In Vitro Closed Chain Kinematics of a Cruciate Retaining, Cruciate Sacrificing, and Posterior Stabilizing Total Knee Replacement Compared to the Natural Knee

INTRODUCTION:
Knee kinematic studies provide important understanding of normal knee function and efficacy of total knee arthroplasty (TKA). Previous in vivo kinematic studies have shown that, throughout an active range of motion, the normal knee exhibits greater lateral compartment anterior/posterior (AP) translation compared to medial, and translation that is generally directed posteriorly in the lateral compartment [1]. TKA designs aim to replicate this normal knee motion, but must also provide increased stability for a diseased or injured knee. Using a novel in vitro cadaver closed-chain device, the translation of tibio-femoral articular contact of cadaveric knees, pre- and post-TKA, during a squat exercise were determined. The purpose of this study was to compare knee kinematics of the normal knee to those after implantation of a primary TKA. Three different EVOLUTION™ (Wright Medical Technology, Inc., Arlington, TN) tibial insert configurations were analyzed (CR, CS and PS). The EVOLUTION™ knee is designed to have a stable articulation in the medial compartment based on a conforming “ball-in-socket” design and a less constrained articulation on the lateral side to allow mobility of the lateral femoral condyle on the tibia. Based on the design intent of the prosthesis, the following hypotheses were tested: 1) lateral compartment AP translation for the normal knee and all implanted configurations would be greater than the medial; 2) AP translation of the tibio-femoral articulation on the medial side after implantation would be no greater than the intact knee; and 3) AP translation of the tibio-femoral articulation on the lateral side after implantation would be less and in the same direction as the intact knee.

METHODS:
Six lower extremity cadaver limbs with no prior surgeries, deformities, or disease were obtained. The soft tissue was removed from the hip to approximately 4 inches proximal to the patella. Radio-opaque markers were rigidly placed on landmarks of the femur, tibia and patella. Prior to experimentation, a full limb CT scan was acquired of each specimen. The images were processed using Mimics and 3Matic software (Materialise, Belgium) to isolate the bones and markers from the surrounding soft tissue, and 3D solid CAD models were created using Solidworks (Dassault System, Concord, Massachusetts).

During experimentation, the foot and femur were securely fixed in the custom closed-chain knee device, designed to record loads and simulate a heel-up squatting motion. The femoral head was constrained to translation only along a vertical axis but was allowed to rotate freely. The foot was completely fixed in translation and only permitted to rotate in plantar/dorsal flexion. The knee was cycled through a range of motion from full-extension (0°) to ~115° of flexion back to full-extension by a linear actuator. The quadriceps tendon was tether sutured to the quadriceps tendon and driven by a tibial insert and driven by a linear actuator. The foot was completely fixed in translation and only permitted to rotate in plantar/dorsal flexion. The knee was cycled through a range of motion from full-extension (0°) to ~115° of flexion back to full-extension by a linear actuator. The quadriceps tendon was tether sutured to the quadriceps tendon and driven by a linear actuator.

RESULTS:
While the location of tibio-femoral contact was not equivalent between the normal, CR, CS, and PS trials, the overall behavior of the contact points were similar within each specimen (Figure 1). The largest AP translation occurred between full-extension and 30° of flexion. Significantly greater motion on the lateral compartment was determined compared to medial during the first 30° of flexion for all trials considered (Normal:0-30°, p=0.01; 30-0°, p=0.02) (CR:0-30°, p=0.00; 30-0°, p=0.00) (CS:0-30°, p=0.00; 30-0°, p=0.02) (PS:0-30°, p=0.00; 30-0°, p=0.00). Normal knee AP translation throughout this same range of motion (full-extension to 30°) was significantly greater than all implant trials for both the medial and lateral compartments. Lateral compartment AP translation from extension to flexion (0-90°) was significantly greater than medial compartment AP translation for all trials considered. After 30 degrees of flexion (30-90°) no significant differences in lateral compartment AP translation were determined between the normal and implanted knees for all implant configurations tested. Additionally, AP translation within the lateral and medial compartments of the implanted knees moved in the same direction as the normal knee from both extension to flexion and flexion to extension.

DISCUSSION:
This closed-chain in vitro analysis provides detailed knee kinematic comparisons of the normal knee to a primary TKA. Similar to previous in vivo fluoroscopy kinematics studies [1,2], greater lateral translation compared to medial was determined for both the intact and implanted knees throughout a squatting range of motion. The largest change in contact position was identified from full-extension to 30° of flexion, where the femoral component moved posterior on the tibia during flexion and anterior during extension. Greater translations in the intact knees compared to implanted knees are most apparent during the first 30° of flexion, as expected as this motion is indicative of “screw-home”, consistently seen in previous studies of normal knees [3]. The contact point profiles determined from the current analysis suggests that the CR, CS and PS implants replicate normal knee motion. Additionally, the decreased tibio-femoral translation in the implanted trials suggests that stability was increased after implantation.

REFERENCES:

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