Correlation between preoperative and postoperative knee kinematics in total knee arthroplasty using cruciate retaining designs

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Abstract The authors evaluated the relationships between preoperative and postoperative kinematics in 50 osteoarthritic knees scheduled for cruciate retaining total knee arthroplasty with regards to posterior femoral roll back and external femoral rotation using a navigation system from 10° to 120° of knee flexion. Although posterior femoral roll back was maintained, external femoral rotation was significantly decreased compared to those of the preoperative knee after total knee arthroplasty. However, the amount of posterior roll back and external femoral rotation after total knee arthroplasty were found to be significantly positively related to those measured preoperatively ($r=0.62$ and 0.57 , respectively). These significant kinematic correlations may explain why preoperative range of knee motion influences range of motion after total knee arthroplasty.

Introduction

Despite favourable long-term survival and patient satisfaction after total knee arthroplasty (TKA), some patients complain of unsatisfactory subjective function [6, 8, 10]. This dissatisfaction may be explained partly by abnormal kinematics following TKA [1], and thus, knee kinematics following TKA have been studied extensively [4, 6, 7, 12, 17, 22–25, 27]. Although preoperative knee conditions, prosthesis design, and surgical technique are generally believed to influence the knee kinematics following TKA,

kinematic studies have primarily focussed on postoperative knee kinematics [4, 6, 7, 17, 22–25, 27]. A few kinematic studies have been undertaken to investigate the kinematics of osteoarthritic knee preoperatively [2, 3, 11, 15, 20], but we are unaware of any kinematic studies that addressed the relationship between the kinematic variables of knees before and after TKA. Initially, navigation systems were used to improve implant alignment during TKA [10, 13, 14], but more recently a number of kinematic studies have used navigation systems to investigate passive knee kinematics in patients with osteoarthritis during TKA [3, 5, 11, 20, 21]. However, it still remains unclear how the preoperative knee kinematics affect the knee kinematics after TKA. Since the range of knee motion after TKA depends on the preoperative knee condition, an understanding of the relationship between preoperative and postoperative knee kinematics might explain why preoperative range of knee motion is a strong predictor for postoperative knee motion in TKA [8, 16].

The aim of this study was to evaluate the anterior-posterior translation and internal-external rotation kinematics before and after TKA and to determine their relationship between preoperative and postoperative kinematic variables of the knee. We postulated that significant correlations exist between the amount of posterior femoral roll back and external femoral rotation before and after TKA.

Materials and methods

The study protocol was approved by the Institutional Review Board at our institute, and a written informed consent was obtained from all the patients. Fifty-six with varus osteoarthritis of the knee scheduled for cruciate

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retaining (CR) total knee arthroplasty (TKA) using a navigation system (Orthopilot®, version 4.08, Aesculap; Tuttlingen, Germany) were included in this study. Patients with a history of open knee surgery (other than meniscectomy), revision TKA, a severe deformity ($>20^\circ$ varus, $>10^\circ$ flexion contracture, or $<120^\circ$ flexion), or with a diagnosis other than osteoarthritis were excluded. Six knees were excluded during the operation due to a flexion contracture more than 10° as measured by the navigation system. All knees had relatively good stability with the continuities of the anterior cruciate and posterior cruciate ligaments. Accordingly, 50 knees (45 female and five male) with an average age of 70.0 ± 5.3 years constituted the study cohort. All knees had a varus deformity ranging from 0° to 13° of mechanical tibiofemoral angle, and the average range of knee motion was 126.2° (range, 110 – 144°).

Surgical technique and kinematic measurement

All TKAs were performed using a standard medial parapatellar approach with patellar eversion under a navigation system control. After medial arthrotomy of the knee joint, the bicortical pins for the infrared optical trackers were fixed directly to the femur and tibia. Initially, the surgeon circumducted the femur to locate the centre of the femoral head, and then the anatomical landmarks of the distal femur, such as the centre of the inter-condylar notch and the medial and lateral epicondyles, were registered to establish an orthogonal femoral coordinate system [19, 20]. The origin of the femoral coordinating system was chosen as the centre of inter-condylar notch. The vector connecting the centre of the head to the origin of the femoral coordinate system was defined as the superior-inferior axis. The medial-lateral and anterior-posterior axes were defined as the cross-products of one axis with the other (Fig. 1). A tibial coordinate system was then created by registering the tibial plateau and medial and lateral malleoli [18, 20, 26]. The tibial spine and the midpoint of the malleoli were used as the origin of the tibial coordinate system and the centre of the ankle, respectively. The superior-inferior axis in the tibial coordinating system was the vector between the centre of the ankle and the tibial origin. The cross-products of the superior-inferior axis with the other vectors were defined as the anterior-posterior and medial-lateral axes (Fig. 1).

Anterior-posterior translation was defined as relative translation of the origin of the femoral coordinate system to the origin of the tibial coordinate system. Internal-external rotation of femur was defined about the superior-inferior axis of the tibia. After patellar reduction and arthrotomy repair using sutures, anterior-posterior translation and internal-external rotation of the femur were measured using the navigation system without any bony cuts or soft tissue

Fig. 1 Definitions of femoral and tibial coordinate systems. *SI* superior-inferior, *AP* anterior-posterior, *ML* medial-lateral

balancing. The kinematics were measured as the motion of the femur relative to the tibia at 10° , 30° , 60° , 90° , and 120° of knee flexion. The kinematics of each knee were measured as knees were passively flexed from 10° to 120° of knee flexion. The passive flexion was achieved by maintaining 90° of hip flexion while the surgeon supported the heel and allowed the weight of the lower leg to flex the knee joint to 120° of knee flexion. Care was taken to ensure that the limb was consistently supported by holding the lower extremity, and the foot was axially supported throughout the range of motion.

After taking kinematic measurements in the preoperative knee, all the osteophytes were removed and the proximal tibial cuts were made at 0° of knee flexion in the coronal and sagittal planes under the navigation guide. The distal femoral cutting block was then placed for a perpendicular cut in the coronal and sagittal planes, and the cut was completed under navigation control. We determined the rotation of the femoral component using anterior-posterior axis (Whiteside line) in all cases. A 4-in-1 cutting block was then placed for anterior and posterior femoral cuts. Adequate soft tissue release was performed to achieve extension and flexion gap balances. The rotational alignment for the tibial component was referenced using the PCL and medial one-third of the tibial tuberosity. After confirming knee stability with trial components, the actual

components (e-motion; Aesculap, Tuttling, Germany) were then fixed with cement. The e-motion implant achieves a large contact area and its femorotibial articulation is of a somewhat conforming design. The tibial base plate has a posterior slope of three degrees and the polyethylene insert is slightly dished in the sagittal plane with a slightly elevated anterior lip.

In all cases, the posterior cruciate ligament was retained and the patella was not resurfaced. After repairing the medial arthrotomy by suturing, postoperative knee kinematics were measured using the navigation system using the same protocol used for the preoperative condition at selected flexion angles. To assess the reliability of kinematics measurements using the navigation system, preoperative and postoperative kinematic measurements were done twice by one surgeon in the first ten subjects. Intrarater reliabilities were assessed by calculating the intraclass correlation coefficients (ICC). Preoperative and postoperative anterior-posterior femoral translations and internal-external femoral rotations were compared at selected flexion angles using the paired *t*-test. Correlation coefficients (Pearson's *r*) were calculated to identify relations between preoperative and postoperative kinematic patterns in each knee with regard to the amount of posterior roll back and rotation during knee flexion from 10° to 120°. All the statistical analyses were performed using SPSS for Windows Release 17.0 (SPSS Inc, Chicago, Ill) with the statistical significance set for *p* values of <0.05.

Results

The intra-rater reliabilities of anterior-posterior femoral translation during the passive flexion, as determined by ICC values, ranged from 0.88 to 0.99 for preoperative knees and from 0.96 to 0.99 for postoperative knees (Table 1). Anterior-posterior translation of the femur were significantly different in postoperative and preoperative knees from 10° to 60° of flexion ($P<0.05$) (Fig. 2). After TKA, the femur was translated posteriorly with a maximum

Table 1 Intraclass correlation coefficients of anteroposterior and rotational kinematics in preoperative and postoperative knees at selected flexion angles

Measurement	10°	30°	60°	90°	120°
Preoperative					
Anteroposterior	0.879	0.952	0.992	0.978	0.987
Rotational	0.753	0.840	0.957	0.978	0.994
Postoperative					
Anteroposterior	0.975	0.956	0.981	0.984	0.989
Rotational	0.955	0.972	0.978	0.981	0.971

Fig. 2 Comparison of femoral posterior translation in preoperative and postoperative knees at selected flexion angles during the passive flexion. * Represents statistical significance ($P<0.05$)

difference of 2.2 ± 4.1 mm at 10° of flexion as compared with the preoperative condition (Fig. 2). During flexion from 10° to 120°, the average amount of posterior femoral roll back was 11.1 ± 5.6 mm for preoperative knees and 10.0 ± 6.9 mm for postoperative knees, which was not significantly different ($P=0.14$). However, a significant positive correlation was observed between preoperative and postoperative ranges of posterior femoral roll back in each knee ($r=0.62$, $P<0.001$) (Fig. 3).

ICC values for internal-external rotation of the femur during passive flexion ranged from 0.75 to 0.99 for preoperative knees and from 0.96 to 0.98 for postoperative knees (Table 1). No significant changes in external femoral rotations were observed after TKA except at 10° of flexion (Fig. 4), at which external rotation of the femur was $2.9\pm 4.5^\circ$ for postoperative knees and $0.4\pm 3.0^\circ$ for preoperative knees ($P=0.001$) (Fig. 4). Postoperative knees showed less external femoral rotation than preoperative knees during flexion from 10° to 120° ($7.9\pm 9.6^\circ$ vs $12.1\pm 13.0^\circ$, $P=0.01$). The postoperative external femoral rotation was found to be significantly related to preoperative values in each knee ($r=0.57$, $P<0.001$) (Fig. 5).

Fig. 3 Correlation of posterior roll back between preoperative and postoperative knees

Discussion

In this study we investigated passive knee kinematics before and after TKA in osteoarthritic knees using a navigation system, and we also evaluated the correlation between preoperative and postoperative kinematics in each knee with regard to posterior femoral roll back and external femoral rotation. It was noted that the posterior femoral roll back of preoperative knees during the passive flexion was maintained after TKA, and that a significant correlation existed between preoperative and postoperative knees. While postoperative knees showed significantly less external femoral rotation than preoperative knees during flexion, postoperative external femoral rotation was positively correlated with the preoperative knee.

Few studies have evaluated the kinematics of osteoarthritic knees [2, 3, 11, 15, 20], whereas the kinematics of TKA have been extensively studied. In a kinematics study using a navigation system, Siston et al. [20] reported that osteoarthritic and normal knees showed similar amounts of posterior roll back, which occurred after 40° of knee flexion. In our study, we found that the femurs of the osteoarthritic knees were translated posteriorly by an average 11.2 mm, mainly after 30° of knee flexion. After TKA, we found that the femurs were more posteriorly translated than preoperative knees, from 10° to 60° of knee flexion, with a maximal difference of 2.2 ± 4.1 mm at 10° of flexion. This pattern in our study was similar to the results reported by Casino et al. [3], which may have been due to transection of the anterior cruciate ligament (ACL) during TKA. We also noted that posterior translation of the femur up to 30° of knee flexion after TKA was not so much during the passive flexion, which is consistent with findings in the previous kinematic studies of TKA under weight-bearing conditions [3, 4, 6, 20, 27]. How-

Fig. 4 Comparison of femoral external rotation in preoperative and postoperative knees at selected flexion angles during the passive flexion. * Represents statistical significance ($P < 0.05$)

Fig. 5 Correlation of external rotation between preoperative and postoperative knees

ever, the average amount of posterior femoral roll back in the preoperative knees was maintained after TKA in our study ($P = 0.14$).

Our observation of $12.1 \pm 13.0^\circ$ of external femoral rotation in osteoarthritic knees differs from previous studies [3, 20]. During passive flexion, Siston et al. [20] measured $4.9 \pm 4.1^\circ$ of external femoral rotation in the osteoarthritic knees, and concluded that the osteoarthritic knees show significantly less rotation than normal knees. However, a quantitative comparison with these previous studies is not feasible because they differed in terms of degrees of osteoarthritis and ACL status. In general, the rotation in knees with TKA is smaller and more variable than those of normal knees [3, 6, 20, 22, 23]. However, little information is available on differences between TKA and osteoarthritic knees in terms of rotational kinematics, and furthermore, available information is contradictory. For example, whereas Siston et al. [20] found that the rotation of osteoarthritic knees (4.9°) was significantly reduced after TKA (2.1°) using a fixed posterior cruciate ligament (PCL) substitution (PS) prosthesis, Casino et al. [2] found no difference between the rotation of knees before (8.0°) and after TKA (6.0°) for a mobile PS prosthesis. In our study, we found that the rotation of osteoarthritic knees (12.1°) significantly decreased after TKA (7.9°) during the passive flexion, which is similar to that reported by previous studies [3, 20]. However, a quantitative comparison with previous studies is difficult due to the differences in bearing type and PCL status. Our findings of rotation after TKA with a CR prosthesis show larger rotations than previously published results with the PS prosthesis, which is consistent with the results of previous studies [6, 27].

Although it is known that the preoperative knee can influence the kinematics following TKA, to our knowledge, no study has investigated the relationship between preoperative and postoperative knee kinematics after TKA. Our study showed that the amount of posterior femoral roll back after TKA during the passive flexion is

closely related to preoperative posterior femoral roll back in each knee ($r=0.62$). Similarly, we found a positive correlation between the amount of rotation between the preoperative and postoperative knees ($r=0.57$), although external femoral rotation decreased after TKA during flexion. These relationships between the kinematics of osteoarthritic knees and knees after TKA may explain why preoperative knee motion is a strong predictor of knee motion after TKA.

This study has certain limitations that should be considered. Specifically, all kinematic measurements were taken by a single surgeon using one type of CR implant and surgical technique, and furthermore, inter-rater reliability was not measured. However, several in vivo studies have shown a high inter-rater reliability for knee kinematic measurements using a navigation system [3, 9, 28]. Thus, we consider that our kinematic data allow valid comparisons of the kinematics of preoperative and postoperative conditions in the same knees. Furthermore, we measured the passive knee kinematics, which cannot reflect the effects of muscle force, and thus, these differ from physiological knee kinematics. However, intraoperative kinematic measurements using a navigation system also allow direct reliable comparisons of knee kinematic variables before and after TKA in same knees when the same coordinate system is used. Moreover, measurement of intraoperative passive knee kinematics using a navigation system has some advantages such as the accuracy and reliability of the kinematic data obtained, because intraoperative passive kinematic data are not prone to the errors caused by muscle forces and external activity-related loads. The final limitation is that the arthrotomy and pin for the optical tracker can affect the kinematics. However, to reduce bias in the measurement of knee kinematics, we repaired the arthrotomy using sutures and put the pin around the arthrotomy site of the femur. Additional studies are required to investigate the relationship between intraoperative passive knee kinematics and postoperative active knee kinematics under weight-bearing conditions. Nevertheless, this study is the first to show the relationship of preoperative knee kinematics on the knee kinematics after TKA.

Based on the findings of this study, we conclude that knees after TKA show similar posterior femoral roll back but less external femoral rotation than preoperative osteoarthritic knees during passive flexion. Furthermore, postoperative passive knee kinematics were found to be significantly correlated to preoperative knee kinematics with regards to posterior femoral roll back and external femoral rotation. We consider that these kinematic relations could potentially explain why the preoperative range of knee motion is the strongest predictor of postoperative range of motion after total knee arthroplasty.

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