Kinematics Analysis of Different Types of Prosthesis in Total Knee Arthroplasty with a Navigation System

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Abstract: Different total knee arthroplasty (TKA) designs showed different intraoperative kinematics when evaluated with a navigation system. This study compared the kinematics of three different prosthesis designs using navigation-based in vivo simulation. Studies were carried out on 18 osteoarthritic knees using a computed tomography (CT)-free navigation system. The TKA designs used for these patients were six each of cruciate-retaining (CR) type, posterior-stabilized (PS) type, and PS mobile type. Intraoperative knee kinematics were measured during a passive range of motion from full extension to 130 degrees of knee flexion. Three types of prosthesis were compared for the following factors: the presence of condylar lift-off (gap difference greater than 1 mm between medial gap and lateral gap) and anterior-posterior (AP) displacement of the center of femur relative to the tibia. The lift-off was found in patients with the PS type between 120° and 130° of flexion, but not in the other two types of implant. The pattern of AP displacement was similar among the three implants. The femur moved to the anterior side from extension to 50-55° of flexion, after that, the femur moved to the posterior side to full flexion. The function of PCL could prevent lift-off in the CR type of implants. In the PS-mobile implants, the mechanism of rotation platform might have contributed to lift-off prevention. The paradoxical anterior slide of the femoral condyles during mid flexion was observed in all types of implant.

Key words: navigation system, in vivo knee kinematics, total knee arthroplasty

Introduction

Recent studies of total knee arthroplasty (TKA) using a navigation system, have provided data on clinical results and alignment1,2 but also on the kinematics during surgery. Changes in the amount of pre and postoperative anterior-posterior (AP) displacement, rotation of tibia, and soft tissue balance were reported3,4, suggesting that varus/valgus stability could be acquired with TKA. Furthermore, in a study assessing intraoperative soft tissue balance using a navigation system with tensor, balance was found to be associated with postoperative outcome5. Moreover, some reports have compared various systems based on the soft tissue balance and kinematics achieved6. We previously compared two different TKA systems, the cruciate-retaining

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(CR) and posterior-stabilized (PS) types, and reported some differences in soft tissue balance between the types.\(^7\) As for the types of TKA, several reports found no difference in clinical results between the fixed-bearing type with the insert being “fixed-”, and the mobile-bearing type with the insert “mobile.”\(^8,9\); however, there are only a few reports available comparing the intraoperative kinematics.

The purpose of this study was to compare intraoperative kinematics for soft tissue balance and AP shift among three TKA types using a navigation system: CR type, PS type, and PS mobile-bearing (PS-m) type. We hypothesized that there might be some difference in the intraoperative kinematics between CR and PS types, as well as between the fixed- and mobile-bearing types. We also considered that knowing the knee kinematic behavior intraoperatively would assist the choice of prosthesis type.

**Materials and methods**

The study followed a prospective randomized design and analyzed the knees of 18 subjects (one male, 17 females) with varus osteoarthritis (OA) that underwent TKA using a CT-free navigation system (Kolibri Knee, Brain LAB). The mean age was 71.8 ± 8.7 years. The patients comprised CR-, PS-, and PS-m-type knees (six of each) according to the PFC-sigma Knee System (DePuy, Warsaw, IN). There was no significant difference in the preoperative parameters among these three groups (Table 1).

Surgery was performed using the measured resection technique. The external rotation angle of the femur was obtained by subtracting 2 degrees, which attributed to the residual cartilage of the lateral posterior condyle, from the angle created by the clinical epicondylar axis and the posterior condylar axis on the preoperative epicondylar axis view. After removing osteophytes from the femoral posterior condyle, the gap and soft tissue balance at 0 degrees of extension and 90 degrees of flexion was adjusted with a spacer block. A femoral trial was then set up and a spring tensor (DePuy Ligament Tensor, DePuy, Warsaw, IN) was inserted. The gap and soft tissue balance were assessed after reduction of the patella. Ligament imbalance was corrected by gradual medial release following a three-step method comprising deep MCL,

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<th>Table 1. Patient Demographics</th>
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<td>Age (years)</td>
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※ There was no statistical difference in patients demographics among the three groups.
semimembranosus, and pie-crust release of the superficial MCL until the gap imbalance was less than 3 degrees.

The spring tensor, which was used to adjust the ligament balance, contains independent springs on the medial and lateral sides. It can apply tension as high as 217 N over the length of 6.5–14.5 mm; 149 N is applied for 1 mm of compression, and 217 N for the maximum of 8 mm of compression.\(^{10}\)

Intraoperative kinematics from 0 degrees of extension to the maximum flexion were measured with the implants fixed in cement. The measurement was performed after releasing the tourniquet by raising the femur and gently holding the heel. The medial and lateral gaps from 0 degrees of extension to 130 degrees of flexion were examined, as well as the AP shift of the femur against the tibia. The center of the femur was defined as the point of intersection with the mechanical axis of the leg and the most underside point of the femur obtained by registration of a navigation system. These items were compared based on implant type. Furthermore, a medial to lateral gap of 1 mm or greater was termed as condylar lift-off (lift-off), following the reports by Baier et al.\(^{11}\) and comparisons were also made based on the presence or absence of this lift-off for all implant types.

In statistical analyses, a risk rate of less than 5 % was considered significantly different using a t-test and ANOVA. The ethics committee of Showa University Fujigaoka Hospital approved this study protocol.

**Results**

For the CR type, the medial gap was significantly smaller than the lateral gap at 0 degrees of extension (Fig. 1), while for the PS type, the medial gap was significantly smaller than the lateral gap at 0 degrees of extension, and at 110–130 degrees the lateral gap was significantly

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**Fig. 1.** Joint gap length of CR type

The medial gap was significantly smaller than the lateral gap at 0 degrees of extension.
greater than the medial gap. The change in the medial gap at each angle became significantly large at 30 degrees of flexion (Fig. 2). In the PS-m type, the lateral gap was significantly greater than the medial gap at 0 and 130 degrees of extension, and the change in the medial gap was significantly greater at 30 and 60 degrees of flexion. On the contrary, the change in the lateral gap was significantly greater at 30 degrees of flexion, followed by a slight decrease, and then increase after 90 degrees (Fig. 3).

Fig. 2. Joint gap length of PS type
The medial gap was significantly smaller than the lateral gap at 0 degrees and at 110–130 degrees of extension. Notably, the change in the medial gap at each angle became significantly large at 30 degrees of flexion.

Fig. 3. Joint gap length of PS-m type
The lateral gap was significantly greater than the medial gap at 0 and 130 degrees of extension. The change in the medial gap was significantly greater at 30 and 60 degrees of flexion. On the other hand, the change in the lateral gap was significantly greater at 30 degrees of flexion, followed by a slight decrease, and then increase after 90 degrees.
The lift-off was observed in PS type prostheses at the deep flexion angles of 120 and 130 degrees, while in the CR and PS-m types, no lift-off was observed in any range of motion (Fig. 4).

A consistent AP shift pattern was observed in all the implant types; the femur moved forward against the tibia from the extension up to the mid flexion at 50-55 degrees, and then moved posteriorly. The mean maximum distance of the anterior shift and the flexion angle were 14 mm at 55 degrees, respectively, in the CR type, 17 mm at 50 degrees in the PS type, and 17 mm at 55 degrees in the PS-m type. The maximum distance of the posterior shift was observed at 130 degrees of flexion in all implant types; 10.5 mm in the CR type, 8.3 mm in the PS type, and 6.9 mm in the PS-m type (Fig. 5). There was no statistically significant difference observed among the three implant types.

![Fig. 4. The gap difference between medial and lateral (Lat. – Med.). The lift-off was observed at deep flexion angles, 120 and 130 degrees in PS type. In the CR type and PS-m type, no lift-off was observed in any range of motion.](image1)

![Fig. 5. AP displacement of the center of the femur relative to the tibia. A consistent pattern was observed with AP-shift in all implant types; the femur moved forward against the tibia from the extension up to the mid flexion at 50-55 degrees, and then moved posteriorly. There was no statistical significance observed among the three types of implant.](image2)
Discussion

Previous reports have evaluated intraoperative kinematics using a navigation system. Mihalko et al.\(^4\) investigated pre and postoperative varus/valgus deformity in CR-type TKAs, and found a significant difference in the deformity observed preoperatively, but then no apparent difference at all flexion angles after the operation. In addition, Casino et al.\(^3\) reported that varus/valgus laxity in PS-m type TKAs improved at 0 degrees of extension, but no change was observed at 30 degrees of flexion. Supporting these two previous reports, the increase in the medial gap at mid flexion detected in this study for the PS and PS-m types, but not the CR type, showed excellent soft tissue balance at all ranges of motion. In PS-type TKA systems, the tension of soft tissue including the medial collateral ligament appeared to be relatively low and was likely to be unstable at a mid flexion angle of 30 degrees even after implant placement. On the contrary, the remaining posterior cruciate ligament (PCL) might have affected the change in medial-lateral gap observed with CR-type TKAs, namely the medial-lateral ligament balance. Lift-off was only observed in PS types at 120 and 130 degrees of flexion. In TKA knees, lateral physiological laxity appeared to be more prominent at a deeper flexion angle, and in PS type, external laxity seemed greater than that of CR type as there was no PCL, while lateral lift-off appeared at deeper angles owing to the rotational stress at the point where a post-cam had been engaged. These factors together were assumed to underlie the increased lateral gap. Additionally, the lift-off detected at 120 and 130 degrees in PS types was not observed in PS-m types at all ranges of motion, hence the mobile system might have contributed to the decrease in lift-off.

In this study, there was no lift-off in the CR and PS-m types, but the lateral gap was significantly greater than the medial gap at 0 and 130 degrees of extension in PS-m types. We therefore concluded that the CR type was the most stable among the three types of prosthesis.

The observed femoral rollback in TKA knees might be induced by tension in the PCL in CR types and by the post-cam system in PS types, hence, the angle of onset and the amount of the shift may vary among implant types, although the results of this study revealed no obvious difference among them. Moreover, an anterior shift of the femur was observed at mid flexion in all implant types. Casino et al.\(^3\) also reported an AP shift postoperatively, but not preoperatively. Additionally, Victor et al.\(^{12}\) and Dennis et al.\(^{13}\) reported paradoxical anterior femoral translation in kinematic analyses. Hence, it was considered important to recognize that there is instability at mid flexion that needs to be improved by changing the design of the implant in the future.

This study has several limitations, including that TKA kinematics were measured unloaded under general anesthesia, the small number of cases, and that the surgical techniques might have influenced the results.

Conclusion

Our study of intraoperative kinematics in CR, PS, and PS-m type implants using a navigation system revealed variation in the soft tissue balance among these implants and that the CR type...
was the most stable. Moreover, there was no difference among these implants in terms of the AP shift, and anterior shift of the femur was observed at mid flexion in all implants.

**Ethics approval and consent to participate**

The local Ethics Committees of the Showa University Fujigaoka Hospital reviewed and approved the research protocol and the patient consent form. Each patient gave informed consent before inclusion in the study.

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**Disclosure statement**

The authors have nothing to disclose.

**Competing interests**

The authors have no competing interests to declare.

**References**


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