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Equivalence of clinical and radiological outcomes in cruciate-retaining and cruciate-substituting total knee arthroplasty with medial pivot knee: A comparative study

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ABSTRACT

Introduction: Total knee arthroplasty (TKA) has been recognized as the most efficacious surgical intervention for individuals suffering from advanced arthritis; however, there is ongoing debate on the technical details of the procedure. It remains unknown whether preservation of the posterior cruciate ligament (PCL) significantly affects the mid-to long-term performance of ADVANCE® medial-pivotal (AMP) knee implants to enhance patient satisfaction. The hypothesis of this study was to investigate whether the preservation of the PCL has a substantial impact on the functional outcomes of medial pivot (MP) implants in patients undergoing TKA. Therefore, this study aimed to compare the midterm clinical and radiographic outcomes of cruciate-retaining (CR) and cruciate-substituting (CS) TKA using MP prostheses.

Methods: We included 376 consecutive patients who underwent unilateral TKA between January 2011 and April 2014. Follow-up evaluations were conducted in April 2021. After propensity score matching analysis, clinical and radiological outcomes and complication rates were compared between patients in the CR and CS groups.

Results: The postoperative outcomes in the two groups significantly improved the preoperative conditions of the patients (all $p > 0.05$). The postoperative outcomes (WOMAC score, $p = 0.517$; KSS, $p = 0.107$; KSFS, $p = 0.240$; ROM, $p = 0.795$; FJS, $p = 0.822$) and radiographic outcomes (preoperative FTA, $p = 0.997$; postoperative FTA, $p = 0.646$; aLDFA, $p = 0.094$; aMPTA, $p = 0.970$; PTS, $p = 0.243$) were comparable between the two groups. The complication and revision rates between the groups were not statistically significant ($p = 0.34$). The Kaplan–Meier cumulative survival of patients in the CRTKA and CSTKA groups was 100 % and 98.6 %, respectively.

Conclusions: This study supports the hypothesis that when MP prostheses are used, both CR and CS procedures achieve equally good mid-to long-term clinical and radiographic outcomes and complication rates. These findings suggest that PCL preservation may not significantly affect the overall performance of MP implants in patients undergoing TKA.

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1. Introduction

Although total knee arthroplasty (TKA) has emerged as the most effective procedure for patients with end-stage arthritis, there is ongoing debate on the technical details of the procedure. A comparative investigation evaluating clinical results, postoperative range of motion (ROM), survival rates, and complication profiles revealed congruences in outcomes for patients subjected to TKA and those who received unicompartmental knee arthroplasty (UKA). This suggests that both surgical interventions are feasible options [1]. Nevertheless, there exists a lack of consensus regarding the potential impact of preserving the posterior cruciate ligament (PCL) on patient satisfaction [2,3]. Considering the physiological perspective, the PCL plays a crucial role in facilitating the posterior movement of the femur during knee flexion, ultimately ensuring the stability in the anteroposterior direction. Furthermore, the PCL contributes significantly to the preservation of varus-valgus stability [4]. Preservation of the PCL during TKA has been suggested to restore normal kinematics, provide better bone stock, and improve proprioception [5]. However, a fluoroscopic analysis investigating the conventional posterior-stabilized (PS) and cruciate-retaining (CR) TKA found that preserving the PCL had limited efficacy in mitigating the occurrence of paradoxical anterior sliding of the femur in conventional implant designs [6]. Numerous studies have conducted comparisons between the clinical outcomes of PS and CR implants designs, with the majority of them reporting similar fingdings [4,7].

The natural motion of the knee is characterized by medial-pivotal movement with a lateral femoral rollback [8]. This medial-pivotal concept has led to the development of the ADVANCE® medial-pivotal (AMP) knee (MicroPort Orthopedics Inc., China) to improve re-establishment of normal kinematics. The AMP implants is characterized by an asymmetric tibial polyethylene insert, which facilitates congruent ball-in-socket medial articulation and includes an arcuate lateral groove. This unique design enables femoral rollback to occur along the medial axis during knee flexion, effectively replicating natural kinematic motion [9]. Numerous studies have reported positive outcomes of AMP implants, including good anteroposterior stability, reduced stress in the intercondylar region, and decreased polyethylene wear [10–12]. Excellent clinical outcomes and survival have been demonstrated with AMP implants [13,14]. The motions of an AMP implant differ from those of a conventional implant with a symmetrical insert, allowing its use in both CR and cruciate-sacrificing (CS) TKA. Although preserving the PCL offers biomechanical advantages, achieving optimal balance during TKA may be challenging and could affect postoperative knee function. Furthermore, Fang et al. [15] suggested that restoring the normal kinematic characteristics of an AMP prosthesis relies on the presence of a PCL or a posterior cam mechanism. However, only two studies have compared postoperative outcomes between CRTKA and CSTKA using AMP implants, with short-term outcomes reported to average 3.9 years [16,17]. Therefore, it remains unknown whether preservation of the PCL significantly affects the mid-to long-term performance of AMP implants. However, building upon prior research findings, we formulated the hypothesis that the preservation of the PCL does not significantly influence the performance of AMP implants in TKA.

This study conducted a 1:2 propensity score-matching analysis between patients who underwent CRTKA and CSTKA using AMP

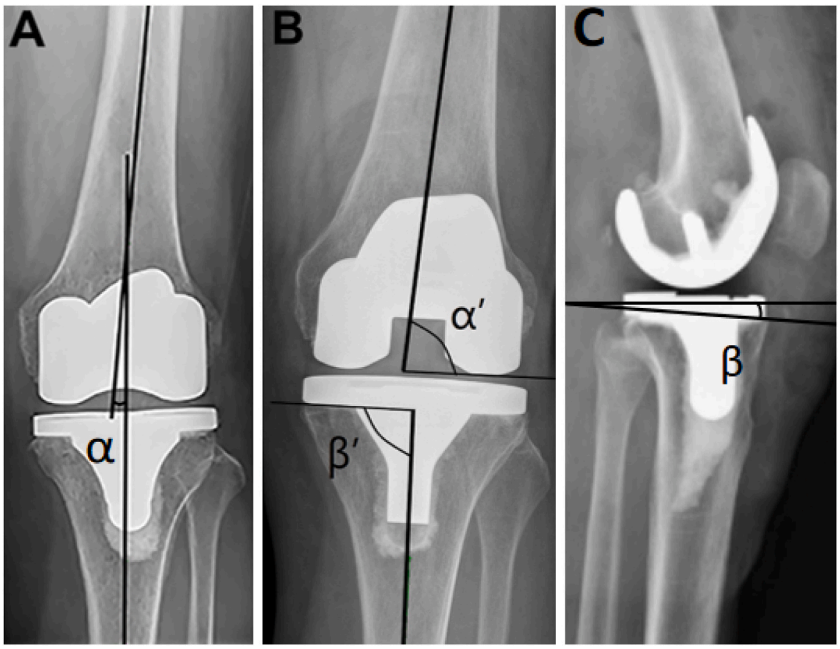

Fig. 1. The measurement of the investigated angles on knee films. (A) α: The FTA was defined as the angle between anatomical axes of the femur and tibia. (B) α': The aLDFA was the lateral angle formed by the anatomical femoral axis and the line connecting the distal medial and lateral femoral condyles; β': The aMPTA was the medial angle formed by the anatomical tibial axis and the inferior aspect of the tibial tray. (C) β: The PTS was defined as the angle between the sagittal tibial joint surface orientation and a perpendicular line to the proximal anatomical tibial axis.
FTA, femorotibial angle; aLDFA, anatomical lateral distal femoral angle; aMPTA, anatomical medial proximal tibial angle; PTS, posterior tibial slope.

implants to compare their mid-to long-term clinical and radiographic outcomes. Our hypothesis was that the use of the MP prosthesis would yield satisfactory results regardless of whether the PCL was removed or retained.

2. Materials and methods

The Institutional Review Board of the Affiliated Hospital of Qingdao University (IRB No. QYFY QZLL 26921) has granted approval for this study. Our retrospective analysis encompassed the clinical records of 578 successive patients who underwent unilateral TKA unitizing AMP prostheses to address osteoarthritis, classified as Kellgren-Lawrence grades II-IV. This examination was conducted on cases recorded between January 2011 and June 2014. An invitation was extended to all patients for participation in the ultimate follow-up session held in June 2021; however, there was a 21.8 % attrition rate, as 126 patients were unaccounted for at the time of follow-up. Additional exclusion criteria were applied, resulting in the disqualification of individuals if they presented with either: (1) a documented instance of trauma affecting the lower limb on thee same side, (2) a diagnosis of inflammatory joint disease, including conditions such as rheumatoid arthritis or ankylosing spondylitis, (3) utilization of the double-high insert in CRTKA, and (4) severe flexion contracture deformities. Finally, 84 and 292 patients were included in the CRTKA and CSTKA groups, respectively.

2.1. Outcomes

Prior to surgery, the residents meticulously captured and chronicled key metrics such as the ROM, the Knee Society Score (KSS), the Knee Society Function Score (KSFS), and the Western Ontario and McMaster Universities Arthritis Index (WOMAC) for all patients slated for TKA. Complementing these evaluations, standing anteroposterior and lateral knee radiographic images, along with weight-bearing full-leg radiographs, were systematically acquired.

In addition to the last follow-up, patients returned for routine follow-up at 6 weeks and 1 year postoperatively. At the last follow-up, the residents recorded their ROM, KSS, KSFS, WOMAC scores, and Forgotten Joint Score (FJS). Standing anteroposterior and lateral images were acquired and measured using a picture archiving and communication system (General Electric, Chicago, IL, USA). The alignment of the lower extremities was represented by the femorotibial angle (FTA) on the anteroposterior film. The assessment of the implant placement involved precise quantification of the anatomical angles, specifically the anatomical medial proximal tibial angel (aMPTA), the anatomical lateral distal femoral angle (aLDFA), and the posterior tibial slope (PTS). The comprehensive protocols employed for these measurements have been meticulously delineated in the prior works of Park et al. [18] and Kim et al. [19] [Fig. 1 (A-C)), which serve as references for these methodologies. Prosthesis loosening was evaluated. Loosening was characterized and documented upon identification of a radiolucent line measuring 2 mm at the interfaces of cement-bone or cement-prosthesis, particularly in instances of component subsidence, or in cases where an alteration in alignment was observed [16]. Complications following surgery were meticulously cataloged for both cohorts. The Kaplan-Meier method was employed to conduct survival analysis, with the occurrence of revision surgery serving as the definitive endpoint.

2.2. Surgical techniques

Senior surgeons (H. X., YZ. W., CY. L., and HZ. Z.) performed the procedures. Every participant was positioned supine and administered general anesthesia, which was augmented with an adductor canal block for enhanced analgesic effect. Throughout the surgical procedure, a thigh tourniquet was applied and pressurized to a level exceeding the patient's systolic blood pressure by 100 mmHg. A midvastus approach was used to extract the joints. The femoral side was resected at a 5° angle using an intramedullary guide.

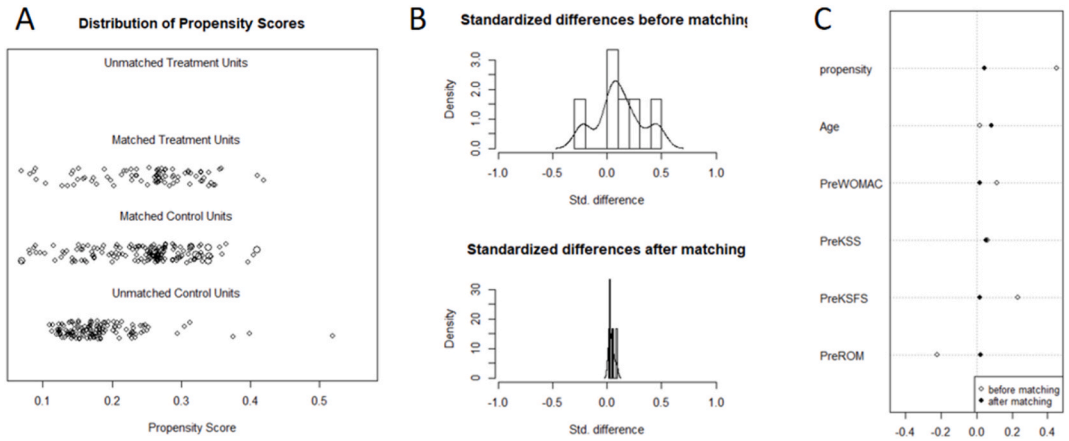

Fig. 2. Results of PSM. (A) Density plots after PSM. (B) Standarized differences before and after PSM. (C) Confounding variables before and after PSM.
PSM: propensity score matching.

Extramedullary osteotomy with a 3° posterior tilt was performed on the tibial side. The patella was then denervated and trimmed. Intraoperative evaluation of the PCL function was performed. When PCL tension was satisfactory, the knee displayed balanced extension and flexion without restrictions and the PCL was preserved.

2.3. Statistical analysis

The statistical analysis was conducted using the Statistical Package for the Social Science26.0 (SPSS Inc., Chicago, IL, USA). To mitigate selection bias and balance covariates, a 1:2 propensity score matching (PSM) was performed between the CRTKA and CSTKA groups. The variables of age, body mass index (BMI), and initial clinical assessments, including the KSS, KSFS, and WOMAC, were recognized as potential confounders. These were incorporated into the logistic regression analysis for the calculation of propensity scores. Additionally, the standardized differences prior to and subsequent to the matching process were evaluated, as depicted in Fig. 2 (A-C). Clinical variables were reported as the mean plus or minus the standard deviation (SD). The Student's t-test was employed to evaluate disparities in continuous variables, whereas the Fisher's exact test was utilized for the assessment of categorical variables. A *P*-value of less than 0.05 was established as the threshold for statistical significance.

3. Results

The study encompassed a cohort of 376 patients. Subsequent to a 1:2 propensity socre matching (PSM), a comparative analysis was conducted on the data from 252 patients, which included 84 patients who underwent CRTKA and 168 patients who underwent CSTKA. Baseline characteristics such as age (68.2 ± 7.3 vs. 67.5 ± 7.5, p = 0.527), body mass index (BMI) (27.9 ± 3.3 vs. 28.1 ± 3.9, p = 0.613), duration of follow-up (8.7 ± 0.9 vs. 8.6 ± 1.3 years, p = 0.477), and hospital length of stay (LOS) (10.7 ± 4.4 vs. 10.5 ± 9.6 days, p = 0.856) demonstrated no significant differences between the two groups as presented in Table 1.

Prior to surgery, there were no significant disparities in clinical scores between the two cohorts (all p-values exceeded 0.05). However, by the time of the final follow-up, there was a marked enhancement in the postoperative clinical scores for both groups when juxtaposed with their respective preoperative scores (all p-values were less than 0.001). WOMAC score (11.4 ± 13.4 vs. 12.6 ± 13.9, p = 0.517), KSS (88.6 ± 11.7 vs. 90.3 ± 5.0, p = 0.107), KSFS (73.9 ± 11.8 vs.71.7 ± 14.9, p = 0.240), ROM (103.8 ± 11.5 vs.104.3 ± 15.6, p = 0.795), and FJS (78.2 ± 23.4 vs. 77.4 ± 25.2, p = 0.822) were equally good in the CSTKA and CRTKA groups (Table 2).

No significant differences were found in the radiographic outcomes. The preoperative FTA (−3.8 ± 6.0 vs. −3.9 ± 4.9, p = 0.997), postoperative FTA (3.7 ± 3.0 vs. 3.5 ± 3.7, p = 0.646), aLDFA (84.4 ± 2.3 vs. 85.0 ± 3.3, p = 0.094), aMPTA (88.2 ± 2.4 vs. 88.2 ± 2.4, p = 0.970), and PTS (4.7 ± 1.7 vs. 4.4 ± 1.4, p = 0.243) between the CSTKA and CRTKA groups were all within the normal range and comparable. Pathologically radiolucent lines were not observed in either group (Table 3).

Among the 376 patients, 15 complications were recorded in the CSTKA group (5.1 %) and four complications were recorded in the CRTKA group (4.8 %). There were no significant differences in the complication rates between the two groups (p = 0.34) (Table 4). At the final follow-up, the cumulative Kaplan–Meier survival in the CRTKA and CSTKA groups was 100 % and 98.6 %, respectively (Fig. 3). Four revision procedures were performed in the CSTKA group, including three cases of periprosthetic joint infection and one case of knee instability.

4. Discussion

This study used PSM analysis to compare the clinical and radiographic mid-to long-term (7.0–10.2 years) outcomes of CSTKA and CRTKA using the AMP implant. The two groups had comparable baseline parameters, and their final clinical and radiographic outcomes were equally good, with a survival rate of 98.9 % at the final follow-up. When using MP prostheses, both CR and CS procedures showed similar mid-to long-term clinical and radiographic outcomes, as well as comparable rates of complications.

The debate about sacrificing the PCL during TKA has been ongoing for decades. This study evaluated the mid-to long-term performance of MP implants with respect to the preservation or absence of PCL. The asymmetrical insert of the AMP knee creates a ball-in-socket articulating surface on the medial side, forming a medial axis during knee flexion. In addition, the lateral arcuate groove facilitates femoral rollback [20]. Previous studies have described the satisfactory long-term performance of AMP implants [21]. Although studies have compared clinical outcomes between AMP and conventional PS implants [22] and AMP and conventional CR implants [23], there are currently no studies specifically examining the 5-year follow-up of postoperative outcomes associated with CS and CR implants [24]. Furthermore, direct comparisons between CSTKA and CRTKA using AMP implants are rare [16,17].

Although an in vitro computational study demonstrated similar kinematic patterns in CRTKA and CSTKA models using AMP knees,

Table 1
Demographic information of patients.

Parameters	CR group (n = 84)	CS group (n = 168)	P value
Age (year)	68.2 ± 7.3	67.5 ± 7.5	0.527
BMI (kg/m^2)	27.9 ± 3.3	28.1 ± 3.9	0.613
Follow-up (Range, Year)	8.6 ± 1.3 (7.0–10.2)	8.7 ± 0.9 (7.0–10.2)	0.477
LOS (Day)	10.7 ± 4.4	10.5 ± 9.6	0.856

CR: cruciate-retaining; CS: cruciate-sacrificing; BMI: body mass index; LOS: length of stay.

Table 2
Clinical outcomes between CR group and CS group.

Parameters	CR group (n = 84)	CS group (n = 168)	P value
Preoperative WOMAC	74.9 ± 7.3	74.6 ± 10.9	0.847
Postoperative WOMAC	11.4 ± 13.4	12.6 ± 13.9	0.517
P value	0.000	0.000	
Preoperative KSS	23.7 ± 4.6	23.4 ± 6.1	0.740
Postoperative KSS	88.6 ± 11.7	90.3 ± 5.0	0.107
P value	0.000	0.000	
Preoperative KSFS	34.4 ± 14.6	34.2 ± 15.3	0.950
Postoperative KSFS	73.9 ± 11.8	71.7 ± 14.9	0.240
P value	0.000	0.000	
Preoperative ROM	84.9 ± 12.3	84.9 ± 16.1	0.999
Postoperative ROM	103.8 ± 11.5	104.3 ± 15.6	0.795
P value	0.000	0.000	
FJS	78.2 ± 23.4	77.4 ± 25.2	0.822

CR: cruciate-retaining; CS: cruciate-sacrificing; WOMAC: the Western Ontario and McMaster Universities osteoarthritis index; KSS knee scoring system; KSFS: Knee Society Function Score; ROM: the range of motion; FJS: Forgotten Joint Score.

Table 3
Radiographic outcomes between CR group and CS group.

Parameters	CR group (n = 84)	CS group (n = 168)	P value
FTA (degrees)			
Preoperative	−3.9 ± 4.9	−3.8 ± 6.0	0.997
Final follow-up	3.5 ± 3.7	3.7 ± 3.0	0.646
aLDFA (degrees)	85.0 ± 3.3	84.4 ± 2.3	0.094
aMPTA (degrees)	88.2 ± 2.4	88.2 ± 2.4	0.970
PTS (degrees)	4.4 ± 1.4	4.7 ± 1.7	0.243

CR: cruciate-retaining; CS: cruciate-sacrificing; FTA: femorotibial angle; aLDFA: anatomical lateral distal femoral angle; aMPTA: anatomical medial proximal tibial angle, PTS: posterior tibial slope.

Table 4
Overall complications of patients.

Complications	CR group (n = 84)	CS group (n = 292)	P value
Pulmonary embolism	0	1	–
Respiratory failure	0	1	–
Periprosthetic joint Infection	0	4	–
Continuous knee clicking	2	4	–
Anterior knee pain	2	3	–
Instable knee	0	2	–
Total	4 (4.8 %)	15 (5.1 %)	0.34

CR: cruciate-retaining; CS: cruciate-sacrificing.

another cadaveric study reached different conclusions [25,26]. Omori et al. [25] observed a consistent posterior shift of the estimated contact point (ECP) within both lateral and medial compartments throughout knee flexion when the PCL was preserved, indicative of a bicondylar rollback phenomenon. Furthermore, when knee flexion surpassed 120°, the ECP of the medial compartment was situated on the posterior lip, which may potentially impede the attainment of greater flexion angles. Motion of the MP was exclusively detected following the excision of the PCL. From 0° to 90° of knee flexion, the medial compartment's ECP maintained a fixed position; however, it demonstrated a minor posterior shift when flexion exceeded 100°. In contrast, the ECP of the lateral compartment continuously translated posteriorly with knee flexion [25]. In the follow-up by Bae et al. which averaged 3.9 years (range from 2.0 to 7.1 years), no significant differences were observed in increased knee and function scores between the two groups [17] Similar outcomes have been reported by Machears et al. [16], who did not report statistically significant differences in knee scoring systems for PCL retention or resection during a mean follow-up of 15.2-years (15–17 years). However, the baseline parameters in their study were not comparable and no statistical significance was identified when considering the increased clinical scores. The present study reduced bias through PSM, resulting in equivalent preoperative clinical scores between the two groups. Under these conditions, the mid-to long-term clinical scores, including the KSS, KSFS, WOMAC score, and FJS, were comparable between CRTKA and CSTKA. Therefore, the results of this study further support the conclusions of Bae et al. [17] and Machears et al. [16], demonstrating that the preservation of the PCL has minimal influence on mid-to long-term clinical outcomes. Regarding radiographic results, postoperative alignment was evaluated using FTA measured on standing anteroposterior films; the FTA of both groups was not significantly different. Previous studies have defined an FTA less than 4° as varus alignment [19,27,28]. In clinical practice, a slight varus alignment is preferred when using the AMP knee to maintain medial tension and guarantee knee stability. Additionally, the positions of the femoral and tibial components

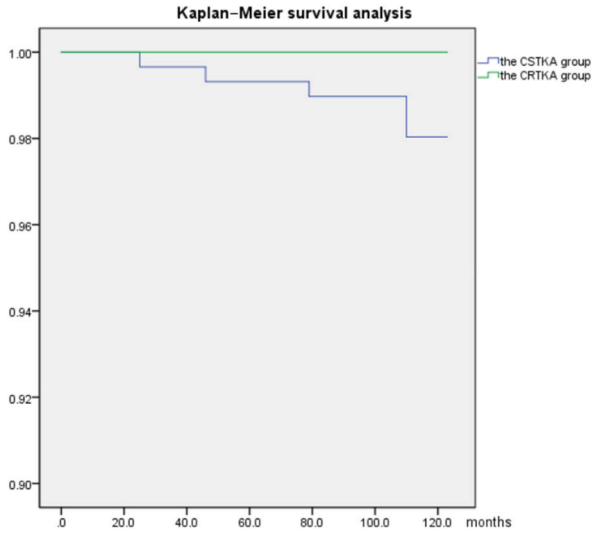

Fig. 3. Kaplan–Meier survivorship graph of the CRTKA and CSTKA groups with revision as an end point showed the cumulative survivorship rates of 100 % and 98.6 %, respectively.

were equally satisfactory and no loosening of the implant was observed at the last follow-up.

4.1. Limitations

This study has several limitations. First, this was a retrospective study and despite our efforts to minimize bias by calculating the propensity score of each variable and matching cases with similar propensity scores, there may have been differences in the preoperative function of PCL between the CSTKA and CRTKA groups. Inevitably, there were cases in the CSTKA group in which the tension of the PCL was compromised, and could not be preserved. However, according to the results of this study, both CRTKA and CSTKA using AMP knees provide comparably excellent mid-to long-term clinical outcomes. Thus, the PCL is not necessarily preserved if the appropriate tension cannot be obtained. Second, 126 patients (21.8 %) were lost follow-up, which may cause data bias. Furthermore, according to the study conducted by Omori et al. [25], the preservation of the PCL may influence the knee's capability to achieve high degrees of flexion, given that it causes the ECP within the medial compartment to shift towards the posterior edge of the tibial insert [25]. However, the mean ROM in both groups in this study was less than 120°, and we could not confirm the laboratory findings of Omori et al. [25]. In addition to the aforementioned limitations, it is crucial to recognize that there might be other unmeasured or unaccounted factors that could have affected the outcomes, which were not addressed in this study. These potentially confounding variables have the potential to introduce bias or influence the generalizability of our findings. Despite these limitations, it is important to note that this study showed comparable and favorable mid-to long-term clinical outcomes between CRTKA and CSTKA when using knees with AMP. This suggests that preserving the PCL may not be crucial in cases where obtaining the appropriate tension poses a challenge.

5. Conclusions

This study presents a comparative analysis of the mid-to long-term clinical and radiological outcomes of two surgeries, CSTKA and CRTKA, using the AMP knee. Clinical scores, radiological outcomes, and complication rates were equally favorable in both groups. In cases with adequate PCL tension, balanced knee extension and flexion, and no restriction in flexion, it may be advantageous to preserve the PCL when using the AMP technique for TKA. This is because it improves the proprioception of patients.

Ethical approval and consent to participate

The Affiliated Hospital of Qingdao Unviersity's Medical Ethics Committee granted approval for this research (QYFY QZLL 26921). All study participants provided informed consent prior to their inclusion. The research involving human subjects adhered to the ethical guidelines of the institutional review board and conformed to the principles of the 1964 Helsinki Declaration, as well as its subsequent updates, or other pertinent ethical standards.

Consent for publication

The patient provided their written informed consent for the dissemination of this case repot and any associated imagery. Documentation of the consent is retained and can be made available for examination by the journal's Editor upon request.

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Data availability statement

Data associated with this study has not been deposited into a publicly available repository, and data will be made available on request.

CRediT authorship contribution statement

Mingwei Hu: Writing – original draft, Visualization, Software, Formal analysis, Data curation. **Shuai Xiang:** Writing – original draft, Visualization, Software, Funding acquisition, Formal analysis, Data curation. **Hao Xu:** Writing – review & editing, Data curation. **Yingzhen Wang:** Supervision, Resources, Data curation. **Chengyu Lv:** Writing – review & editing, Data curation. **Haining Zhang:** Writing – review & editing, Supervision, Project administration, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Haining Zhang reports financial support was provided by National Natural Science Foundation of China. Shuai Xiang reports financial support was provided by Youth Program of National Natural Science Foundation of China. Shuai Xiang reports financial support was provided by Youth Program of Natural Science Foundation of Shandong Province. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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