Kinematic Analysis of Conventional and High-Flexion Cruciate-Retaining Total Knee Arthroplasties

An In Vitro Investigation

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Abstract: This study examined the kinematics of a cruciate-retaining (CR) total knee arthroplasty (TKA) component that attempts to enhance knee flexion by improving posterior tibiofemoral articular contact at high-flexion angles. Using an in vitro robotic experimental setup, medial and lateral femoral translations of this CR design were compared with that of a conventional CR TKA design and intact knee under a combined quadriceps and hamstring muscle load. Both CR TKA designs showed similar kinematics throughout the range of flexion (0°-150°). The TKAs restored nearly 80% of the posterior femoral translation of the intact knee at 150°. The posterior cruciate ligament (PCL) forces measured for the high-flexion CR TKA component indicate that the PCL is important in the mid-flexion range but has little effect on knee kinematics at high flexion. **Key words:** total knee arthroplasty, posterior cruciate ligament, cruciate retaining, kinematics, knee biomechanics, high flexion.

The goals of total knee arthroplasty (TKA) are to improve knee function and to allow patients to return to activities of daily living. Posterior cruciate-retaining (CR) TKA has been advocated as a means of preserving anatomical femoral rollback and potentially improving knee flexion [1-5]. However, after contemporary CR TKA, most patient follow-up studies showed that on average, the maximal flexion angles were below 120° [6-13]. Patients whose movement is restricted after TKA might experience disability. In the Far and Middle East, the inability to flex beyond 120° may hinder patients from participating in normal cultural activities that involve kneeling and squatting [14,15].

The factors that limit high knee flexion are not well understood. Using sagittal plane videofluoroscopic images, Bellemans et al [12] investigated the mechanism that allows knees to flex to the maximum extent after CR TKA (Profix; Smith and Nephew, Memphis, Tenn). They concluded that the main factor limiting high knee flexion could be direct impingement of the tibial insert posteriorly against the back of the femur. Other authors [1,16] have implied that insufficient posterior femoral translation is a cause for limited knee flexion, resulting in early posterior impingement.

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The role of the posterior cruciate ligament (PCL) in CR TKA on femoral rollback has been examined, mainly for flexion up to 120° [1,4,17-19]. It has been suggested that retaining the PCL in a CR TKA, while keeping its original tension, can improve the range of knee motion by allowing femoral rollback [13,20,21]. However, limited information is available regarding the biomechanical role of the PCL in CR TKA on knee function beyond 120° of flexion.

Intended to allow knee motion beyond 120°, the NexGen CR-Flex TKA (Zimmer Inc, Warsaw, Ind) component includes femoral condyles that extend 2 mm beyond the conventional CR TKA model (NexGen CR, Zimmer Inc). This feature allows a larger contact area between the femoral component and the tibial poly component at high-flexion angles. However, no information is available regarding the kinematics of the CR-Flex TKA design. The objective of this study is to compare femoral translation and tibial rotation of these 2 NexGen CR TKA designs from full extension (0°) to full flexion (150°), as well as investigating PCL forces in the CR-Flex TKA design.

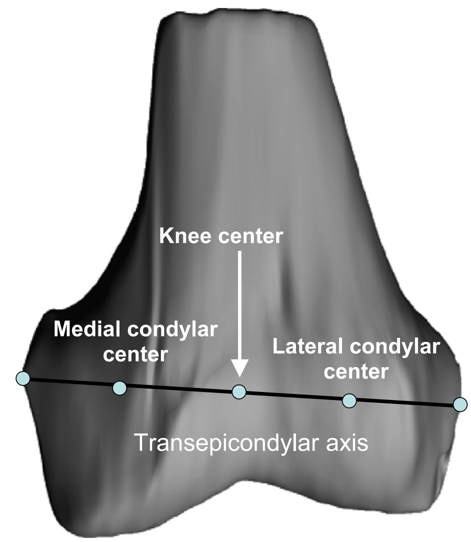

Fig. 1. Anterior view of a right knee and the outline of the transepicondylar axis.

Materials and Methods

Specimen Preparation

Ten fresh-frozen postmortem human cadaveric knees (2 knees from male and 8 knees from female; average age, 74 ± 15 years; age range, 48-96 years) were used in this study. Each specimen was approximately 50 cm long (25 cm from the joint line of femur and tibia). Each specimen was thawed overnight at room temperature and x-rayed to exclude specimens with previous injuries. The muscles, ligaments, capsule, skin, and menisci remained intact around the knee joint. The fibula was secured to the tibia bone in its anatomical position using a cortical screw. All knees used in this project were capable of flexing from full extension to 150° of flexion.

Coordinate System Determination

This study quantified femoral translation and tibial rotation as a function of flexion angle using the transepicondylar axis [22,23]. For each specimen, the insertion areas of the lateral and medial collateral ligaments were identified. On the lateral condyle, the center of the lateral collateral ligament was identified and the most prominent point within the insertion site was chosen. On the medial condyle, the prominent anterior to the sulcus point was selected. The transepicondylar axis was defined as a line connecting these 2 prominent points [23,24] (Fig. 1). The midpoint of the axis was identified as the knee center. The centers of the lateral and medial condyles were selected to be 25 mm lateral and medial to the midpoint of the transepicondylar axis [22] (Fig. 1). A coordinate system was constructed using the transepicondylar axis as the y-axis, the long axis of the tibia as the x-axis, and the cross product of these 2 as the z-axis. Anteroposterior translation of the medial and lateral centers on the transepicondylar axis represented femoral translations. All measurements were reported with respect to the knee at full extension.

Kinematic Analysis

Each specimen was manually preconditioned 10 times before its installation on the robotic testing system. The robotic testing system is composed of a 6– degree of freedom (DOF) robotic manipulator (Kawasaki UZ150; Kawasaki Heavy Industries, Ltd, Akashi, Japan) and a 6-DOF load cell (JR3, Woodland, Calif). The system provided both displacement and force control modes. A detailed description of the robotic system can be found in our previous publications [4,22,25]. The intact knee was tested first. Its passive path was determined and served as a baseline for all other tests. The 6-DOF kinematics (both translations and rotations) under combined muscle loads (400 N quadriceps and 200 N hamstrings) were determined. Surgery was then performed to convert the