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# The effect of femoral component malrotation on patellar biomechanics

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ABSTRACT

Patellofemoral complications are among the important reasons for revision knee arthroplasty. Femoral component malposition has been implicated in patellofemoral maltracking, which is associated with anterior knee pain, subluxation, fracture, wear, and aseptic loosening. Rotating-platform mobile bearings compensate for malrotation between the tibial and femoral components and may, therefore, reduce any associated patellofemoral maltracking. To test this hypothesis, we developed a dynamic model of quadriceps-driven open-kinetic-chain extension in a knee implanted with arthroplasty components. The model was validated using tibiofemoral and patellofemoral kinematics and forces measured in cadaver knees. Knee kinematics and patellofemoral forces were measured after simulating malrotation ($\pm 3^\circ$) of the femoral component. Rotational alignment of the femoral component affected tibial rotation near full extension and tibial adduction at higher flexion angles. External rotation of the femoral component increased patellofemoral lateral tilt, lateral shift, and lateral shear forces. Up to 21° of bearing rotation relative to the tibia was noted in the rotating-bearing condition. However, the rotating bearing had minimal effect in reducing the patellofemoral maltracking or shear induced by femoral component rotation. The rotating platform does not appear to be forgiving of malalignment of the extensor mechanism resulting from femoral component malrotation. These results support the value of improving existing methodologies for accurate femoral component alignment in total knee arthroplasty.

## 1. Introduction

Restoring normal function and relieving pain are the major goals of total knee arthroplasty (TKA). Although survivorship greater than 90% after 15 years has been reported (Rodricks et al., 2007; Buehler et al., 2000), patellofemoral complications are among the major factors leading to revision TKA (Fehring et al., 2001; Boyd et al., 1993). Abnormal patellar tracking is associated with subluxation, fracture, and component loosening (Brick and Scott, 1988; Merkow et al., 1985). In addition, abnormal patellar tracking can result in increased polyethylene wear and damage.

Femoral component alignment to the transepicondylar axis has been shown to result in the most normal patellar tracking and the least patellar shear forces (Miller et al., 2001; Armstrong et al., 2003). Femoral component malposition can result in patellofemoral maltracking (Armstrong et al., 2003; Anouchi et al., 1993). The potential for error in axial rotation of knee component alignment is significant. The use of surgical navigation tools still results in 4° to 7° of relative femorotibial axial malrotation (Chauhan et al., 2004; Matziolis et al., 2007; Siston et al., 2005). When using the balanced-gap technique for femoral component rotation alignment, the variability can be even greater (Insall et al., 1976; Fehring, 2000). Component malalignment or malposition accounts for nearly 12% of TKA revisions (Sharkey et al., 2002). Excessive femorotibial malrotation has been linked to significant anterior knee pain, increased incidence of lateral retinacular releases, and other patellofemoral complications (Berger et al., 1998; Barrack et al., 2001; Akagi et al., 1999).

The major design rationale behind rotating-platform mobile-bearing components is the concept of self alignment. It has been proposed that the rotating platform accommodates small malrotations of the tibial and femoral components after TKA (Buechel and Pappas, 1989). This capacity for self-alignment might alleviate patellofemoral maltracking associated with femoral component malalignment.

Patellofemoral kinematics in knees implanted with a rotating-platform design have been compared to normal knees and fixed-bearing knees using fluoroscopic analysis in vivo under weight-bearing conditions (Stiehl et al., 2001). Sagital patellar kinematics using a rotating-platform mobile-bearing knee design approximated normal kinematics more closely than the kinematics of a fixed-bearing knee design. On the other hand, a prospective, randomized clinical trial of a rotating-platform design did not reduce

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the incidence of lateral retinacular release or improve patellofemoral outcomes such as radiographic patellofemoral tilt (Pagnano et al., 2004). Patellofemoral maltracking is multifactorial in nature, and these clinical studies did not attempt to correlate patellar maltracking with femoral component malposition. Therefore, any corrective effect of rotating-platform bearings on femoral malposition and patellar maltracking could not be quantitated.

We hypothesized that a rotating-platform mobile-bearing design would reduce the changes in patellofemoral kinematics and forces induced by femoral component malrotation. To test this hypothesis, we validated a computational model of a knee implanted with arthroplasty components. We recorded the effect of femoral and tibial component malrotation on tibiofemoral and patellofemoral kinematics and forces. We then determined the efficacy of a rotating-platform mobile-bearing design in restoring the altered patellofemoral biomechanics.

## 2. Material and methods

### 2.1. Cadaver model

Six normal fresh-frozen cadaver lower extremity specimens were surgically implanted with fixed-bearing Scorpio CR (Stryker Orthopaedics, Mahwah, NJ) components. A Stryker Navigation system was used for implant alignment. The femur was implanted perpendicular to the mechanical axis of the femur in the coronal and sagital planes and parallel to the transepicondylar line in the axial plane. Alignment to the transepicondylar axis was chosen as the neutral position, since this orientation has been shown to result in the most normal patellar tracking and least patellar shear forces (Miller et al., 2001; Armstrong et al., 2003). The tibial tray was implanted perpendicular to the axis of the tibial shaft in the coronal and the sagital planes. The tibial tray was rotationally aligned to the junction of the central and lateral thirds of the tibial tubercle. The bony attachments of the collateral ligaments, posterior cruciate ligaments, patellar tendon, and quadriceps tendon were digitized using the Stryker Navigation system. The femur was mounted rigidly in the horizontal position (parallel to the floor) in a custom testing rig (Fig. 1A). An electric motor applied tensile force on the quadriceps tendon by means of a nylon strap to extend the tibia against gravity (simulating a seated open-kinetic-chain knee extension) at a nominal rate of 1° per second. Hamstring forces were not simulated as hamstring activity is negligible in this open-chain extension activity. A custom tibial tray instrumented with force transducers measured the tibiofemoral forces (Kaufman et al., 1996; D'Lima et al., 2005). The Stryker Navigation infrared trackers mounted on the femur, tibia, and patella were used to monitor knee kinematics.

### 2.2. Computational model

A rigid-body dynamic model of open-kinetic-chain extension in a knee implanted with TKA components was constructed in MSC.ADAMS (MSC Software, Santa Ana, CA, Fig. 1B). CAD models of the femoral, tibial, and patellar components (Scorpio CR, Stryker Orthopaedics, Mahwah, NJ) were aligned in 0° of flexion, adduction, and external rotation. A Scorpio CR insert design was used for the fixed condition and a Scorpio rotating-platform design was used for the mobile-bearing condition. The soft tissues (collateral ligaments, posterior cruciate ligaments, patellar tendon, and quadriceps tendon) were modeled as non-linear springs using previously reported spring stiffness parameters (Blankevoort et al., 1991). The digitized bony attachments of the collateral ligaments, posterior cruciate ligaments, patellar tendon, and quadriceps tendon on each cadaver specimen were scaled to a medium-sized cadaver knee (implanted with size 7 components). The scaled attachment sites were then averaged to represent a scaled average medium knee. The femoral attachment of the medial and lateral collateral ligaments were aligned to the center of rotation of the sagital radius of the femoral component (the Scorpio design had a single sagital radius of curvature from −15° to 75° flexion). The quadriceps tendon was aligned at a nominal 5° valgus to the mechanical axis of the femur. Contact was modeled between tibial insert and femoral component, between patellar and femoral components, and between quadriceps tendon and trochlear groove. Multiple ellipsoids connected by springs were used to simulate the wrapping of the quadriceps tendon around the trochlear groove. The same fixed-bearing geometry was used for the rotating-bearing condition: a frictionless uniaxial articulation between the (fixed) bearing insert and the tibia was simulated. The femur was fixed and aligned horizontally to represent the in vitro conditions. The tibia and patella was constrained only by soft tissues and contact with the femoral component. An external force on the tibia representing gravity (equaling the average weight of the cadaver lower legs) generated a flexion moment at the knee. A translation of the proximal attachment of the quadriceps tendon generated an extension moment on the knee simulating quadriceps contraction. The model computed tibiofemoral and patellofemoral kinematics and contact forces during open-kinetic-chain knee extension when the femoral component was malrotated ±3° relative to the epicondylar axis. Embedded coordinate systems in the femur, tibia, and patella were generated to describe tibiofemoral and patellofemoral kinematics. Patellofemoral and tibiofemoral kinematics were described with reference to the embedded femoral coordinate system (except for femoral rollback, which was described as translation of the center of the femoral coordinate system relative to the tibial coordinate system). The center of the transepicondylar line was used to define the center of the femoral coordinate system; the center of the mediolateral and superoinferior extents of the patella was used to define the patellar coordinate system; and the center of the mediolateral and anteroposterior extents of the tibia was used to define the tibial coordinate system. Kinematics is reported relative to the

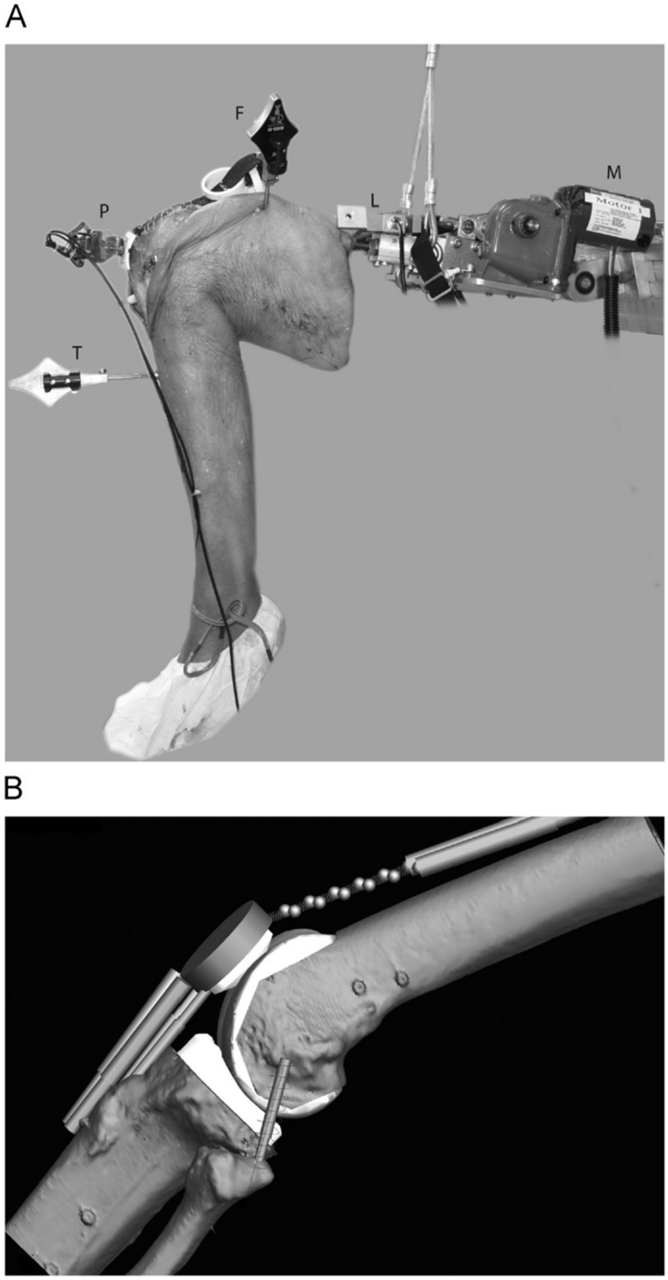

**Fig. 1.** (A) Cadaver Model. T = tibial tracker; P = patellar tracker; F = femoral tracker; L = quadriceps load cell; M = electric motor. (B) Computer Model. The quadriceps tendon (with ellipsoids for trochlear contact), the lateral collateral ligament, and patellar ligament are shown modeled as nonlinear springs. The bone geometry is for display only and represents a knee of medium size.