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Original Research

Posterior capsular release improves intraoperative flexion contracture without affecting knee kinematics in posterior-stabilized total knee arthroplasty

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A R T I C L E I N F O

Keywords:
Posterior capsular release
Total knee arthroplasty
Knee extension angle
Intraoperative flexion contracture
Intraoperative knee kinematics

A B S T R A C T

Objectives: Posterior capsular release (PCR) is widely performed in total knee arthroplasty (TKA) for late-stage knee osteoarthritis with severe flexion contracture. PCR enables obtaining an appropriate bone gap, resulting in an improvement in the knee extension angle after TKA. Despite its efficacy, little is known about its influence on knee kinematics. This study aimed to measure the change in knee extension angle after PCR in TKA and clarify its influence on knee kinematics.

Methods: Posterior-stabilized (PS) TKA was performed on eight cadaveric knees under Thiel fixation using a navigation system. In the trial component setting, the knee extension angle was measured. Subsequently, we performed PCR at the intercondylar fossa. The maximum knee extension angle and knee kinematics, which were calculated using the anteroposterior, compression–distraction, and mediolateral positions and the rotational knee angle obtained from the navigation system, were measured before and after PCR. Then, changes in the knee extension angle and knee kinematics were assessed following PS-TKA and intraoperative PCR.

Results: PCR at the intercondylar fossa resulted in a significant $9.1 \pm 3.6^{\circ}$ improvement in the knee extension angle ($P = 0.01$). The anteroposterior position of the femur relative to the tibia throughout the range of motion did not change significantly after PCR. Regarding rotational knee kinematics, six cases showed a parallel pattern and two showed a medial pivot pattern with PS-TKA before PCR. Rotational knee kinematics did not change after PCR in any case.

Conclusion: PCR at the intercondylar fossa is a critical surgical technique for addressing intraoperative flexion contracture in PS-TKA without affecting intraoperative knee kinematics.

Level of evidence: III.

What are the new findings?

- We measured the change in knee extension angle after posterior capsular release in total knee arthroplasty.
- Posterior capsular release did not change knee kinematics, despite its efficacy for flexion contracture.
- Anteroposterior position of the femur relative to the tibia throughout the range of motion did not change after posterior capsular release.

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INTRODUCTION

Total knee arthroplasty (TKA) is an effective treatment for late-stage knee osteoarthritis. However, previous reports have shown that 15–20 % of patients are not satisfied with their clinical outcomes [1]. Various factors can affect patient satisfaction [2], with one of the most common complaints being flexion contracture [3]. Residual flexion contracture after TKA affects postoperative outcomes [4]. Moreover, severe flexion contracture leads to mechanical overload of the limb [5]. In addition, the intraoperative knee extension angle after TKA has been reported to correlate with the postoperative knee extension angle [6]. Thus, surgeons should manage this intraoperatively.

Previous studies have highlighted the efficacy of intraoperative surgical techniques for intraoperative flexion contracture [7]. Osteophyte removal from the posterior femoral condyle improves the knee extension angle in TKA [8]. Additional distal femoral resection improves flexion contracture [9–11]. Moreover, posterior capsular release (PCR) is widely known as an effective technique for flexion contractures in TKA [12,13]. The posterior capsule can conflict with the post-cam mechanism in posterior-stabilized (PS) TKA (PS-TKA) at the intercondylar fossa, resulting in flexion contracture [14]. Thus, in PS-TKA, surgeons should consider performing PCR at the intercondylar fossa to ensure favorable clinical outcomes.

However, the influence of PCR at the intercondylar fossa on knee kinematics remains unclear. In this study, we aimed to investigate the efficacy of PCR for intraoperative flexion contracture in PS-TKA and to clarify the influence of PCR on knee kinematics. We hypothesized that PCR in PS-TKA results in a critical improvement in flexion contracture and that PCR has no influence on knee status, apart from the knee extension angle.

METHODS

This study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of our institution (identification number: 2106020). We performed PS-TKA (Physica System PS; Lima Corporate, Udine, Italy) on eight knees from five cadavers (three males and two females) under Thiel fixation [15,16]. The mean patient age at the time of death was 85.4 ± 6.7 years (range, 75 to 94). None of the cadavers had a history of knee surgery or macroscopic degenerative or traumatic changes. All knees had mild osteoarthritis.

A navigation system (version 4.0, Precision Knee Navigation Software; Stryker, Kalamazoo, MI, USA) was used to evaluate the intraoperative knee status. Specific anatomical reference points were located by anchoring infrared signal transducers to the femur and tibia using pins. A skin incision was made to expose the subcutaneous tissue. Registration was performed using osteophytes and soft tissues, and the anterior cruciate ligament was preserved. The rotational axes of the femur and tibia were identified based on the anatomical landmarks. The femoral rotational axis was defined as the axis perpendicular to the Whiteside's line and parallel to the transepicondylar axis. The tibial rotational axis was set parallel to the line connecting one-third of the tibial tubercle to the center of the transverse diameter.

After registration, the joint capsule was temporarily closed using four suture strands. Mild passive knee flexion was manually performed without angular acceleration while moving the leg from full extension to deep flexion. The anteroposterior, mediolateral, and compression–distraction positions; the internal–external angles of the tibia relative to the femur at maximum extension angles of 0, 5, 10, 15, 20, 30, 45, 60, 90, 105, and 120°; and the maximum flexion angle were automatically measured using the navigation system. If there was flexion contracture, the data from the angle of maximum extension to the angle of the above angles that was measurable was utilized. For the anteroposterior position, positive values indicated an anterior position, whereas negative values indicated a posterior position of the tibia relative to the femur. For the mediolateral position, positive values indicated a medial position, whereas negative values indicated a lateral position of the tibia relative to the femur. For the compression–distraction position, positive values indicated compression, whereas negative values indicated a distraction position of the tibia relative to the femur. For the rotational angle, positive values indicated internal rotation, whereas negative values indicated external rotation of the tibia relative to the femur. Data were measured every 0.5° or 1 mm.

All surgeries were performed by the same surgeon. To confirm the accuracy of the measurements, we calculated the test–retest reliability of each status obtained using the navigation system. Our calculations indicated that the interclass and intraclass correlation coefficients were sufficiently high, with values > 0.9 at each measured angle of knee flexion. We also evaluated the test–retest reliability of the anteroposterior, mediolateral, and compression–distraction positions and the rotational angle, observing sufficiently high interclass and intraclass correlation coefficients (>0.9 at each measured angle of knee flexion). Regarding the anteroposterior position of the femur relative to the tibia, we evaluated the femoral center movement relative to the tibia as previously described [17,18]. From the anteroposterior and compression–distraction positions of the tibia relative to the femur obtained using the navigation system, we calculated the anteroposterior position of the femur relative to the tibia.

Regarding the surgical method, a distal femoral cut and a proximal tibial cut was made perpendicular to the mechanical axis, based on the concept of mechanical alignment. The rotational angle of the femoral component was set at 3° external to the posterior condylar axis. The thickness of each bone resection was determined to be the same as the thickness of the implant according to the measured resection technique. The femoral sagittal bone resection angle and posterior tibial slope were set at 0° and 5°, respectively, using a navigation system. After removing the osteophytes, the trial components and trial inserts were placed. We utilized a 10-mm insert (the thinnest insert thickness in this TKA procedure). The joint capsule was closed using trial components and inserts. We subsequently assessed each knee status at maximum extension angles of 0, 5, 10, 15, 20, 30, 45, 60, 90, 105, and 120°; and the maximum flexion angle obtained by the navigation system, similar to the procedures performed preoperatively.

After the evaluation with PS-TKA, a single surgeon performed PCR on the intercondylar fossa using a curved osteotome as previously described (Fig. 1) [14]. The posterior capsule of the intercondylar fossa was completely released from the femoral cortex. The released width at the attachment site of the posterior capsule was the width of the box used in the PS procedure. Subsequently, the knee extension angle and knee status were measured with the same trial components using the navigation system. Regarding knee extension angle, positive value indicates flexion contracture and negative value indicates hyperextension based on the value of the angle in a navigation system. We performed PCR in all cadaveric knees regardless of the intraoperative knee extension angle to confirm the change in extension angle following PCR.

The intraoperative knee kinematics were assessed using a previously reported method [18]. Following the information obtained by the navigation system, the two-dimensional translation of the femoral center was measured, knee kinematics were evaluated, the femoral axial axis at all measured angles was projected onto the tibial axial plane, and femoral movement was evaluated relative to the tibia. The axial diameter of the femur was set at 80 mm, and the position of the femur at each knee angle was calculated from the rotation angle of the tibia relative to the femur using the navigation system. Furthermore, we utilized the mediolateral position of the femur relative to the tibia in the same manner and projected the femoral axis movement to the tibial axial plane at each knee flexion. We defined the knee kinematic patterns based on a previous study [17]: parallel, medial, and lateral pivot patterns. Two senior orthopedic surgeons evaluated all kinematic patterns. Based on their judgment, we determined the intraoperative knee kinematics.

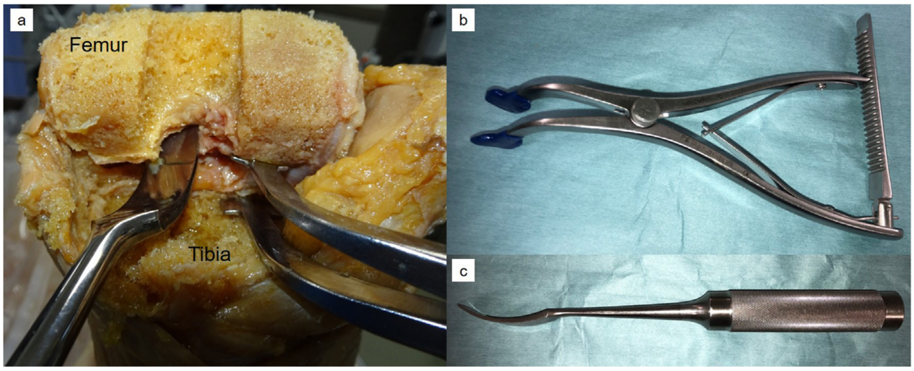

Fig. 1. Posterior capsular release using a curved osteotome. a: After evaluating the knee extension angle and other knee statuses using a navigation system following primary total knee arthroplasty (TKA), we performed posterior capsular release (PCR). The width of the released posterior capsule is defined as the width of the box between the condyles. b: A spreader is used to obtain the appropriate gap for posterior capsular release. c: A curved osteotome.

Statistical analysis

Analyses were performed using the JMP software (version 14.0; SAS Institute, Cary, NC, USA). Non-parametric tests were used because the data in this study were found to be non-normally distributed using the Shapiro–Wilk test. The Friedman test was performed to compare the knee extension angle among multiple groups, and the Steel–Dwass test was performed to identify differences in the knee extension angle between each step. The non-parametric Wilcoxon signed-rank test was used to identify differences between the anteroposterior position of the femur and tibia before and after PCR.

Power analysis was conducted based on the mean and standard deviation calculated from three preliminary measurements. The required minimum sample size of seven was determined to achieve a correlation of $\delta = 8$ and $\sigma = 3$, with 80 % power and $\alpha = 0.05$, accounting for the results of the mean difference in extension before and after PCR. Accordingly, we assessed eight participants to compensate for the small sample size. *P*-values <0.05 were considered to denote statistical significance.

RESULTS

Efficacy of PCR for intraoperative flexion contracture

The maximum knee extension angle was $-2.5^\circ \pm 4.2^\circ$, $9.0^\circ \pm 3.9^\circ$, and $-0.1^\circ \pm 3.9^\circ$ preoperatively, with PS-TKA before PCR, and with PS-TKA after PCR, respectively. The maximum knee extension angle changed in a statistically significantly manner after PS-TKA and PCR (*P* = 0.0027 and 0.01, respectively). After PS-TKA, all patients showed a deterioration of the knee extension angle. After PCR, five of the eight knees presented full knee extension (Table 1). The mean change after PCS at the intercondylar fossa was $9.1 \pm 3.6^\circ$. The maximum knee flexion angle was $126.1^\circ \pm 9.5^\circ$, $129.5^\circ \pm 5.6^\circ$, and $131.1^\circ \pm 5.8^\circ$ preoperatively, with PS-TKA before PCR, and with PS-TKA after PCR, respectively. There was no statistically significant difference among each step.

Table 1
Knee extension angle at each step evaluated using a navigation system.

	Native	PS-TKA before PCR	PS-TKA after PCR
Case 1	−4.0°	3.5°	−4.0°
Case 2	3.0°	3.5°	−5.0°
Case 3	2.5°	7.0°	−0.5°
Case 4	−2.5°	15.5°	4.0°
Case 5	−10.0°	14.5°	−2.5°
Case 6	−5.5°	7.0°	−1.0°
Case 7	−3.0°	9.5°	6.0°
Case 8	−0.5°	11.5°	2.0°

Native = before total knee arthroplasty; PS-TKA = posterior-stabilized total knee arthroplasty; PCR = posterior capsular release.

Changes in knee kinematics after PCR

The mean anteroposterior positions of the femur relative to the tibia at each measured angle before and after PCR are shown in Table 2. No statistically significant differences were observed before and after PCR. Moreover, anteroposterior translation of the femur relative to the tibia before and after PCR showed the same pattern (Fig. 2). Regarding two-dimensional rotational kinematics before TKA, five cases represented a medial pivot pattern and three represented a parallel pattern. After PS-TKA, three of the five cases that presented a medial pivot pattern preoperatively changed to a parallel pattern. However, after PCR, there was no change in the two-dimensional rotational knee kinematics (Table 3; Fig. 3).

DISCUSSION

The most important finding of this study was that PCR did not change knee kinematics, despite its efficacy for flexion contracture. In this cadaveric study, we investigated the anteroposterior position of the femur relative to the tibia and the rotational knee kinematics using a navigation system and found that this did not change and that it exhibited similar motion throughout the range of motion. To the best of our knowledge, this is the first study to clarify the effects of PCR on knee kinematics.

The efficacy of PCR in TKA has been widely reported. Okamoto et al. [12] reported that PCR of the intercondylar fossa after PS-TKA results in an increase in the extension gap. Katagiri et al. [19] reported that PCR ameliorates the medial component gap in PS-TKA. Moreover, they

Table 2
The AP positions at each angle before and after PCR.

	Before PCR	After PCR	*P*
	Mean ± SD (mm)	Mean ± SD (mm)	
Maximum knee extension	–	10.0 ± 5.2 (n = 5)	–
0°	–	9.4 ± 6.5 (n = 5)	–
5°	6.7 ± 3.8 (n = 2)	10.7 ± 5.7 (n = 7)	–
10°	11.5 ± 6.5 (n = 5)	10.9 ± 6.5 (n = 8)	–
15°	13.2 ± 6.3 (n = 7)	10.9 ± 5.5 (n = 8)	–
20°	13.8 ± 5.7 (n = 8)	12.1 ± 5.9 (n = 8)	0.46
30°	15.6 ± 7.3 (n = 8)	14.9 ± 6.1 (n = 8)	0.87
45°	17.9 ± 5.3 (n = 8)	18.0 ± 5.0 (n = 8)	0.87
60°	17.4 ± 5.2 (n = 8)	17.9 ± 5.1 (n = 8)	0.63
90°	10.5 ± 4.8 (n = 8)	11.4 ± 4.4 (n = 8)	0.70
105°	3.8 ± 4.4 (n = 8)	4.6 ± 3.2 (n = 8)	0.71
120°	−5.4 ± 5.1 (n = 8)	−4.4 ± 4.2 (n = 8)	0.87
Maximum knee flexion	−11.3 ± 7.2 (n = 8)	−11.0 ± 5.5 (n = 8)	0.87

AP position = the anteroposterior position of the femur relative to the tibia; PCR = posterior capsular release; SD = standard deviation.

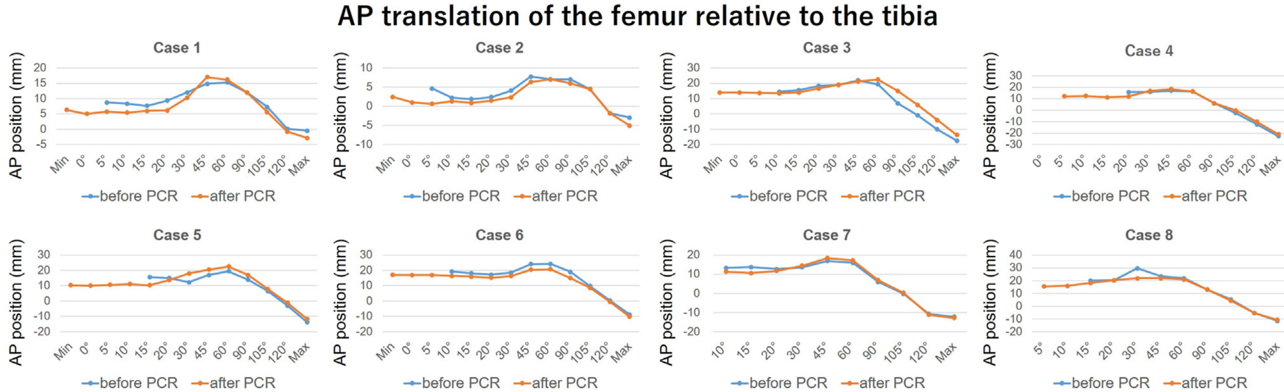

Fig. 2. Anteroposterior position of the femur relative to the tibia at each angle before and after PCR at the intercondylar fossa. Mean anteroposterior position of the femur relative to the tibia at each knee flexion angle. The graph shows the changes in the anteroposterior position of the femur relative to the tibia throughout the range of motion. The horizontal line shows the knee flexion angle, and the vertical line shows the anteroposterior position of the femur relative to the tibia (a positive value indicates an anterior position of the femur relative to the tibia). AP = anteroposterior; PCR = posterior capsular release.

Table 3
Rotational knee kinematics at each knee status.

	Native	PS-TKA before PCR	PS-TKA after PCR
Case 1	Medial pivot	Parallel	Parallel
Case 2	Medial pivot	Parallel	Parallel
Case 3	Medial pivot	Medial pivot	Medial pivot
Case 4	Medial pivot	Parallel	Parallel
Case 5	Medial pivot	Medial pivot	Medial pivot
Case 6	Parallel	Parallel	Parallel
Case 7	Parallel	Parallel	Parallel
Case 8	Parallel	Parallel	Parallel

Native = before total knee arthroplasty; PS-TKA = posterior-stabilized total knee arthroplasty; PCR = posterior capsular release; Medial pivot = medial pivot pattern; Parallel = parallel pattern.

demonstrated that PCR improves the joint gap mismatch between knee extension and flexion [20]. Regarding the safety of PCR, PCR with a curved osteotome with proper direction prevents the severe complication about bleeding [21]. However, the influence of soft tissue release on knee instability has long been debated [22–25]. Tibial internal rotation during knee flexion in PS-TKA is reduced by the excessive release of the medial collateral ligament [22]. Furthermore, the release of the superficial medial collateral ligament induces medial and anteromedial instability [23]. Concerning PCR, Athwal et al. [24] measured changes in anteroposterior knee stability after PCR in TKA and reported that PCR causes a small change in anteroposterior laxity. In our study, PCR had no influence on the anteroposterior knee position of the femur relative to the tibia or on the rotational knee kinematics. Postoperative knee kinematics have been reported to affect outcomes [26]. The results of our study further demonstrated the efficacy of PCR for intraoperative flexion contractures.

Previous studies have referred to the intraoperative surgical strategies for flexion contractures in TKA [9,10,12,27,28]. These strategies can be classified into two types: bone resection and soft tissue release. Additional bone resection is widely performed during TKA. An improvement of 4–9° has been reported in the knee extension angle after an additional

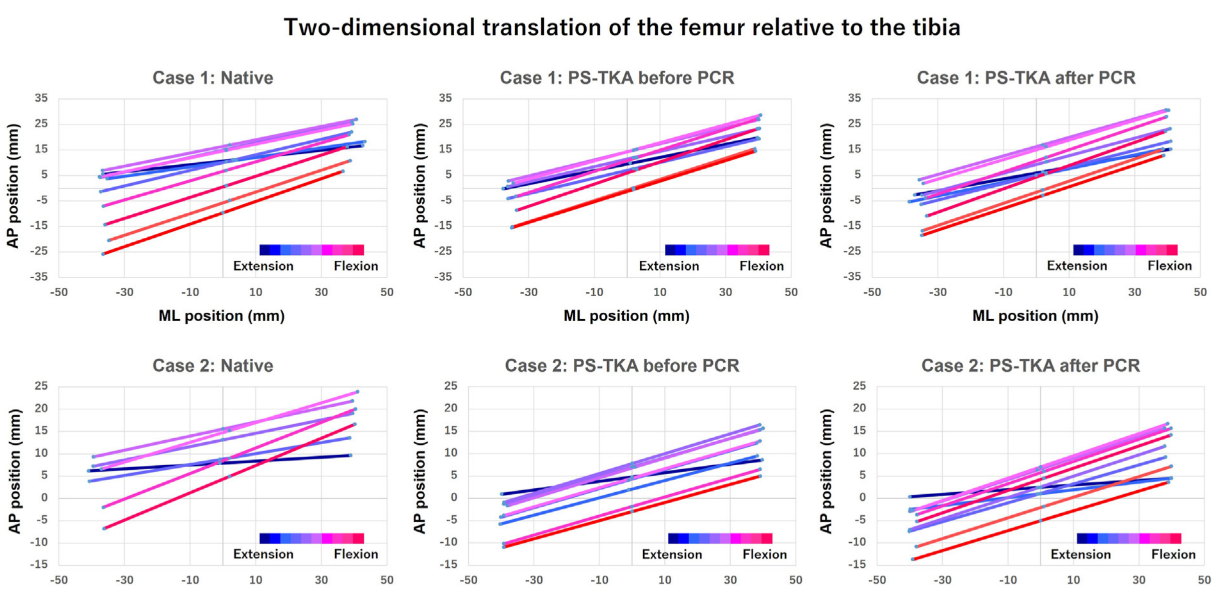

Fig. 3. Rotational knee kinematics; two-dimensional translation of the femoral center relative to the tibia (Cases 1 and 2), Two-dimensional translation of the femoral center relative to the tibia. The horizontal line shows mediolateral position of the femur relative to the tibia, and the vertical line shows the anteroposterior position of the femur relative to the tibia. Native = before total knee arthroplasty; PS-TKA before PCR = with posterior-stabilized total knee arthroplasty before posterior capsular release at the intercondylar fossa; PS-TKA after PCR = with posterior-stabilized total knee arthroplasty after posterior capsular release at the intercondylar fossa; AP position = anteroposterior position of the femur relative to the tibia; ML position = mediolateral position of the femur relative to the tibia.

2-mm femoral bone resection. However, the risks associated with this convenient method have also been reported. Luyckx et al. [29] and Chalmers et al. [30] assessed the influence of additional distal femoral bone resection on midflexion knee laxity. Minoda et al. [31] found that a 4-mm additional distal femoral bone resection resulted in a 2-mm increase in the extension gap and summarized that a 4-mm additional bone resection in the distal femur does not result in an equivalent increase in the extension gap in TKA. Therefore, in cases of severe flexion contracture, surgeons should combine several surgical techniques. Thus, the technique of PCR in PS-TKA should be considered for controlling intraoperative flexion contractures.

In this study, despite the appropriate bone resection using a navigation system, flexion contracture occurred after PS-TKA. Even in some cases wherein the preoperative knee extension angle showed hyperextension, the knee extension worsened after PS-TKA. This drastic change after PCR in PS-TKA may be a result of the unique implant shape, which differs from the natural knee in the cam design of the femoral component. Okamoto et al. [12] mentioned that a large-cam design of the femoral component in PS-TKA may tighten the extension gap. Furthermore, a previous cadaveric study demonstrated that the attachment site of the posterior capsule at the intercondylar fossa is 27.2 ± 3.2 mm and found that it resulted in a conflict between the cam and the posterior capsule at the attachment site [14]. In this study, changes in the knee extension angle were different among cases. It might be affected by the degree of the adhesion of the posterior capsule and the attachment site of the posterior capsule.

After PCR of the intercondylar fossa, almost all knees showed full knee extension. Similarly, a previous study reported an 11° improvement in knee extension after PCR of the intercondylar fossa in PS-TKA [14]. The implant design used in this study differed from that used in a previous study. The difference in the changes in the knee extension angle may be due to the design of the cam mechanism. The effect of conflict between the cam design and posterior capsule adhesion in knee osteoarthritis should be assessed by comparing the usage of PS-TKA and cruciate retaining TKA, which has no cam mechanism. Moreover, the attachment form of the posterior capsule at medial and lateral condyle was different than that of the intercondylar fossa [14,32]. The gastrocnemius tendon and posterior capsule were integrally attached to the femoral cortex at the medial and lateral condyles, whereas the posterior capsule at the intercondylar fossa was independently attached directly to the femoral cortex. Therefore, the clinical effects and safety of PCR at the medial and lateral condyle should be investigated. Further studies are required to confirm these findings.

Limitations

This study had some limitations. We did not assess limb alignment or knee joint deformity. Furthermore, the evaluation was not performed in a weight-bearing state because of the intraoperative evaluation. Although knee kinematics have been reported to exhibit the same pattern under weight-bearing and non–weight-bearing conditions except for the early phase [33], further research is required. In addition, the preoperative conditions of cartilage wear, the anterior cruciate ligament, and the posterior cruciate ligament, which may influence the anteroposterior position of the femur relative to the tibia, were not investigated. Moreover, we did not assess the differences between PS-TKA and cruciate-retaining TKA in this study. Regarding the cadaver, we used a Thiel-fixed cadaver instead of a fresh frozen cadaver. Previous studies have reported no significant differences between these two types of cadavers in terms of anatomical evaluation and muscle or tendon quality assessment [16,34]. In this study, the extension angle prior to PS-TKA exhibited an average hyperextension. This may be attributed to the laxity associated with Thiel-fixed cadavers. However, this study aimed to evaluate changes in the extension range following each procedure. While the validity of the results should be further verified through investigations using fresh frozen cadavers or clinical studies, it is important to highlight that flexion contracture occurred after PS-TKA and was improved with PCR. Finally, the number of knees examined was limited. These limitations may restrict the generalizability of the results. However, we propose that PCR is an effective surgical procedure to ensure an appropriate intraoperative knee extension angle without affecting knee kinematics.

CONCLUSION

PCR at the intercondylar fossa is a critical surgical technique for addressing intraoperative flexion contracture in PS-TKA without affecting the intraoperative knee kinematics.

Article summary

Posterior capsular release is a critical surgical technique for addressing flexion contracture in posterior-stabilized total knee arthroplasty without affecting intraoperative knee kinematics.

Authors' contributions

T. Kinoshita contributed to conceptualization, methodology, writing—original draft, writing—review and editing, investigation. KH contributed to conceptualization, methodology, T. Kutsuna. KW, TT, and YH contributed to investigation. MT contributed to conceptualization.

Ethics approval and consent to participate

This study was approved by the Institutional Review Board of Ehime University (identification number: 2106020). All participants provided written informed consent prior to death.

Consent for publication

Not applicable.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jisako.2025.100848.

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