Effect of Joint Line Elevation after Posterior-stabilized and Cruciate-retaining Total Knee Arthroplasty on Clinical Function and Kinematics

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Abstract

Background: Joint line (JL) is a very important factor for total knee arthroplasty (TKA) to restore. The objective of this study was to evaluate the early clinical and kinematic results of TKAs with posterior-stabilized (PS) or cruciate retaining (CR) implants in which the JL was elevated postoperatively.

Methods: Data were collected from patients who underwent TKA in our department between April 2011 and April 2014. The patients were divided into two groups based on the prosthesis they received (PS or CR). At 1-year postoperatively, clinical outcomes were evaluated by the American Knee Society (AKS) knee score, AKS function score, and patella score. *In vivo* kinematic analysis after TKA was performed on all patients and a previously validated three-dimensional to two-dimensional image registration technique was used to obtain the kinematic data. Anteroposterior (AP) translation of the medial and lateral femoral condyles, and axial rotation relative to the tibial plateau, were analyzed. The data were assessed using the Mann–Whitney test.

Results: At time of follow-up, there were differences in the AKS knee scores ($P = 0.005$), AKS function scores ($P = 0.025$), patella scores ($P = 0.015$), and postoperative range of motions ($P = 0.004$) between the PS group and the CR group. In the PS group, the magnitude of AP translation for the medial and lateral condyle was 4.9 ± 3.0 mm and 12.8 ± 3.3 mm, respectively. Axial rotation of the tibial component relative to the femoral component was $12.9 \pm 4.5°$. In the CR group, the magnitude of AP translation for the medial and lateral condyle was 4.3 ± 3.5 mm and 7.9 ± 4.2 mm, respectively. The axial rotation was $6.7 \pm 5.9°$. There were statistically different between PS group and CR group in kinematics postoperatively.

Conclusion: Our results demonstrate that postoperative JL elevation had more adverse effects on the clinical and kinematic outcomes of CR TKAs than PS TKAs.

Key words: Fluoroscopic Analysis; Kinematics; Posterior Cruciate-retaining; Posterior-stabilized; Total Knee Arthroplasty; Two-dimensional/Three-dimensional Registration

INTRODUCTION

Total knee arthroplasty (TKA) is one of the most successful procedures performed by orthopedic surgeons. In TKA, whether the posterior cruciate ligament (PCL) should be retained or resected has been the subject of argument for many years. Previous studies have shown no notable differences between the clinical outcomes after posterior-stabilized (PS) or cruciate retaining (CR) TKA.

Recently, much attention has been focused on knee kinematics, as more physiological movement patterns might correlate with better postoperative knee function.[1] In their kinematic comparison of PS and CR TKAs, Dennis *et al.* investigated femorotibial contact paths during deep knee

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bending and observed abnormal kinematics (anterior femoral translation) in patients who had undergone CR TKA. In contrast, Banks *et al*. performed a similar kinematic analysis during a step-up activity and found that the ranges of rotation and translation were closer to the reported physiological values in CR knees than in PS knees. However, it is difficult to draw any definitive conclusions from the data currently available in the literature.

Restoration of the normal joint line (JL) has been a common goal of all TKA techniques.[2] JL elevation results in patella baja,[3,4] which in turn results in decreased range of motion (ROM) and poor clinical function.[1]

There is a paucity of research whether postoperative JL elevation after PS or CR TKA has different clinical and kinematic outcomes. In this study, all patients underwent TKA for osteoarthritis. At the time of follow-up, the clinical function was evaluated, and a fluoroscopic analysis of the implanted knee was conducted using a three-dimensional (3D) model fitting technique. The objectives of this study were to compare the early clinical results and kinematic differences between PS and CR TKAs that resulted from significant postoperative JL elevation.

METHODS

Patients

The study was approved by the Institutional Review Board of our hospital, and informed consent was obtained from all volunteers.

We collected data on patients who underwent TKA in adult joint reconstruction department of our hospital from April 2011 to April 2014. The patients included in our study satisfied the following criteria: (1) Their preoperative diagnosis was osteoarthritis, (2) a GENESIS II (Smith and Nephew, Memphis, Tennessee, USA) prosthesis was used for both the PS and CR TKAs, but the patella was not resurfaced, and (3) the postoperative JL was elevated by more than 4 mm relative to its preoperative level. In total there were 1058 TKAs performed using GENESIS II implants during the study period; of these, 722 were PS TKAs and 336 were CR TKAs.

The JL was evaluated on pre- and post-operative knee radiographs relative to a line drawn from the adductor tubercle of the femur according to Hofmann's method,[5] as shown in Figure 1. The difference in the distance between the pre- and post-operative location of the JL was considered the postoperative change in JL location.

Fifty-five patients, all of whom had undergone unilateral TKA, were included in this study. Among them, 37 had received a PS prosthesis, and 18 had received a CR prosthesis. The patients consisted of 10 men and 45 women, with an average age of 65.1 ± 6.1 years (range 35–80 years). The patients were divided into PS group and CR group based on which prosthesis they had received.

All TKAs were performed using the standard medial parapatellar approach. The patients were placed under
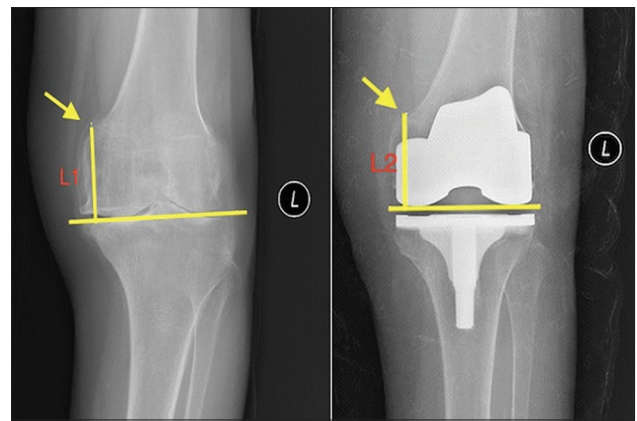

Figure 1: In anteroposterior plain radiographs of the knee, the joint line was defined as the tangent of the articular surfaces of the medial and lateral femoral condyles. The pre- and post-operative distances between the adductor tubercle of the femur and the joint line were measured. The difference in the location of the joint line = (L2 − L1).

general or spinal-epidural combined anesthesia and an air tourniquet was applied in all cases. An parapatellar approach anterior straight midline skin incision was made approximately 12 cm from the suprapatellar area extending to the medial side of the tibial tubercle. Using a dedicated instrument, the rotation of the femoral component was determined parallel to the surgical epicondylar axis and the femoral cut was made. After preparation of the femoral condyles, the proximal tibia was cut perpendicular to the tibial shaft in the frontal plane; and in the sagittal plane an adequate posterior slope was created. Osteophytes were removed from both the femoral and tibial condyles. The flexion and extension spaces were equalized, soft tissues were balanced, and a trial reduction was performed with provisional components. In CR knees, special care must be taken to assess the PCL at this stage of the procedure. If the PCL was too tight, further balancing was performed as required. The patella was not resurfaced. After assessing patellar tracking, a lateral retinacular release was performed if necessary. Circumpatellar electrocautery was used after cementing the components. The incision was then irrigated and closed.

Clinical evaluation

Patients received clinical and radiographic evaluations preoperatively and 1-year after surgery. Clinical evaluations included assessments of ROM, American Knee Society (AKS) knee score,[6] AKS function score and patella score.[7]

Kinematics measurements

An *in vivo* kinematic analysis was performed at the 1-year follow-up. Fluoroscopy was continuously used to capture lateral images of the knee during a weight-bearing deep knee bend from maximum extension to maximum flexion. Patients were allowed to hold onto a handrail for safety during the procedure. Successive images ($1024 \times 1024 \times 12$ bits/pixels as a DICOM file) were recorded using a digital image fluoroscopy system (Sonial-vision Saline II, Shimadzu, Japan). Fluoroscopy data were then uploaded to a computer,

and computer-aided design models of the femoral and tibial components were evaluated after correcting for distortion. A previously validated 3D to two-dimensional image registration technique was used to obtain the kinematic data.[8] In this manner, 3D kinematic analysis of the metal implant components was performed [Figure 2]. The accuracy of relative position estimation using this system is within 0.5° rotation and 0.4 mm translation.[8,9]

We evaluated the flexion angles and axial rotation angles of the femoral components relative to the tibial tray components, and the anteroposterior (AP) translation of the points on the medial and lateral femoral condyles nearest to the tibial tray [Figure 3]. The position of those points when the knee was fully extended was denoted as 0. The anterior or posterior translation was defined as negative or positive, respectively. The rotation of the femoral component relative to the tibial tray component was defined as 0° when the knee was fully extended. Internal rotation of the tibia relative to the femur was denoted as positive and external rotation was negative. In addition, we also recorded the flexion angle at which the cam and post engaged in the PS group [Figure 3].

Statistical analysis

Statistical analyses were conducted using Statistics 21.0 (IBM, Armonk, NY, USA). All data are expressed as a means ± standard deviation (range). Continuous variables were assessed using the Mann–Whitney test. For categorical data, the Pearson Chi-squared test was used. A $P < 0.05$ was considered statistically significant.
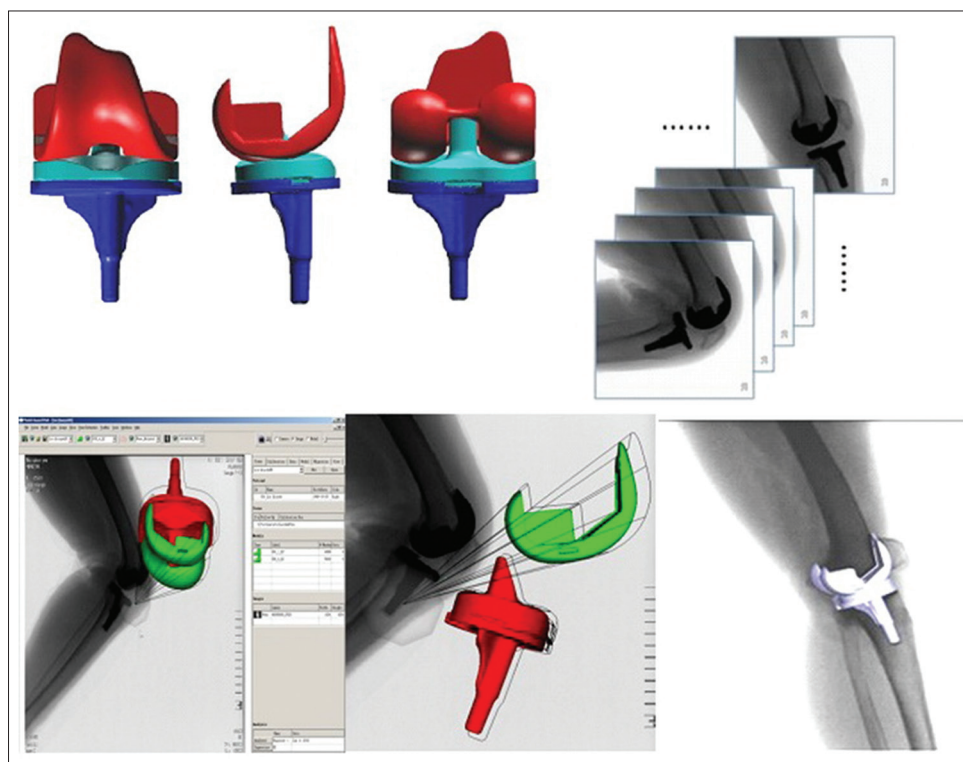

Figure 2: The two-dimensional/three-dimensional registration technique uses computer-assisted design models to reproduce the spatial position of the femoral and tibial components from single-view fluoroscopic images.
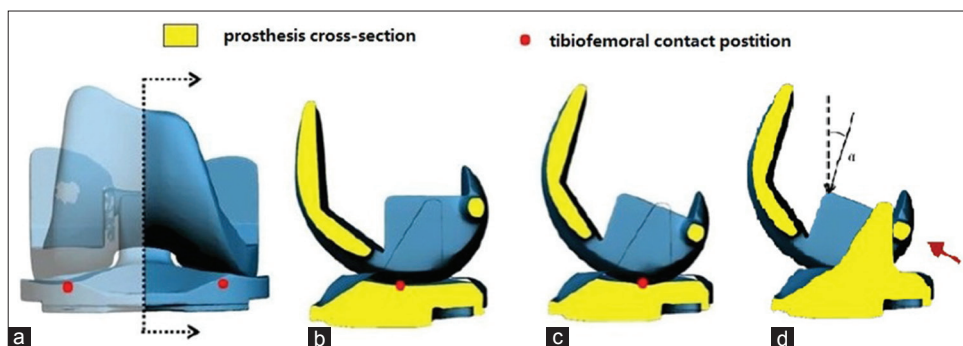

Figure 3: Schematic diagram showing the contact position between the femoral condyle and tibial plateau. Red dots indicate the points at which the medial and lateral femoral condyles contact the tibial plateau. (a) The location of the prosthesis cross-section; (b and c) The tibio femoral joint contact points and positions at 0° and 30° of flexion, respectively. (d) Contact between the femoral cam (yellow dot, cam shown in cross-section) and the tibial post. The α indicates the flexion angle at which the cam and post first contact.

RESULTS

Clinical results

There were no significant differences between the PS group and CR group in demographic parameters, preoperative AKS knee scores ($P = 0.270$), preoperative AKS function scores ($P = 0.496$), preoperative patella scores ($P = 0.643$) and preoperative ROMs ($P = 0.448$).

Follow-up examinations were conducted on all patients 1-year after surgery. No serious complications, such as prosthesis loosening or infection, had occurred. Patients showed clinical improvements relative to their preoperative status. The AKS knee score of the PS group improved from a mean of 54.4 ± 14.4 (29–73) points preoperatively to 83.8 ± 9.4 (64–100) points postoperatively. The AKS function score was 53.2 ± 8.8 (40–70) preoperatively and 80.7 ± 13.1 (60–100) postoperatively; the patella score was 12.4 ± 3.8 (4–15) preoperatively and 21.2 ± 4.5 (9–27) postoperatively. Average ROM increased from $92.6 \pm 16.9°$ (65–120°) before surgery to $116.4 \pm 9.6°$ (90–130°) after surgery.

In the CR group, the AKS knee score improved from a mean of 50.1 ± 10.0 (37–78) points preoperatively to 77.1 ± 11.8 (50–99) points postoperatively. The AKS function score was 55.3 ± 9.6 (40–70) preoperatively and 70.0 ± 11.6 (45–90) postoperatively. The patella score was 12.3 ± 2.9 (7–19) preoperatively and 17.2 ± 4.4 (11–24) postoperatively. Average ROM increased from $95.9 \pm 16.0°$ (70–120°) before surgery to $108.9 \pm 9.6°$ (90–125°) after surgery.

The clinical function was better in both the PS and CR groups after surgery relative to preoperatively. However, the outcomes of CR group was inferior to that of PS group. There were statistically significant differences in the AKS knee scores ($P = 0.005$), AKS function scores ($P = 0.025$), patella scores ($P = 0.015$), and postoperative ROMs ($P = 0.004$) between the PS group and the CR group.

Kinematics results

In the PS group, movement from full extension to maximum flexion of the knee resulted in average AP translations of the medial and lateral condyles of 4.9 ± 3.0 mm (0–12.1 mm) and 12.8 ± 3.3 mm (5.4–16.8 mm), respectively. The average medial nearest points moved posteriorly to reach 0.4 ± 1.4 mm (−2.4–3.4 mm) at 30° flexion, 2.8 ± 3.9 mm (−4.4–9.4 mm) at 60° flexion, and 3.9 ± 3.5 mm (0–10.5 mm) at 90° flexion. The average lateral nearest points moved posteriorly to reach 1.8 ± 2.7 mm (−2.4–6.8 mm) at 30° knee flexion, 5.9 ± 2.0 mm (3.4–10.4 mm) at 60° knee flexion, 11.3 ± 2.7 mm (7.9–16.4 mm) at 90° knee flexion [Figure 4]. Regarding axial rotation of the tibial component relative to the femoral component, the mean degree of axial rotation was $12.9 \pm 4.5°$ (5.5°–16.1°) during the knee flexion cycle. The average rotation was $3.0 \pm 1.6°$ at 30° knee flexion, $6.2 \pm 2.5°$ at 60° knee flexion and $11.5 \pm 3.6°$ at 90° knee flexion. The mean axial rotation of the tibial component exhibited gradual internal rotation from full extension to maximum flexion, and internal rotation increased until maximum flexion was achieved [Figure 5].

In the CR group, movement from full extension to maximum flexion resulted in average AP translations for the medial and lateral condyles of 4.3 ± 3.5 mm (−3.0–9.4 mm) and 7.9 ± 4.2 mm (2.4–10.6 mm), respectively. The average medial nearest points moved posteriorly to reach $−0.4 \pm 2.0$ mm (−4.4–3.4 mm) at 30° flexion, 0.9 ± 1.9 mm (−1.5–5.1 mm) at 60° flexion, and 2.5 ± 3.2 mm (−3.5–8.5 mm) at 90° flexion. The average lateral nearest points moved posteriorly to reach 1.4 ± 1.4 mm (−1.5–3.4 mm) at 30° flexion, 3.2 ± 3.8 mm (−4.4–9.4 mm) at 60° flexion, and 7.1 ± 3.7 (−3.5–10.1 mm) at 90° flexion [Figure 6]. Regarding the axial rotation of the tibial
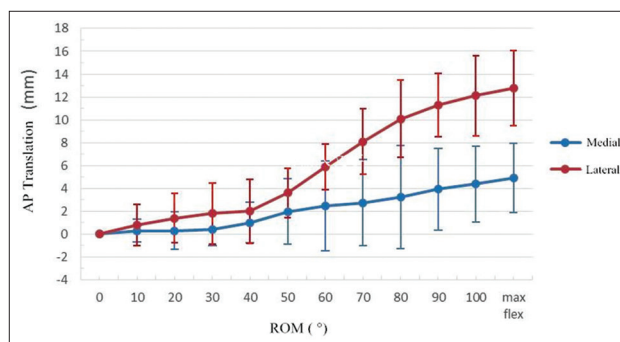

Figure 4: Anteroposterior translation of the medial and lateral condyles in the posterior-stabilized group.
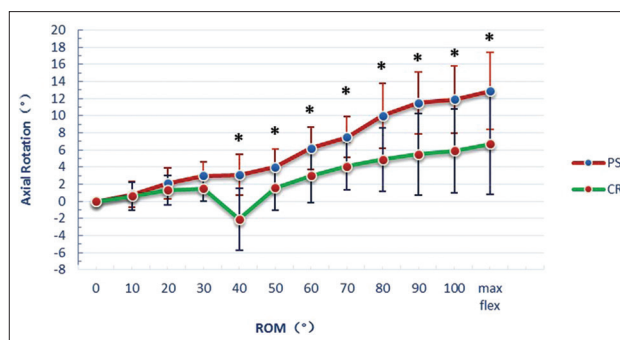

Figure 5: Axial rotation of the tibial component relative to the femoral component in the posterior-stabilized and cruciate-retaining groups during movement from full extension to maximum flexion of the knee (*$P < 0.05$).
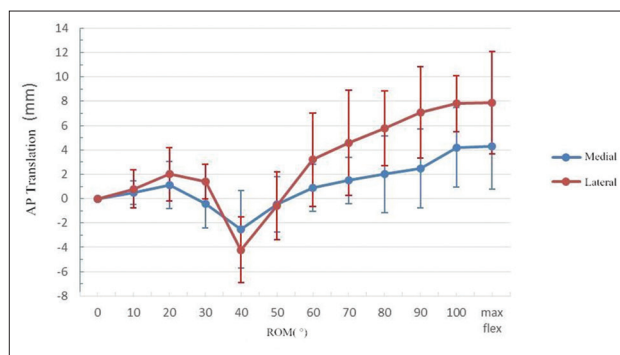

Figure 6: Anteroposterior translation of the medial and lateral condyles in the cruciate-retaining group.

component relative to the femoral component, the mean degree of axial rotation was $6.7 \pm 5.9°$ ($3.5–10.4°$) during the knee flexion cycle. The average rotation was $1.5 \pm 1.5°$ at $30°$ knee flexion, $3.0 \pm 3.2°$ at $60°$ knee flexion, and $5.5 \pm 4.8°$ at $90°$ knee flexion [Figure 5]. The mean axial rotation of the tibial component exhibited gradual internal rotation at $0–30°$ flexion, external rotation at $30–50$ flexion, and internal rotation again until maximum flexion. The axial rotation of CR group was different statistically from that of PS group when the flexion was beyond $40°$ [Figure 5].

In the PS group, the α angle was $43 \pm 6°$. Contact between the femoral cam and tibial post occurred at this knee flexion angle.

Discussion

Exact reconstruction of the natural JL is considered a key factor in successful knee arthroplasty.[10] Anatomic landmarks, including the medial and lateral femoral condyles, tibial tubercle, fibular head, and the lower pole of the patella, have commonly been used.[10-12] However, the fibular head and the tibial tuberosity can have very variable positions.[13] The method proposed by Hofmann *et al.* measures the distance from the adductor tubercle of the femur to the distal femoral articular surface.[5] Maderbacher *et al.*[14] and Iacono *et al.*[15,16] concluded that the femoral adductor tubercle was an accurate and stable anatomical landmark for measurement of knee JL position, and that its position was not affected by knee flexion or extension. Weber concluded that internal or external rotation were no influence on measurement result if the angle was $<10°$.[17] Thus, in this study we measured the position of the JL relative to the femoral adductor tubercle.

Selvarajah and Hooper[2] reported that retaining the PCL during TKA could result in a conservative tibial resection, with subsequent JL elevation, in an attempt to protect the ligament. Conversely, Schnurr *et al.*[18] concluded that PCL release or removal leads to an increase in the size of the flexion gap, which explains the need to move the distal femoral JL proximally in order to establish flexion-extension gap equality when the PCL has been excised or completely released. However, Snider's study that suggested no statistically significant differences in the JL changes between PS and CR designs within the same implant system.[19] Patients were selected for our study if their JL elevation was greater than 4 mm after surgery. Thirty-seven out of 722 PS TKAs (5.1%) and 18 out of 336 CR TKAs (5.3%) were selected. There were no significant between-group differences in the incidence of JL changes significantly ($P = 0.882$).

Most authors believe that there are no differences in postoperative functional results between PS and CR TKAs. However, no previous studies have compared PS and CR TKAs of patients with postoperative JL elevation. JL elevation results in patella baja, which in turn results in decreased ROM.[3] In CR TKAs, when JL is elevated the tension on the PCL is higher than the tension on a normal PCL. In this case, moving the knee from extension to flexion may stretch the PCL and restrict movement. A study showed that JL elevation of >4 mm affected the biomechanics of knee.[20] Therefore, we evaluated patients with postoperative JL elevation after PS or CR TKA to compare the clinical and kinematic outcomes.

Although clinical outcomes for both groups in this study were worse than what previous studies have reported,[21] the PS group had a significantly better AKS knee score ($P = 0.005$), AKS function score ($P = 0.025$), patella score ($P = 0.015$), and ROM ($P = 0.004$) than that of CR group after surgery. Thus, we concluded that postoperative JL elevation had more adverse effects on the clinical outcome of CR TKAs than the outcome of PS TKAs. Surgeons should pay more attention to intraoperative JL control if a CR prosthesis is used. Significant postoperative elevation of the JL in CR TKAs results in poor clinical outcomes.

Both the CR and PS TKA systems offer surgeons a wide variety of choices in terms of polyethylene components (e.g., conformity, shape/slope, and design) and femoral morphology (e.g., single- or multi-radius design, and symmetric or asymmetric femoral condyles). All of these factors may play a role in sagittal stability and flexion mechanics.[22,23] In this study, we compared the kinematics of knees that had undergone implantation of a PS or CR prosthesis of type GENESIS II. Because the designs of the PS and CR prosthetic were identical in their congruity between the femoral condyle and polyethylene insert, differences in kinematics were mainly attributed to whether the PCL was retained.

In the normal knee, the lateral condyle rolls a greater posterior distance than the medial condyle during flexion, leading to internal rotation of the tibia relative to the femur. Kinematic analyses by Komistek demonstrated that the average amount of normal tibial axial rotation was $16.8°$ of rotation relative to the femur during knee movement from full extension to maximum flexion; the concomitant translations of the medial and lateral femoral condyles were only 1.5 mm and 11.4 mm, respectively.[24] A variety of kinematic studies that compared TKA knees with normal knees concluded that all TKA designs experience significantly less axial rotation than the normal knee.[25] The magnitude of translation and rotation in PS TKAs were similar to those in the normal knee, even though the JL was elevated.

The PS TKA can result in bicondylar rollback and axial rotation due to the action of the postcam mechanism.[26] In our study, the most part of femoral rollback and tibial internal rotation in the PS group occurred mainly when the knee flexed beyond $40°$. Rollback and axial rotation increased slightly from full knee extension to $40°$ of flexion. Rollback, especially axial rotation, accelerated obviously after flexion beyond $40°$ [Figure 5]. We observed the engagement between the femoral cam and the tibial post occurred at $43 \pm 6°$ angle. Thus, asymmetric femoral rollback and tibial internal rotation mainly occurred after contact between the cam and

post in the PS group. We concluded that the cam and post could still guide femoral rollback and tibial internal rotation after the engagement, even if the JL had elevated.

The PCL may guide rollback and axial rotation in CR TKAs. However, in our study, the translations of the medial and lateral femoral condyle during movement from full extension to maximum flexion were less in the CR group than in the PS group. The axial rotation was also less than in the PS group and these between-group differences were statistically significant. The AP translations of the femoral condyles and internal rotations of the tibia were less than reported in other studies.[27-29] In the CR group, paradoxical anterior translation occurred at flexion from 30° to 50° [Figure 6]; this may be due to poor PCL function leading to sagittal knee instability.[30] Axial rotation and AP translation are considered essential for good patellar tracking and achievement of maximal knee flexion after TKA. Thus, it is easy to explain why the patellar score and ROM of the CR group are both poor compared with the PS group.

It is very difficult to restore PCL tension to normal after CR TKAs. It is believed that some PCLs were too tight and the other were too loose. A previous study has proven that femoral translation and tibial rotation lessen when the PCL is injured during CR TKA.[25] JL elevation can result in PCL too tight at the moment of knee flexion, even lead to rupture of PCL knee and joint instability.

In CR TKAs, the femoral attachment of the PCL shifts upward when the JL moves proximally, but the tibial attachment does not change. Thus, the distance between the proximal and distal attachments of the PCL increases and the tension also increases. It has been shown that if the PCL is elongated excessively, beyond 115% of its normal length, overstretching occurs along with dysfunction, or even rupture, of the ligament.[26] In addition, the femoral attachment of the PCL is drop shape, and the anterior lateral bundle is the lowest in the fiber of PCL, part of which may be injured when distal femur was cut too much. However, continuity of PCL still can be touched intraoperatively because medial bundle is intact. In the CR group, we observed paradoxical anterior translation and external rotation of the tibia relative to the femur, which may be related to dysfunction of the PCL resulting in midterm flexion instability.

To sum up, surgeons should avoid JL elevation after TKA as much as possible. Especially in CR TKAs, elevation of the JL may lead to PCL dysfunction causing the PCL to be unable to replicate normal knee kinematics. Our results indicate that JL elevation of more than 4mm after surgery was likely to result in PCL dysfunction, thus changing the kinematics of the knee. If, either pre- or intra-operatively, the surgeons predict that the postoperative JL will rise, then they should consider using the PS prosthesis instead of the CR prosthesis in order to reduce the effects of the elevated JL on postoperative kinematics and clinical outcomes.

However, there were some limitations in this study. If we have the data of preoperative and postoperative magnetic resonance imaging or computed tomography that can reconstruct femoral condyle, the measurement of JL elevation may be more accurate. If a synchronous dual-plane fluoroscopy technique was used to capture kinematic data, the accuracy of kinematics evaluation can be improved and other parameters, such as femoral condylar lift-off and sequential changes in the kinematic pattern also can be analyzed.

Conflicts of interest

There are no conflicts of interest.

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