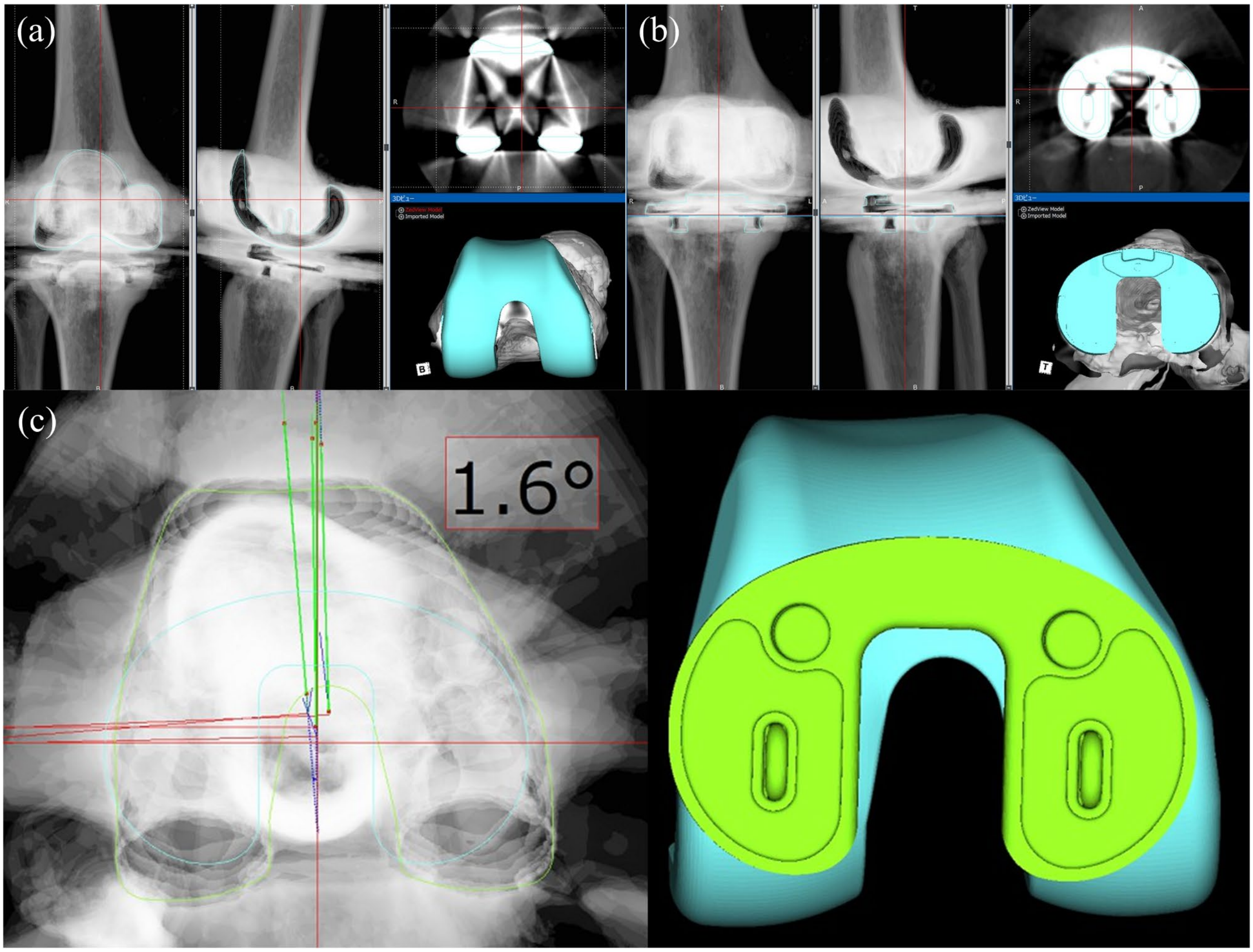

Fig. 1 Assessment of rotational alignment and rotational mismatch. (**a**) Rotational alignment of the femoral component, (**b**) rotational alignment of the tibial component, and (**c**) rotational mismatch between the femoral and tibial components

has a new-generation design with a narrowed and funnel-shaped anterior femoral flange.

BCR TKA was performed by the mid-vastus approach after inflating the tourniquet to 300 mmHg at the beginning of the procedure. Distal femoral osteotomy was performed perpendicular to the mechanical axis in the coronal plane identified on preoperative 3D-CT planning, using an accelerometer-based portable navigation system. Femoral rotational alignment was adjusted to the surgical epicondylar axis of the femur. An extramedullary resection guide was used for the tibial osteotomy. The osteotomy angle aimed to be perpendicular to the mechanical axis in the coronal plane. In the sagittal plane, the osteotomy angle was decided by the native tibial posterior slope of each patient. If a patient had a tibial posterior slope of ≥ 10°, the osteotomy angle was set to 10° in the sagittal plane. Tibial rotational alignment was adjusted to the medial third of the patellar tendon attachment. The anterior and posterior cruciate ligaments were protected during femoral preparation and the tibia was prepared with a guide designed to preserve a bone island with the anterior cruciate ligament insertion. The patella was resurfaced during all TKAs. The thickness of patellar resection was determined by the thickness of the patellar component to be used. The patellar components were positioned medially and superiorly to the center of the patellar cut surface to prevent patellar maltracking. All TKAs were confirmed to have no intraoperative patellar maltracking. On the first day after BCR TKA, patients were allowed to walk with full weight bearing after the drainage tube had been removed.

Clinical evaluation

The 2011 KSS was developed in 2011 that included a current patient-reported outcome section that also measures satisfaction, functional activities, and expectations. The 2011 KSS has been validated in terms of reliability and consistency [30]. The 2011 KSS has been widely adopted worldwide, and several translation and validation studies have been published in other languages [31–34]. The patient-reported outcome measurement portion of the Japanese version of the 2011KSS was evaluated at 3, 6, and 12 months postoperatively. The 2011KSS comprises 3 questions regarding symptoms, 5 regarding satisfaction, 3 regarding expectations, and 18 regarding functional activities [29, 35]. Patients graded the 2011KSS items as follows: symptoms, maximum 25 points; satisfaction, maximum 40 points; expectations, maximum 15 points; and functional activities, maximum 100 points [36].

Statistical analysis

All statistical analyses were performed with EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan), a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria). Simple linear regression analysis between the alignment of the femoral and tibial components in the coronal, sagittal, and rotational planes and each parameter of the 2011KSS were analyzed. Simple linear regression analysis between rotational mismatch between the femoral and tibial components and each parameter of the 2011KSS were also analyzed. Continuous data were analyzed using the nonparametric Spearman's rank correlation coefficient. Values of $P < 0.05$ were considered significant.

Multivariate logistic regression analysis was performed to evaluate the predictive factors of poor clinical outcomes based on each parameter of the 2011KSS at 12 months. The results are presented as odds ratios with 95% confidence intervals.

According to a previous study, the following cut-off values of the 2011KSS were defined as a indicative of a poor clinical outcome: symptoms, ≤ 17 points; satisfaction, ≤ 20 points; expectations, ≤ 9 points; and functional activities, ≤ 43 points [26].

A post hoc power analysis was performed with G*Power version 3.1.9 (University of Kiel, Germany). A prior power analysis showed that 34 knees were required to detect a moderate correlation (0.40), with a power of 0.80 and alpha error of 0.05.

The reproducibility of rotational alignment and rotational mismatch was confirmed. For intra-observer reliability, each parameter was randomly measured twice in 10 knees, at an interval of ≥4 weeks, by one orthopedic surgeon (ST). For inter-observer reliability, two orthopedic surgeons (ST and YN) measured each parameter twice in 10 knees, at an interval of ≥4 weeks. Intra-class and inter-class correlation coefficients were calculated to analyze variability between observers. Values of 0.81–1.00 indicated excellent correlation; 0.61–0.80, substantial correlation; 0.41–0.60, moderate correlation; 0.21–0.40, fair correlation; and 0.00–0.20, poor correlation.

Table 1 Patient demographics

Variable	Results
Age at operation, years	75.4 ± 8.1
Gender (male: female)	5: 34
Operation side (right: left)	18: 21
Height, cm	151.1 ± 6.9
Weight, kg	56.9 ± 8.0
Body mass index, kg/m^2	24.8 ± 2.6
Preoperative knee flexion angle, °	129.2 ± 12
Preoperative knee extension angle, °	7.6 ± 5.2
K-L grade (3: 4)	18: 21
Preoperative hip-knee-ankle angle, °	171.7 ± 4.1

Results

The patient demographics are listed in Table 1. The intra-class and inter-class correlation coefficients for rotational alignment of the femoral component were 0.90 and 0.99, respectively. The intra-class and inter-class correlation coefficients for rotational alignment of the tibial component were 0.99 and 0.99, respectively. The intra-class and inter-class correlation coefficients for rotational mismatch between the femoral and tibial components were 0.99 and 0.99, respectively.

Mean rotational alignment angle of the femoral component was 1.7 ± 1.7° (range, −1.9° to 5.6°). Mean rotational alignment angle of the tibial component was −2.8 ± 5.0° (range, −17.3° to 5.5°). Mean rotational mismatch angle between the femoral and tibial components was 1.7 ± 1.7 (range, −9.0° to 16.1°). Mean values of symptoms, patient satisfaction, patient expectations and functional activities at 3, 6, and 12 months postoperatively were shown in Table 2.

Table 2 Mean values of clinical parameters of the 2011KSS at 3, 6, and 12months postoperatively

	symptoms	Patient satisfaction	Patient expectations	Functional activities
Preoperative (point)	11.9 ± 5.3 (0–23)	15.2 ± 5.3 (4–28)	12.7 ± 2.3 (3–15)	48.0 ± 15.0 (18–74)
3 months postoperatively (point)	18.3 ± 5.1 (6–25)	23.1 ± 7.0 (8–38)	8.7 ± 2.4 (3–14)	56.2 ± 14.4 (35–93)
6 months postoperatively (point)	19.1 ± 5.4 (3–25)	23.0 ± 6.2 (12–38)	8.5 ± 2.2 (3–14)	58.9 ± 17.5 (25–97)
12 months postoperatively (point)	20.3 ± 3.9 (8–25)	24.8 ± 7.2 (14–40)	8.8 ± 2.5 (4–15)	62.8 ± 17.2 (27–98)

Table 3 Correlation between rotational parameters and 2011KSS at 3 months postoperatively

		symptoms	Patient satisfaction	Patient expectations	Functional activities
Rotational alignment of femoral component (°)	Correlation coefficient	0.143	-0.0624	0.0897	-0.00811
	p value	0.417	0.71	0.592	0.961
Rotational alignment of tibial component (°)	Correlation coefficient	-0.0191	-0.0265	0.18	-0.137
	p value	0.91	0.875	0.28	0.412
Rotational mismatch between femoral and tibial components (°)	Correlation coefficient	-0.398	-0.484	-0.259	-0.465
	p value	< 0.05*	< 0.01*	0.117	< 0.01*

*Significant difference: $p < 0.05$

Table 4 Correlation between rotational parameters and 2011KSS at 6 months postoperatively

		symptoms	Patient satisfaction	Patient expectations	Functional activities
Rotational alignment of femoral component (°)	Correlation coefficient	0.14	0.0335	0.135	0.019
	p value	0.397	0.84	0.412	0.908
Rotational alignment of tibial component (°)	Correlation coefficient	0.00595	0.0636	-0.0593	-0.183
	p value	0.971	0.701	0.72	0.265
Rotational mismatch between femoral and tibial components (°)	Correlation coefficient	-0.366	-0.304	-0.308	-0.452
	p value	< 0.05*	0.0564	0.0564	< 0.01*

*Significant difference: $p < 0.05$

Table 5 Correlation between rotational parameters and 2011KSS at 12 months postoperatively

		symptoms	Patient satisfaction	Patient expectations	Functional activities
Rotational alignment of femoral component (°)	Correlation coefficient	0.138	0.129	-0.0464	0.119
	p value	0.401	0.434	0.779	0.471
Rotational alignment of tibial component (°)	Correlation coefficient	-0.0656	-0.026	-0.0863	-0.24
	p value	0.691	0.686	0.601	0.142
Rotational mismatch between femoral and tibial components (°)	Correlation coefficient	-0.53	-0.43	-0.539	-0.396
	p value	< 0.01*	< 0.01*	< 0.01*	< 0.05*

*Significant difference: $p < 0.05$

No correlation was found for component alignment in either the coronal or sagittal plane with symptoms, patient satisfaction, patient expectations, or functional activities at 3, 6, or 12 months postoperatively. Tables 3, 4 and 5 show the correlation between each rotational parameter and 2011KSS at 3, 6, and 12 months postoperatively. Rotational alignment of the femoral and tibial components was not significant difference with all parameters at 3, 6, and 12 months postoperatively. Rotational mismatch between the femoral and tibial components was negatively correlated with symptoms, patient satisfaction and functional activities at 3 months postoperatively, with symptoms and functional activities at 6 months postoperatively, and with all parameters of 2011KSS at 12 months postoperatively. Figure 2 shows the distributions between rotational mismatch and each 2011KSS category at 12 months postoperatively. External rotation of the tibial component relative to the femoral component reduced the score in all parameters of 2011KSS at 12 months postoperatively. The multivariate logistic regression analysis for each parameter of the 2011KSS revealed that rotational mismatch between femoral and tibial component was an independent risk factor for poor symptoms of the 2011KSS at 12 months. The odds ratio was 1.69 (Table 6).

Discussion

The main finding of this study was the negative correlation between rotational mismatch of the tibial component relative to the femoral component and most of the 2011KSS parameters at 3, 6, and 12 months after BCR TKA. Specifically, excessive external rotation of the tibial component relative to the femoral component caused worse early clinical results. Namely, excessive external rotation of the tibial component relative to the femoral component affected pain worsening and decreased satisfaction. On the other hand, no rotational mismatch and internal rotation of the tibial component relative to the femoral component tended not to result in pain worsening and decreased satisfaction.

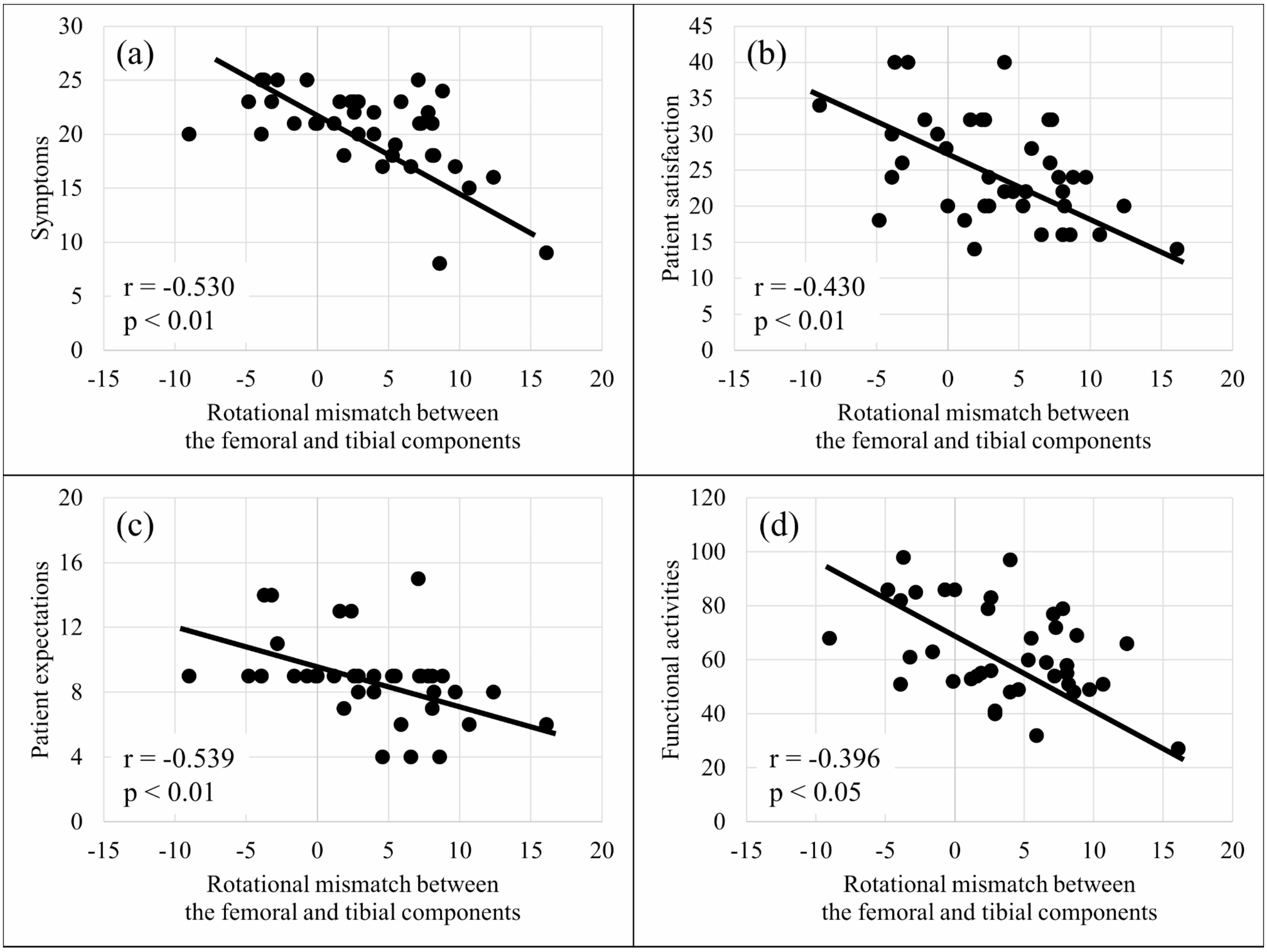

Fig. 2 Correlation between rotational mismatch and 2011KSS at 12 months postoperatively. Rotational mismatch was negatively correlated with all clinical parameters of the 2011KSS

Table 6 Multivariate logistic regression analysis for poor symptoms of the 2011 KSS at 12months

	Odds ratio	95% Confidence Interval	*p* value	VIF
Age	0.96	0.81–1.14	0.64	1.46
Body mass index	0.86	0.35–2.90	0.74	2.69
Gender (male = 0, female = 1)	0.73	0.01–149	0.90	1.91
Preoperative knee flection angle	1.07	0.96–1.19	0.22	1.48
Rotational alignment of femoral component	1.34	0.61–2.94	0.46	1.37
Rotational alignment of tibial component	1.01	0.73–1.41	0.95	1.26
Rotational mismatch between femoral and tibial components	1.69	1.04–2.75	< 0.05	1.16

VIF: Variance Inflation factor, *significant difference: $p < 0.05$

Implants that can preserve both the anterior and posterior cruciate ligaments include BCR TKA and Bi UKA, both of which have reported good clinical outcomes. Pritchett reported that survival analysis of BCR TKA designs with follow-up of up to 24 years showed a survival rate of 89% [37]. Sabouret et al. showed similarly good results using BCR TKA on 163 knees with a mean follow-up of 22.4 years [38]. On the other hand, Confalonieri et al. reported similar survivorship and better outcomes for Bi UKA at a minimum follow-up of 4 years compared to TKA [39]. However, there are no reports that have mentioned rotational alignment and rotational mismatch of the components that preserve both the anterior and posterior cruciate ligaments.

Several studies have reported the relationship between rotational alignment of the femoral component and clinical outcomes after conventional TKA. Kawahara et al. reported that internal rotation of the femoral component relative to the surgical epicondylar axis significantly decreased the score of functional activities and slightly decreased the score of satisfaction in 2011KSS for PS TKA with fixed bearing [40]. Thielemann et al. reported that both internal and external rotational femoral malalignment exceeding 3° was associated with significantly poorer Knee Society Score and Knee Injury and

Osteoarthritis Outcome Score at 5 to 7 years after CR TKA with fixed bearing [41]. Regarding rotational alignment of the tibial component, Nicoll et al. reported that internal rotational errors of the tibial component were a major cause of pain and functional deficit after CR and PS TKA with fixed bearing.

In contrast, few reports have investigated the relationship between rotational mismatch and clinical outcome after conventional TKA [42]. Lutzner et al. reported that rotational mismatch of beyond ±10° among the femoral and tibial components resulted in worse functional scores using the Knee Society score after CR TKA with rotating platform [43]. In our previous study, postoperative rotational mismatch of the femoral and tibial components was correlated with postoperative numerical rating scale scores at one year in BCR TKA [44].

To the best of our knowledge, no previous report has investigated the relationship of rotational mismatch between the femoral and tibial components with early clinical outcomes using patient-reported outcome measures after BCR TKA. Therefore, this study is the first to report the factors affecting early clinical outcomes after BCR TKA. This finding of the study is in disagreement with those of previous studies in conventional TKA. The difference can be attributed to the retention of both cruciate ligaments, which may affect the reduction of rotational permittance between the components. It is known that SEA is a useful reference axis for determining the rotational alignment of the femoral component, whereas there is disagreement regarding the reference axes for rotational alignment of the tibial component because of the high variability in rotational alignment of the tibial component among the axes [20, 45–50]. Moreover, the rotational position of the tibial baseplate in BCR TKA might depend on the tibial attachment of the anterior cruciate ligament. Therefore, it is difficult to determine the rotational reference axis of the tibial component in BCR TKA; i.e., the rotational position of the appropriate components is unknown. However, the present results suggest that minimizing postoperative rotational mismatch between the femoral and tibial components might improve clinical outcomes.

There were several limitations in this study. First, this study had a small cohort size. Second, CT scans deliver a higher radiation dose compared to the patient compared with conventional radiography [51]. However, the present results confirm the usefulness of CT evaluation, which enables evaluation of the rotational alignment of the components that is difficult to achieve with conventional radiography. Third, CT scans were performed in the supine position without weight bearing. Therefore, it is unclear whether the same results would be obtained in the standing position with weight bearing. Fourth, since the only clinical parameter used in this study was the 2011KSS, it is difficult to compare the results of this study to other clinical studies because the results of this study may not necessarily align with other clinical parameters. Fifth, the 2011 KSS was reported to have high clinical quality but low completion rates [52]. However, omissions did not occur because the patients' completion status was monitored in this study. When using the 2011 KSS as a clinical outcome, it is important to check for omissions.

Conclusion

The study evaluated whether rotational alignment of the femoral and tibial components and rotational mismatch of the components were associated with 2011KSS following BCR TKA. Rotational mismatch between the femoral and tibial components was negatively correlated with 2011KSS. Excessive external rotation of the tibial component relative to the femoral component resulted in worse early clinical outcomes.

Abbreviations

TKA	Total knee arthroplasty
CR	Cruciate retaining
PS	Posterior stabilized
BCR	Bi-cruciate retaining
2011KSS	New 2011 version of the Knee Society Scoring System
CT	computed tomography
3D	Three-dimensional
SEA	Surgical epicondylar axis

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Not applicable.

Author contributions

ST collected the data, performed the measurement and analysis, participated in the study design and drafted the manuscript. MH participated in the study design, supervised the analysis and helped to draft the manuscript. YN collected the data, performed the measurement, help to draft the manuscript. HW participated in the study design. AS participated in the study design and coordination, supervised the analysis. All authors read and approved the final manuscript.

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Data availability

The datasets used and analysed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by Institutional Review Board at Mie University hospital. All patients provided their informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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