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Anterior Position of the Femoral Condyle During Mid-Flexion Worsens Knee Activity After Cruciate-Retaining Total Knee Arthroplasty

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ABSTRACT

Background: The effects of kinematics on patient-reported outcome measures (PROMs) after cruciate-retaining (CR) total knee arthroplasty (TKA) remain unclear. This study investigated the effects of kinematic patterns after CR-TKA on PROMs.

Methods: We examined 35 knees (27 patients) undergoing primary CR-TKA. Knee kinematics and 2011 Knee Society Score were evaluated at a mean follow-up of 72.4 ($\pm$ 28.2) months. Knee kinematics was analyzed using fluoroscopy, and the femoral antero-posterior position relative to the tibial component was assessed separately for medial and lateral compartments during a squat. The correlations between kinematics and PROMs were evaluated.

Results: The average amount of posterior femoral translation from full extension to maximum flexion was 0.2 ($\pm$ 2.6) mm for the medial femoral condyle and 4.1 ($\pm$ 2.9) mm for the lateral condyle. Medial pivot motion was observed in 24 knees (68.6%) with a low rate (14.3%) of paradoxical anterior translation. The anterior position of the medial femoral condyle at 60° had a negative impact on discretionary activities ($\rho = -0.37$; $P = .039$), and at maximum flexion, had a negative impact on total functional activities ($\rho = -0.46$; $P = .005$), advanced activities ($\rho = -0.45$; $P = .006$), and discretionary activities ($\rho = -0.63$; $P < .001$). Anterior position of the lateral femoral condyle at 30° had a negative impact on total functional activities ($\rho = -0.48$; $P = .005$), walking and standing ($\rho = -0.56$; $P < .001$), and advanced activities ($\rho = -0.49$; $P = .004$), and at 60° had a negative impact on walking and standing ($\rho = -0.45$; $P = .010$).

Conclusions: The anterior positions of the medial and lateral femoral condyles at mid-flexion and maximum flexion had negative impacts on PROMs. Soft tissue conditions should be carefully managed to achieve medial knee joint stability, which can improve PROMs.

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Achieving near-normal kinematics is a goal of total knee arthroplasty (TKA); however, it is difficult to reproduce normal kinematics after TKA [1]. Dissatisfaction after TKA has been reported by approximately 20% of patients [2]. Aberrant kinematics may have some impact, but it is necessary to determine which

elements of the various kinematic patterns after TKA have the maximum effect on patient-reported outcome measures (PROMs).

Several studies have demonstrated relationships between kinematics and PROMs [3–8]. During closed kinetic chain movements, patients who have poor PROMs after TKA experience more anterior translation on the medial side followed by a medial mid-flexion instability and less posterior translation on the lateral side in deep flexion compared to patients who have good PROMs [7]. Higher values of anterior translation of the lateral compartment correlate with higher clinical scores, whereas higher values of anterior translation of the medial compartment correlate with lower clinical scores [3]. However, the relationships between kinematics and PROMs have been evaluated in posterior-stabilized (PS), medial-stabilized, or bicruciate-substituting implants. Unlike these implant designs, the posterior cruciate ligament (PCL) is

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Table 1
Characteristics of the Study Population.

Variables	35 Knees (27 Patients)
Age at surgery, y	73.0 ± 7.5 (51 to 82)
Age at fluoroscopy, y	79.2 ± 7.9 (57 to 91)
Sex, men/women	15 (42.9%)/20 (57.1%)
Side, right/left	14 (40.0%)/21 (60.0%)
Height, cm	156.4 ± 11.4 (137.9 to 179.4)
BW, kg	63.3 ± 11.4 (43.5 to 91.3)
BMI, kg/m ²	25.8 ± 3.6 (21.0 to 35.9)
Follow-up duration, mo	72.4 ± 28.2 (35 to 121)

BW, body weight; BMI, body mass index.

preserved in cruciate-retaining (CR) TKA without a prosthetic postcam mechanism or congruity between the femoral component and the tibial insert, which means that the kinematic pattern of CR-TKA is dependent on soft tissue balance. However, little information is available regarding the effect of knee kinematics on PROMs in CR-TKA.

Soft tissue balance affects postoperative knee kinematics, in which postoperative larger medial knee joint gaps are correlated with more anterior position of the medial femoral condyle from 0 to 60° flexion during a squat [9]. Intraoperative medial soft tissue release is occasionally performed in TKA for severe varus knees to balance the medial and lateral joint gaps. However, over-release

results in a large medial gap, which may have an unfavorable effect on clinical outcomes [10, 11]. We previously proposed a surgical technique to preserve the structures of superficial medial collateral ligament (MCL) and PCL without ligamentous release (the medial stabilizing technique), which may aid in improving postoperative medial knee joint stability [12, 13]. However, the kinematics and its direct impact on PROMs after CR-TKA performed using the ligament-preserving technique remains unclear.

Thus, the present study aimed to analyze knee kinematics during a squat using a 2-dimensional (2D) to 3-dimensional (3D) registration technique after CR-TKA with ligament preserving technique, and to investigate the effect of the kinematic patterns on PROMs. The hypotheses were that a medial pivot pattern similar to that of healthy knees would be achieved in CR-TKA without ligamentous release, and that the anterior position of the medial femoral condyle relative to the tibia would have a negative impact on PROMs.

Materials and Methods

Patients

A cohort of 96 consecutive knees of 75 patients who underwent CR-TKAs (NexGen CR-Flex, Zimmer Biomet, Warsaw, Indiana, USA) was enrolled. The inclusion criteria were (1) severe radiographic

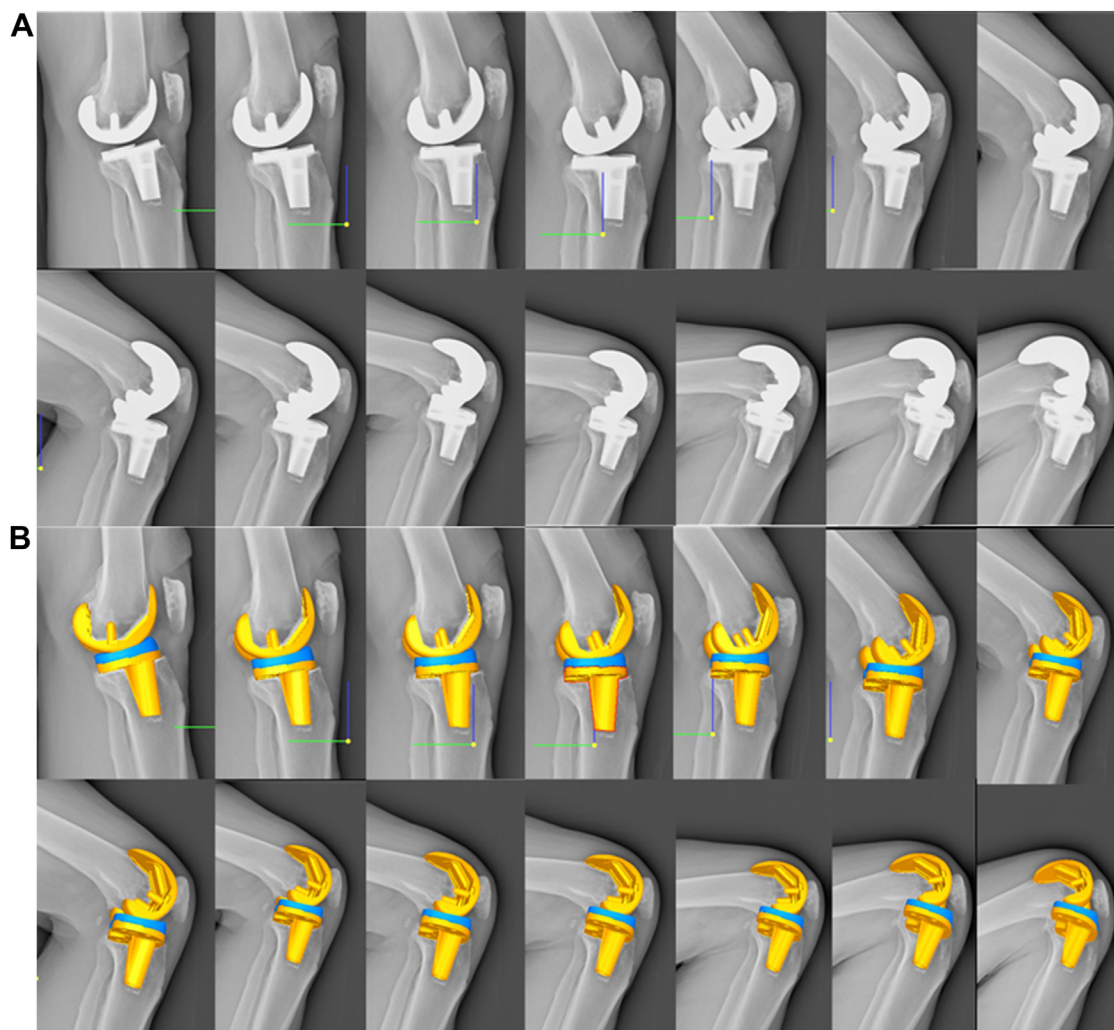


Fig. 1. Kinematics was analyzed using a 2-dimensional to 3-dimensional registration technique. The figures show a squat from full extension at the top left to maximum flexion at the bottom right, before (A) and after (B) image matching.

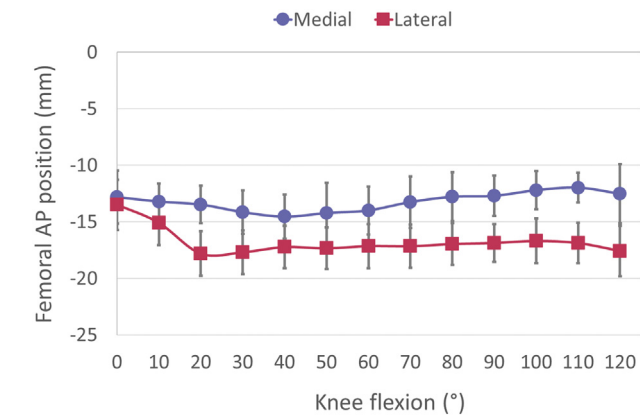


Fig. 2. The average anteroposterior positions of the medial and lateral femoral condyles every 10° from 0 to 120° of flexion during a squat. The lateral femoral condyle was always positioned posterior to the medial femoral condyle, and translated more posteriorly than the medial femoral condyle throughout the range of motion.

osteoarthritis (Kellgren-Lawrence grades 3 and 4) with varus alignment and (2) patients scheduled for primary TKA. Patients who had severe bone defects, valgus alignment, inflammatory arthritis, and knees with attenuated PCL function as determined by preoperative subjective symptoms, manual testing, and lateral knee radiographs were excluded from the study. Overall, 13 patients (17 knees) were lost to follow-up, and 5 patients (6 knees) died. Participants were recruited via telephone between August 2, 2022 and September 1, 2023. A total of 27 patients (35 knees) willingly participated in the study. Patient characteristics are listed in Table 1. This prospective study was approved by our institutional review board (R-3486) and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all the participants prior to the commencement of the study.

Surgical Techniques

All surgeries were performed or supervised by a single senior surgeon, using a medial stabilizing technique [12, 13]. The NexGen CR-Flex had a flat tibial surface and multiple radius femoral components. Using a medial parapatellar approach, the distal femur was cut perpendicular to the femoral mechanical axis in the coronal plane and parallel to the distal femoral anatomical axis in the sagittal plane. The axial rotation of the femoral component was aligned with the surgical epicondylar axis. The femoral component size was determined based on a posterior reference. The proximal tibia was also cut perpendicular to the tibial mechanical axis in the coronal plane, approximately 10 mm from the most proximal surface of the lateral tibial plateau, while retaining the PCL attachment as a bone island. The posterior tibial slope (PTS) was aimed at equal to that of the original PTS. The maximum PTS was set at 10°. The

Table 2
The Amount of AP Translations of the Medial and Lateral Femoral Condyles.

Flexion Phases	AP Translation (mm)	
	Medial	Lateral
Early flexion (full extension to 30°)	-1.1 ± 1.5 (-5.2 to 2.1)	-3.8 ± 2.5 (-8.0 to 1.4)
Mid-flexion (30 to 60°)	0.3 ± 1.5 (-3.0 to 3.5)	0.4 ± 1.5 (-2.4 to 5.0)
Late flexion (60 to 90°)	1.4 ± 1.0 (-1.7 to 3.4)	0.3 ± 1.5 (-3.4 to 2.7)
Deep flexion (90° to maximum flexion)	-0.9 ± 2.3 (-7.7 to 1.9)	-1.5 ± 2.7 (-9.7 to 2.0)

AP, anteroposterior.

Table 3
Preoperative and Postoperative 2011 KSS.

2011 KSS	Preoperative Scores	Postoperative Scores	P Value ^a
Symptoms	10.3 ± 5.5 (0 to 19)	22.2 ± 3.1 (12 to 25)	<.001
Patient satisfaction	16.1 ± 5.9 (6 to 32)	31.7 ± 7.7 (18 to 40)	<.001
Patient expectation	13.9 ± 1.5 (10 to 15)	10.5 ± 2.9 (4 to 15)	<.001
Total functional activities	50.1 ± 20.2 (4 to 88)	77.1 ± 21.6 (27 to 100)	<.001
Walking and standing	17.1 ± 8.6 (0 to 30)	24.5 ± 7.7 (5 to 30)	<.001
Standard activities	17.4 ± 5.9 (6 to 28)	24.9 ± 5.5 (12 to 30)	<.001
Advanced activities	8.8 ± 5.6 (1 to 21)	16.7 ± 7.3 (2 to 25)	<.001
Discretionary activities	7.9 ± 3.7 (0 to 13)	11.1 ± 4.3 (0 to 15)	<.001

KSS, Knee Society Score.
^a Wilcoxon signed-rank test.

axial rotation of the tibial component was aligned with the tibial antero-posterior (AP) axis parallel to the line connecting the PCL attachment and the medial margin of the patellar tendon. The concept of the medial stabilizing technique is to preserve medial soft-tissue structure. The deep MCL was detached from the tibial attachment approximately 1 centimeter distal to the medial tibial articular surface, and the osteophytes were resected. No additional medial soft-tissue release was performed to achieve an equal medio-lateral joint gap balance, even if greater lateral laxity was observed in comparison to the medial side. A tight MCL or PCL was managed with bone re-cutting or downsizing of the femoral component, and ligamentous release of the superficial MCL or PCL was not performed.

Evaluation of Kinematics and PROMs

Fluoroscopic surveillance was conducted at a mean follow-up of 72.4 months (range, 35 to 121) (Table 1). Patients had to squat at a comfortable pace under single fluoroscopy in the sagittal plane. Motion was dynamically captured at 3 frames per second from full extension to maximum comfortable flexion. Kinematics during the squats was analyzed using a 2D to 3D registration technique (ZedMotion, LEXI, Tokyo, Japan). This technique is based on a contour-based registration algorithm that uses single-view fluoroscopy images and 3D computer-aided design models (Figure 1) [5]. The precision of this software was reported to be 0.3 to 0.8 millimeter (mm) for in-plane translation, 2.2 mm for out-plane translation, and 0.2 to 0.6° for rotation [14, 15]. The AP position of the femoral component in the local coordinate system of the tibial component [5, 9] was analyzed at every 10°. The central point of the tibial component was defined as the origin, and the anterior positions of the femoral component relative to the tibial component were defined as positive values. There were 4 flexion phases defined: early flexion (full extension to 30°), mid-flexion (30 to 60°), late flexion (60 to 90°), and deep flexion (90° to maximum flexion), and >2 mm anterior translation of the femoral component was detected for each flexion phase. The AP position of the most distal point of the femoral component was analyzed separately for the medial and lateral compartments.

Simultaneously, the fluoroscopy patients completed the 2011 Knee Society Score (KSS) as PROMs [16, 17]. The 2011 KSS comprises 4 validated subscales: “symptom” (scored from 0 to 25), “patient satisfaction” (scored from 0 to 40), “patient expectations” (scored from 0 to 15), and “functional activities” (scored from 0 to 100). “Functional activities” is the sum of 4 categories: “walking and standing” (scored from 0 to 30), “standard activities” (scored from 0 to 30), “advanced activities” (scored from 0 to 25), and “discretionary activities” (scored from 0 to 15). Higher scores indicated

Table 4

Correlations Between AP Positions of the Medial and Lateral Femoral Condyles and 2011 Knee Society Score.

2011 KSS	Medial									
	Full Extension		30° Flexion		60° Flexion		90° Flexion		Maximum Flexion	
	ρ	P Value ^a	ρ	P Value ^a	ρ	P Value ^a	ρ	P Value ^a	ρ	P Value ^a
Symptoms	−0.25	.145	0.02	.929	−0.19	.295	−0.28	.132	−0.26	.130
Patient satisfaction	−0.01	.938	0.02	.900	−0.10	.601	0.03	.867	−0.19	.269
Patient expectations	−0.02	.908	−0.33	.061	−0.13	.492	−0.04	.827	−0.11	.539
Total functional activities	0.16	.362	0.07	.689	−0.23	.218	−0.09	.620	−0.46	.005
Walking and standing	0.35	.040	0.14	.434	−0.06	.768	0.06	.743	−0.30	.076
Standard activities	0.17	.336	0.17	.348	−0.13	.489	0.02	.915	−0.26	.134
Advanced activities	0.08	.645	0.03	.856	−0.26	.160	−0.18	.342	−0.45	.006
Discretionary activities	−0.02	.889	−0.07	.703	−0.37	.039	−0.17	.360	−0.63	<.001

2011 KSS	Lateral									
	Full Extension		30° Flexion		60° Flexion		90° Flexion		Maximum Flexion	
	ρ	P Value ^a	ρ	P Value ^a	ρ	P Value ^a	ρ	P Value ^a	ρ	P Value ^a
Symptoms	−0.17	.336	0.04	.832	−0.08	.667	0.02	.908	0.09	.592
Patient satisfaction	−0.09	.618	−0.21	.253	−0.02	.915	0.15	.415	0.10	.573
Patient expectations	0.14	.416	−0.02	.898	−0.00	.980	0.22	.237	0.13	.457
Total functional activities	−0.16	.357	−0.48	.005	−0.29	.117	−0.25	.174	−0.25	.154
Walking and standing	−0.07	.708	−0.56	<.001	−0.45	.010	−0.36	.053	−0.33	.050
Standard activities	−0.02	.926	−0.27	.132	−0.11	.566	−0.16	.388	−0.12	.483
Advanced activities	−0.21	.230	−0.49	.004	−0.30	.100	−0.22	.233	−0.21	.216
Discretionary activities	−0.14	.417	−0.32	.073	−0.13	.475	−0.13	.495	−0.21	.233

Significant differences were shown in bold and italics.

KSS, Knee Society Score; AP, anteroposterior; ρ , correlation coefficient.^a Spearman's rank correlation test.

better outcomes. The correlations of the PROMs with medial and lateral femoral AP positions were evaluated at full extension, 30°, 60°, 90°, and maximum flexion.

Data Analyses

Statistical analyses were performed using the R software (version 4.2.1; R Foundation for Statistical Computation, Vienna, Austria). Categorical data were summarized as frequencies and percentages, and continuous data as means $\pm$ standard deviations and ranges. Normality and homoscedasticity were examined using the Shapiro–Wilk and Levene's tests, respectively. Wilcoxon signed-rank tests were used to compare the preoperative and postoperative data. Mann–Whitney U tests were used to compare AP positions between the subgroups. Correlations between kinematics and PROMs were evaluated using Pearson's correlation or Spearman's rank correlation tests. The level of significance was set at $P = .05$. An *a priori* sample size estimation according to a previous study [3] was performed using G*power version 3.1.9.7 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) with an α error of 0.05 and a power ($1-\beta$) of 0.8, which indicated a requirement of sample size of 21 knees.

Results

Kinematics

The full extension and maximum flexion angles during a squat were 4.9 ± 9.0 (range, -10 to 30) and 108.9 ± 18.9 (range, 75 to 140°), respectively. The AP translation from full extension to maximum flexion was -0.2 ± 2.6 (range, -9.3 to 3.6) mm for the medial femoral condyle and -4.1 ± 2.9 (range, -10.0 to 2.6) mm for the lateral femoral condyle (Figure 2). Medial pivot motion was observed in 24 knees (68.6%), wherein posterior translation of the lateral condyle was more than that of the medial condyle. Paradoxical anterior translation of >2 mm of the medial femoral condyle and both femoral condyles was observed in 4 (11.4%) and 1

(2.9%) knees, respectively. Both medial and lateral femoral condyles translated posteriorly during early and deep flexion and moved slightly anteriorly during mid-flexion and late flexion (Table 2). Paradoxical anterior translation of >2 mm of the medial femoral condyle was observed in 1 (2.9%), 2 (5.7%), and 7 knees (20.0%) during early flexion (full extension to 30°), mid-flexion (30 to 60°), and late flexion (60 to 90°), respectively, and there were no medial femoral condyles with anterior translation >2 mm during deep flexion (90° to maximum flexion). Paradoxical anterior translation of >2 mm of the lateral femoral condyle was observed in 2 knees (5.7%) during both mid-flexion and late flexion, and there were no lateral femoral condyles with anterior translation >2 mm during both early and deep flexion.

2011 KSS

The scores of the 2011 KSS subscales, except for patient expectations, significantly improved postoperatively compared with the

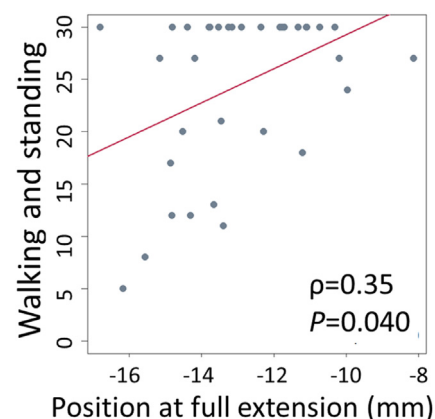


Fig. 3. Scatter plots for the anteroposterior position of the medial femoral condyle at full extension, and walking and standing.

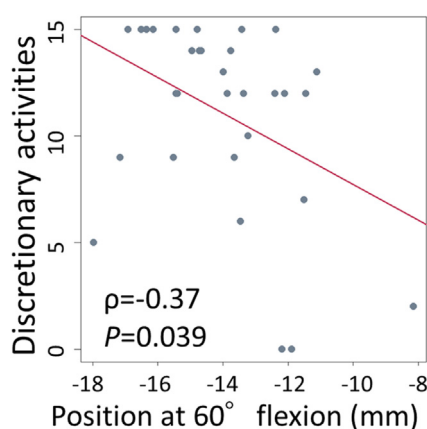


Fig. 4. Scatter plots for the anteroposterior position of the medial femoral condyle at 60° flexion and discretionary activities.

preoperative scores (Table 3). Functional activity subcategories significantly improved postoperatively.

Correlation Between Kinematics and Postoperative 2011 KSS

Correlations between kinematics and postoperative 2011 KSS are shown in Table 4. Correlations were observed between AP positions of the medial femoral condyle at full extension, and walking and standing ($\rho = 0.35$; $P = .040$) (Figure 3), at 60° and discretionary activities ($\rho = -0.37$; $P = .039$) (Figure 4), and at maximum flexion and total functional activities ($\rho = -0.46$; $P = .005$), advanced activities ($\rho = -0.45$; $P = .006$), and discretionary activities ($\rho = -0.63$; $P < .001$) (Figure 5A-C). The anterior position of the medial femoral condyle at mid-flexion and maximum-flexion had a negative impact on functional outcomes. Significant correlations were observed between AP positions of the lateral femoral condyle at 30° flexion and total functional activities ($\rho = -0.48$; $P = .005$), walking and standing ($\rho = -0.56$; $P < .001$), and advanced activities ($\rho = -0.49$; $P = .004$) (Figure 6A-C), and at 60° flexion and walking and standing ($\rho = -0.45$; $P = .010$) (Figure 7). The anterior position of the lateral femoral condyle at mid-flexion had a negative impact on functional outcomes.

Discussion

This study analyzed knee kinematics during a squat using a 2D-3D registration technique after CR-TKA was performed with a ligament-preserving technique (medial stabilizing technique) and

investigated the relationship between kinematic patterns and PROMs. Overall, in the present study, a medial pivot pattern without paradoxical anterior translation was observed with excellent clinical outcomes. Patients who had more anterior positions of both medial and lateral femoral condyles had worse 2011 KSS activity scores. Therefore, hypotheses that a medial pivot pattern similar to that of healthy knees would be represented by achieving medial stability and that the anterior position of the medial femoral condyle relative to the tibia would have a negative impact on PROMs were reinforced by our findings.

A medial release is often performed to balance varus knee deformity; however, excessive release can cause AP instability because the MCL is an important soft tissue for AP stability. Paradoxical anterior motion is reportedly often observed after CR-TKA [3, 8, 18–21]. One study reported that 95 of 136 patients after CR-TKA experienced >3 mm anterior translation of either the medial or lateral femoral condyle [19]. This might be emphasized by excessive medial soft tissue release, increasing femorotibial AP movement, and medial looseness [22, 23]. Morcos et al. compared the kinematics after PS TKA among 3 groups divided by degree of medial soft tissue release, and reported that the release of superficial MCL resulted in more anterior translation of the medial femoral condyle from 20 to 80° and more anterior positions of the lateral femoral condyle at 40° flexion. These results indicated that excessive medial soft tissue release induces more anterior translation of the lateral and medial femoral condyles. In the present study, wherein a medial stabilizing technique with minimal release of the deep MCL was performed, anterior translation of medial and lateral femoral condyles was rarely observed. Moreover, the mean 0.5 mm AP translation of the medial femoral condyle from full extension to maximum flexion was 3 mm less than the value previously reported using the same prosthesis as in the present study [24].

Management of PCL tension is another important procedure in CR-TKA [25]. The PCL is the primary resistance for femoral internal rotation beyond 90° flexion, and the anterolateral and posteromedial bands of the PCL mainly function beyond 70° flexion and from 0 to 15°, respectively, as resistance for femoral anterior translation [26]. Due to the difficulty in tensioning the PCL, CR-TKA implies various patterns of AP translation of the femoral condyle compared to PS TKA [8]. In the present study, PCL tension was adjusted by additional bone cutting or downsizing of the femoral component for an excessively tight PCL without ligamentous release [13, 27], which could sufficiently preserve PCL function, as reflected by posterior translations of both the medial and lateral femoral condyles during early and deep flexion.

The results of the present study indicated that more anterior positions in both medial and lateral compartments after TKA had a

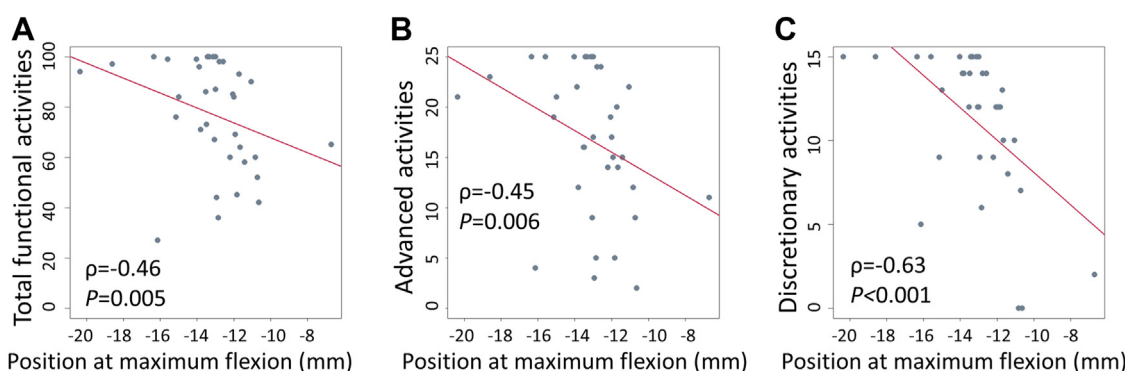


Fig. 5. A-C Scatter plots for the anteroposterior position of the medial femoral condyle at maximum flexion and total functional activities (A); advanced activities at maximum flexion (B); and discretionary activities (C).

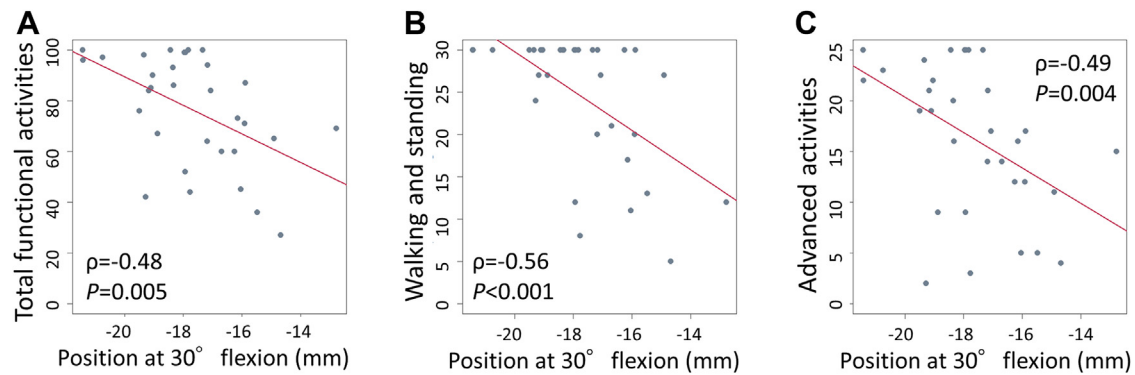


Fig. 6. A–C Scatter plots for the anteroposterior position of the lateral femoral condyle at 30° flexion and for total functional activities (A); walking and standing (B); and advanced activities (C).

considerable impact on PROMs. Hodge et al. found that greater satisfaction and decreased pain were obtained with a more posterior femur position at maximum flexion during a deep knee bend in CR-TKA [4]. However, kinematics was not evaluated during mid-flexion. Moreover, the medial and lateral compartments were not investigated separately. The present study investigated the relationship between knee kinematics after CR-TKA and PROMs at 30°, 60°, and 90° flexion, as well as at full extension and maximum flexion. Notably, more posterior positions of the medial femoral condyle at full extension and more anterior positions at 60° flexion were negatively correlated with activity scores. This may reflect the negative impact of anterior translation of the medial femoral condyle from full extension to 60° on PROMs, although the position at 30° flexion was not correlated with clinical outcomes. The present study revealed the importance of AP stability in PROMs from the perspective of kinematics, which was consistent with the findings of Van Onsem et al, which demonstrated a 7 mm more anterior translation of the medial femoral condyle in the lower-PROMs cluster compared to the higher-PROMs cluster during a squat after PS TKA [7]. The present study also indicated negative correlations of the more anterior positions of the lateral femoral condyle at 30 and 60° flexion with activity scores. The anteriorly located lateral femoral condyle just before the PCL function might have an adverse effect on sufficient femoral rollback. Various factors are reportedly associated with femoro-tibial AP translation after CR-TKA such as MCL tension, PCL tension, radius of femoral component, conformity of tibial surface, PTS, femoral sagittal alignment, and muscle strength [28–36]. The NexGen CR-Flex has a

multiradius femoral component and a flat tibial surface; thus, care must be taken to ensure the medial structure is not loose. The findings of the present study suggest that the meticulous management of the medial soft tissue and PCL by preserving carefully without excessive release contributes to sufficient overall AP stability and PROMs.

The present study had some potential limitations. A sample size of 35 knees in 27 patients may be considered low for statistical analysis; the same applies to the study by Alesi et al, which was used for the power analysis [3]. The small sample size can affect the generalizability of the present study. A single implant with a medial stabilization technique was used. Different results may be obtained by using other prostheses and surgical techniques. Not all eligible patients participated in the study. Only squat motion was investigated. Daily activities that may be affected more by mid-flexion stability, such as walking or step-ups, should be investigated. The direct relationship between MCL or PCL tension and kinematics was not evaluated. In addition, the relevance of actual muscle strength was not considered. Anterior translation of the femur decreases the quadriceps moment arm, resulting in reduced quadriceps efficiency [18]. Therefore, the activity scores might have been particularly affected.

Conclusions

A medial pivot pattern was represented by using a medial stabilizing technique without ligamentous release of the MCL and PCL in CR-TKA. The anterior positions of the medial and lateral femoral condyles had a negative impact on PROMs. Soft tissue conditions should be carefully managed to achieve medial knee joint stability, which can improve PROMs.

CRediT authorship contribution statement

Sayako Sakai: Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation. **Shinichiro Nakamura:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Formal analysis, Data curation, Conceptualization. **Shinichi Kuriyama:** Writing – review & editing, Visualization, Validation, Supervision, Formal analysis, Conceptualization. **Kohei Nishitani:** Writing – review & editing, Visualization, Validation, Supervision, Formal analysis, Conceptualization. **Yugo Morita:** Writing – review & editing, Visualization, Validation, Supervision, Formal analysis. **Shuichi Matsuda:** Writing – review & editing, Visualization, Validation, Supervision, Project

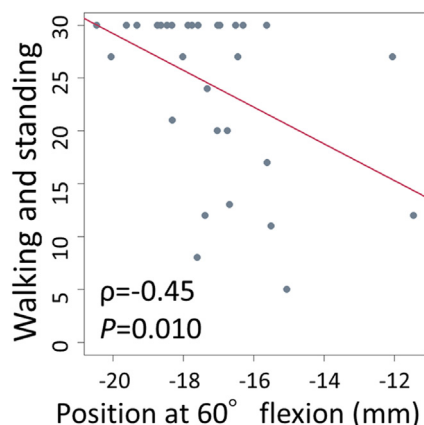


Fig. 7. Scatter plots for the anteroposterior position of the lateral femoral condyle at 60° flexion and walking and standing.

administration, Methodology, Investigation, Formal analysis, Conceptualization.

References

- [1] Angerame MR, Holst DC, Jennings JM, Komistek RD, Dennis DA. Total knee arthroplasty kinematics. *J Arthroplasty* 2019;10:2502–10. <https://doi.org/10.1016/j.arth.2019.05.037>.
- [2] Gunaratne R, Pratt DN, Banda J, Fick DP, Khan RJK, Robertson BW. Patient dissatisfaction following total knee arthroplasty: a systematic review of the literature. *J Arthroplasty* 2017;12:3854–60. <https://doi.org/10.1016/j.arth.2017.07.021>.
- [3] Alesi D, Marcheggiani Muccioli GM, Roberti di Sarsina T, Bontempi M, Pizzi N, Zinno R, et al. In vivo femorotibial kinematics of medial-stabilized total knee arthroplasty correlates to post-operative clinical outcomes. *Knee Surg Sports Traumatol Arthrosc* 2021;2:491–7. <https://doi.org/10.1007/s00167-020-05975-w>.
- [4] Hodge PE, Rabak OJ, Perriman DM, Scarvell JM, Smith PN, Lynch JT. Are kinematics an indicator of outcome after total knee arthroplasty? *J Arthroplasty* 2023;39:343–349.e1. <https://doi.org/10.1016/j.arth.2023.08.010>.
- [5] Kono K, Inui H, Tomita T, Yamazaki T, Taketomi S, Yamagami R, et al. The higher patient-reported outcome measure group had smaller external rotation of the femur in bicruciate-stabilized total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc* 2022;4:1292–9. <https://doi.org/10.1007/s00167-021-06577-w>.
- [6] Pizzi N, Di Paolo S, Zinno R, Marcheggiani Muccioli GM, Agostinone P, Alesi D, et al. Over-constrained kinematic of the medial compartment leads to lower clinical outcomes after total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc* 2022;2:661–7. <https://doi.org/10.1007/s00167-020-06398-3>.
- [7] Van Onsem S, Verstraete M, Van Eeno W, Van Der Straeten C, Victor J. Are TKA kinematics during closed kinetic chain exercises associated with patient-reported outcomes? A preliminary analysis. *Clin Orthop Relat Res* 2020;2:255–63. <https://doi.org/10.1097/CORR.0000000000000991>.
- [8] Fantozzi S, Catani F, Ensini A, Leardini A, Giannini S. Femoral rollback of cruciate-retaining and posterior-stabilized total knee replacements: in vivo fluoroscopic analysis during activities of daily living. *J Orthop Res* 2006;12:2222–9. <https://doi.org/10.1002/jor.20306>.
- [9] Nakamura S, Ito H, Yoshitomi H, Kuriyama S, Komistek RD, Matsuda S. Analysis of the flexion gap on in vivo knee kinematics using fluoroscopy. *J Arthroplasty* 2015;7:1237–42. <https://doi.org/10.1016/j.arth.2015.01.046>.
- [10] Azukizawa M, Kuriyama S, Nakamura S, Nishitani K, Lyman S, Morita Y, et al. Intraoperative medial joint laxity in flexion decreases patient satisfaction after total knee arthroplasty. *Arch Orthop Trauma Surg* 2018;8:1143–50. <https://doi.org/10.1007/s00402-018-2965-2>.
- [11] Tsukiyama H, Kuriyama S, Kobayashi M, Nakamura S, Furu M, Ito H, et al. Medial rather than lateral knee instability correlates with inferior patient satisfaction and knee function after total knee arthroplasty. *Knee* 2017;6:1478–84. <https://doi.org/10.1016/j.knee.2017.09.004>.
- [12] Ishibashi K, Sasaki E, Sasaki S, Kimura Y, Yamamoto Y, Ishibashi Y. Medial stabilizing technique preserves anatomical joint line and increases range of motion compared with the gap-balancing technique in navigated total knee arthroplasty. *Knee* 2020;2:558–64. <https://doi.org/10.1016/j.knee.2019.12.002>.
- [13] Matsuda S, Ito H. Ligament balancing in total knee arthroplasty-Medial stabilizing technique. *Asia Pac J Sports Med Arthrosc Rehabil Technol* 2015;4:108–13. <https://doi.org/10.1016/j.asmart.2015.07.002>.
- [14] Tanifuji O, Mochizuki T, Sato T, Watanabe S, Omori G, Kawashima H. Mobile medial pivot (lateral slide) type total knee arthroplasty exhibits a medial pivot pattern: three-dimensional motion analysis using cadaveric knees. *J Exp Orthop* 2022;1:122. <https://doi.org/10.1186/s40634-022-00558-9>.
- [15] Tanifuji O, Sato T, Kobayashi K, Mochizuki T, Koga Y, Yamagiwa H, et al. Three-dimensional in vivo motion analysis of normal knees employing trans-epicondylar axis as an evaluation parameter. *Knee Surg Sports Traumatol Arthrosc* 2013;10:2301–8. <https://doi.org/10.1007/s00167-012-2010-x>.
- [16] Hamamoto Y, Ito H, Furu M, Ishikawa M, Azukizawa M, Kuriyama S, et al. Cross-cultural adaptation and validation of the Japanese version of the new Knee Society Scoring System for osteoarthritic knee with total knee arthroplasty. *J Orthop Sci* 2015;5:849–53. <https://doi.org/10.1007/s00776-015-0736-2>.
- [17] Scuderi GR, Bourne RB, Noble PC, Benjamin JB, Lonner JH, Scott WN. The new knee society knee scoring system. *Clin Orthop Relat Res* 2012;1:3–19. <https://doi.org/10.1007/s11999-011-2135-0>.
- [18] Dennis DA, Komistek RD, Mahfouz MR. In vivo fluoroscopic analysis of fixed-bearing total knee replacements. *Clin Orthop Relat Res* 2003;410:114–30. <https://doi.org/10.1097/01.blo.0000062385.79828.72>.
- [19] Dennis DA, Komistek RD, Mahfouz MR, Haas BD, Stiehl JB. Multicenter determination of in vivo kinematics after total knee arthroplasty. *Clin Orthop Relat Res* 2003;416:37–57. <https://doi.org/10.1097/01.blo.0000092986.12414.b5>.
- [20] Stiehl JB, Komistek RD, Dennis DA, Paxson RD, Hoff WA. Fluoroscopic analysis of kinematics after posterior-cruciate-retaining knee arthroplasty. *J Bone Joint Surg Br* 1995;6:884–9.
- [21] Yue B, Varadarajan KM, Moynihan AL, Liu F, Rubash HE, Li G. Kinematics of medial osteoarthritic knees before and after posterior cruciate ligament retaining total knee arthroplasty. *J Orthop Res* 2011;1:40–6. <https://doi.org/10.1002/jor.21203>.
- [22] Inui H, Taketomi S, Yamagami R, Kawaguchi K, Nakazato K, Tanaka S. The relationship between anteroposterior stability and medial-lateral stability of the bi-cruciate stabilized total knee arthroplasty. *Knee* 2018;6:1247–53. <https://doi.org/10.1016/j.knee.2018.08.002>.
- [23] Wierier G, Milinkovic D, Robinson JR, Raschke MJ, Weiler A, Fink C, et al. The superficial medial collateral ligament is the major restraint to anteromedial instability of the knee. *Knee Surg Sports Traumatol Arthrosc* 2021;2:405–16. <https://doi.org/10.1007/s00167-020-05947-0>.
- [24] Bertin KC, Komistek RD, Dennis DA, Hoff WA, Anderson DT, Langer T. In vivo determination of posterior femoral rollback for subjects having a NexGen posterior cruciate-retaining total knee arthroplasty. *J Arthroplasty* 2002;8:1040–8. <https://doi.org/10.1054/arth.2002.35793>.
- [25] Conditt MA, Noble PC, Bertolusso R, Woody J, Parsley BS. The PCL significantly affects the functional outcome of total knee arthroplasty. *J Arthroplasty* 2004;7:107–12. <https://doi.org/10.1016/j.arth.2004.06.006>.
- [26] Pache S, Aman ZS, Kennedy M, Nakama GY, Moatshe G, Ziegler C, et al. Posterior cruciate ligament: current concepts review. *Arch Bone Jt Surg* 2018;1:8–18.
- [27] Watanabe M, Kuriyama S, Nishitani K, Nakamura S, Matsuda S. What is the optimal posterior cruciate ligament tension to achieve patient satisfaction in cruciate-retaining total knee arthroplasty? *J Arthroplasty* 2023;65:S183–9. <https://doi.org/10.1016/j.arth.2023.01.050>.
- [28] Jones CW, Jacobs H, Shumorski S, Talbot S, Redgment A, Brighton R, et al. Sagittal stability and implant design affect patient reported outcomes after total knee arthroplasty. *J Arthroplasty* 2020;3:747–51. <https://doi.org/10.1016/j.arth.2019.10.020>.
- [29] Kang KT, Koh YG, Son J, Kwon OR, Lee JS, Kwon SK. Influence of increased posterior tibial slope in total knee arthroplasty on knee joint biomechanics: a computational simulation study. *J Arthroplasty* 2018;2:572–9. <https://doi.org/10.1016/j.arth.2017.09.025>.
- [30] Longo UG, Candela V, Pirato F, Hirschmann MT, Becker R, Denaro V. Mid-flexion instability in total knee arthroplasty: a systematic review. *Knee Surg Sports Traumatol Arthrosc* 2021;2:370–80. <https://doi.org/10.1007/s00167-020-05909-6>.
- [31] Nagle M, Glynn A. Midflexion instability in primary total knee arthroplasty. *J Knee Surg* 2020;5:459–65. <https://doi.org/10.1055/s-0039-1678537>.
- [32] Nakamura S, Kuriyama S, Nishitani K, Ito H, Murata K, Matsuda S. Correlation between intraoperative anterior stability and flexion gap in total knee arthroplasty. *J Arthroplasty* 2018;8:2480–4. <https://doi.org/10.1016/j.arth.2018.03.030>.
- [33] Ramappa M. Midflexion instability in primary total knee replacement: a review. *SICOT J* 2015;1:24. <https://doi.org/10.1051/sicotj/2015020>.
- [34] Saeki K, Mihalko WM, Patel V, Conway J, Naito M, Thrum H, et al. Stability after medial collateral ligament release in total knee arthroplasty. *Clin Orthop Relat Res* 2001;392:184–9. <https://doi.org/10.1097/00003086-200111000-00022>.
- [35] Schmidt R, Komistek RD, Blaha JD, Penenberg BL, Maloney WJ. Fluoroscopic analyses of cruciate-retaining and medial pivot knee implants. *Clin Orthop Relat Res* 2003;410:139–47. <https://doi.org/10.1097/01.blo.0000063565.90853.a4>.
- [36] Shimmin A, Martinez-Martos S, Owens J, Iorgulescu AD, Banks S. Fluoroscopic motion study confirming the stability of a medial pivot design total knee arthroplasty. *Knee* 2015;6:522–6. <https://doi.org/10.1016/j.knee.2014.11.011>.