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Rotational alignment of the tibial component affects the kinematic rotation of a weight-bearing knee after total knee arthroplasty

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ABSTRACT

Purpose: The purpose of this study is to elucidate how the rotational malalignment of prosthesis after total knee arthroplasty affects the rotational kinematics in a weight-bearing condition.
Methods: In this study of 18 knees replaced with the posterior stabilizing fixed-bearing system, which has a relatively low-restricting design, rotational angles between the femoral and tibial components and between the femur and tibia during stair climbing were evaluated in vivo in three dimensions using radiologically based image-matching techniques. Rotational alignments of the components were assessed by postoperative CT. The correlations between the rotational alignments and the rotational angles during stair climbing were evaluated.
Results: Rotational alignment of the tibial component significantly correlated with rotational angles between the components as well as between bones during stair climbing. Rotational malalignment of the tibial component toward internal rotation caused a rotational mismatch of the tibial component toward internal rotation relative to the femoral component in 0° extension and caused a rotational mismatch of the tibia (bone) toward external rotation relative to the femur (bone). The knee in which the tibial component was placed close to the AP axis of the tibia did not show any rotational mismatch between either components or bones.
Conclusions: Rotational alignment of the tibial component affects the kinematic rotation of the replaced knee during a weight-bearing condition even though using a low-restricting designed surface, and the AP axis can be a reliable reference in determining rotational alignment for the tibial component.

1. Introduction

It has been suggested that the surgical epicondylar axis (SEA) approximates the femoral rotational axis of normal and osteoarthritic knees and that Akagi's anterior–posterior tibial axis (AP axis) is perpendicular to the SEA in knee extension [1–3]. Therefore, the SEA and the AP axis have been used as one of the rotational landmarks for femoral and tibial components during total knee arthroplasty (TKA). Other rotational landmarks in aligning the components are also used: whiteside line, clinical epicondylar axis, posterior condylar line and gap balancing technique for the femoral component; medial one third of the tubercle and allowing component to seek its own position through a range of motion for the tibial component [4,5]. However, component rotational alignments have the potential to deviate from preoperative landmarks, and the tibial rotational alignment is particularly susceptible to error [6–9]. Because femoral and tibial component rotational alignment could influence the patellofemoral joint and quadriceps [10–13], component position could affect knee joint kinematics during weight-bearing [14]. It is generally considered that the component rotational alignment would affect the rotational position of the tibia relative to the femur. However, the influence of the component rotational alignment on the joint kinematics might be different depending on the surface designs regarding constraints for rotation. Rotational malalignment of the components may be compensated for if the design of the tibiofemoral articulation allows some rotation. In fact, it is sometimes seen that postoperative non-weight-bearing radiographs show rotational mismatch between the components, suggesting that rotational laxity of the joint surface compensates the rotational malalignment of the components. However, it is unclear this rotational mismatch still exists under weight-bearing conditions. This issue has received little objective or quantitative study.

Recently, a postoperative kinematic analysis using fluoroscopy has been used for evaluating femoral rotation, roll-back, condylar lift-off, and post-cam impingement [15–20]. The replaced knee has been reported to show external rotation of the tibial component relative to the femoral component during extension from flexion in weight-bearing condition; however, it shows more variation of its movement

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compared to the normal knee. Rotational kinematics might be influenced by many factors, such as geometry or design of the components, ligament balance and rotational alignment of the component. However, no study has described the relation between the component rotational alignment and the component rotational motion during flexion-extension movement during weight-bearing.

Therefore the following clinical questions have arisen: Does the rotational alignment of each component affect the rotational relationship between tibial component and the femoral component and the rotational relationship between the femur and tibia during stair climbing?

2. Materials and methods

2.1. Subjects

A total of 18 patients who had undergone TKA were recruited. They gave informed consent and the institutional review board approved this study. All patients were women with a mean age of 76.4 years (range, 66–83 years). The preoperative diagnosis was osteoarthritis in all patients. Patients with rheumatoid arthritis, previous arthroplasty, osteotomy, severe extra-articular deformity, and fractures about the knee were excluded. All patients received a posterior-stabilized (PS) fixed bearing TKA (NexGen LPS-Flex, Zimmer, Warsaw, IN). The mean follow-up was for 26.7 months (range, 3.1–65.9 months).

2.2. Surgical technique

One experienced surgeon performed all the cases. Using the measured resection technique, the components were aligned to allow the mechanical axis to pass through the center of the prosthetic knee in the coronal plane. The femoral component was aligned perpendicularly to the anatomical axis in the sagittal plane and positioned along the SEA in the axial plane based on the preoperative planning on a computed tomography (CT) images. The tibial bone cut was planned to be parallel to the lateral anatomical slope in the sagittal plane. The rotational alignment of the tibial component was adjusted to the AP axis of the tibia (the line connecting the center of PCL at its tibial attachment and the medial border of patellar tendon at the tibial tubercle). Soft tissue balancing was performed to achieve varus and valgus stability in both extension and flexion.

2.3. Computed tomography scan evaluation

Transverse CT scans were taken at levels ranging from the hip joint to the ankle joint at two millimeter intervals before and two weeks after surgery, and a three-dimensional (3D) image of the lower extremity was reconstructed on the computer using the program 3D Template (version 02.02.02, Japan Medical Materials, Corp., Osaka, Japan). Rotational alignment of the femoral component was determined by measuring the angle between the SEA and the line joining the posterior margins of the femoral component (Fig. 1a). The angle in the component external position was defined as a positive value. For the AP axis of tibia, the medial border of the patellar tendon at its attachment level and the middle of the posterior cruciate ligament (PCL) at its tibial attachment were identified preoperatively (Fig. 1b), and the AP axis was projected accurately to the postoperative CT (Fig. 1c). Rotational alignment of the tibial component was assessed by measuring the angle between the AP axis and the anteroposterior line of the tibial component (Fig. 1c). The angle in component external position was defined as a positive value. Coronal alignment and posterior inclination of the tibial component relative to the tibial mechanical axis were also measured.

2.4. Kinematic analysis

Continuous sagittal radiological images of stair climbing were obtained for each patient using a flat-panel detector (Ultimax-i, Toshiba, Tochigi, Japan) (Fig. 2a). This produced 10 frames per second with an image area of 420 mm (H) × 420 mm (V), and 0.148 mm × 0.148 mm/pixel resolution (Fig. 2b). The angles of flexion and axial rotation of the components were measured using the image-matching method [20]. The accuracy and precision of the measurement technique was determined by in vitro investigations. The root-mean-square (RMS) accuracy errors for the femoral component were 0.075 mm for inplane translation, 0.071 mm for out-of-plane translation, and 0.076 for rotation, and the accuracies for the tibial component were 0.178 mm for in-plane translation, 0.208 mm for out-of-plane translation, and 0.169 for rotation. We found higher accuracy than reported in previous literature [19] because the resolution of images became higher, the number of images obtained in one second increased and the identification of the source of X-rays was completed more correctly [21]. The rotational relationship of the tibial component relative to the femoral component was measured in 0° knee extension, and 30° and 60° knee flexion. External rotation of the tibia with respect to the femur was considered positive. Based on the postoperative CT data, described in the computed tomography scan evaluation section, the angle between the perpendicular line of the SEA (defined as SEA′) and the AP axis in extension was measured and defined as “bony rotational relationship angle”. If the AP axis was externally rotated relative to the SEA′ the angle was positive.

2.5. Statistical analysis

We used the Pearson correlation analysis to determine the correlation of the rotational alignment of either tibial or femoral component to the rotational relationship between the components in 0° extension, and in 30° and 60° of flexion, or to the bony rotational relationship angle in extension. The relationship between coronal alignment and posterior inclination of the tibial component and the kinematic rotation was also evaluated. Statistical analyses were performed with JMP 9.0 (SAS Institute Inc, Cary, NC, USA). Significance was set at a p-value of <0.05.

3. Results

The rotational alignment angles of the femoral and tibial components were −0.4 ± 2.2° (mean ± SD) (range, −3.8 to 4.6°) and −0.9 ± 6.5° (range, −11.3 to 10.2°), respectively. There was no significant correlation of the rotational alignment angle of the femoral component to the rotational relationship between tibial component and femoral component at any flexion angles (Table 1). However, there was a significant correlation between the rotational alignment angle of the tibial component and the rotational relationship angle between tibial component and femoral component in 0° extension (Table 1, Fig. 3). Increased malalignment of the tibial component toward internal rotation (toward a negative value) resulted in an increased tibial component rotation relative to the femoral component toward internal rotation (toward a negative value). This correlation indicates that malalignment of tibial component causes rotational mismatch between the components in 0° extension. When the tibial component was aligned close to the AP axis, the rotational relationship angle between the components in extension approximated 0°. There was no significant correlation of the rotational alignment angle of the tibial component to the rotational relationship between the components in 30° and 60° flexion (Table 1).

The bony rotational relationship angle (the angle between the SEA′ and the AP axis of tibia) in extension was 2.5 ± 10.7° (range, −16.6 to 16.4°). There was not a significant correlation between the bony rotational relationship angle and the rotational alignment angle of the femoral component ($p = 0.08$). However, there was a significant correlation between the bony rotational relationship angle and the rotational alignment angle of the tibial component (Table 1, Fig. 4). In 0° extension, rotational malalignment of the tibial component caused a bony rotational mismatch in the opposite direction of the rotational alignment: Increased malalignment of the tibial component toward internal rotation (toward a negative value) resulted in an increased rotation of the tibia (bone) relative to the femur (bone) toward external rotation (toward a positive value) (Fig. 4). When the tibial component was aligned close to the AP axis, the bony rotational relationship angle in extension approximated 0°.

The coronal alignment angle and posterior inclination angle of the tibial component did not significantly correlate with the rotational relationship between components or the bones (Table 1).

4. Discussion

In this study, the rotational alignment of the tibial component significantly correlated with the rotational relationship between the femoral