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Extensor malalignment arising from femoral component malrotation in knee arthroplasty: Effect of rotating–bearing

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ABSTRACT

Background: Many patellofemoral complications such as anterior knee pain, subluxation, fracture, wear, and aseptic loosening after total knee arthroplasty are attributed to malrotation of the femoral component. Rotating-platform mobile bearings can reduce malrotation between the tibial and femoral components and may also improve patellofemoral maltracking.

Methods: A computer model (LifeMOD/KneeSIM) of a weight-bearing deep knee bend was validated using cadaver knees tested in an Oxford-type knee rig. Changes in knee kinematics and patellofemoral forces were measured after femoral component malrotation of ±3°. The effect of a rotating–bearing on these kinematics and forces was determined.

Findings: In a fixed-bearing arthroplasty femoral component internal malrotation increased tibiofemoral internal rotation by 3.4°, and external malrotation increased tibiofemoral external rotation by 4°. Femoral component malrotation affected patellofemoral lateral shift by up to 2.5 mm, and patellofemoral lateral shear by up to 19 N. When the malrotated femoral component was tested against a rotating–bearing the change in tibiofemoral rotation and patellofemoral lateral shift was less than 1° and 1 mm respectively. The rotating–bearing reduced peak lateral shear by 7 N and peak medial shear by 17 N. Increasing the conformity of the rotating–bearing reduced changes in tibiofemoral rotation due to femoral malrotation and increased the net rotation of the bearing (by approximately 5°) during flexion.

Interpretation: Our results are consistent with one randomized clinical outcome study and emphasize the value of computational modeling for preclinical design evaluation. It is important to continue to improve existing methodologies for accurate femoral component alignment especially in rotation.

1. Introduction

Complications relating to the patellofemoral joint are ranked highly among important reasons for revision knee arthroplasty (Fehring et al., 2001, Boyd et al., 1993). Patellar malalignment disorders and maltracking have been implicated as major contributing factors. Femoral component malrotation can affect mediolateral knee balance in flexion and can also alter patellofemoral biomechanics, which is associated with anterior knee pain, subluxation, fracture, wear, and aseptic loosening (Brick and Scott, 1988, Merkow et al., 1985).

Improvements in surgical instrumentation and the introduction of computer-aided surgery have significantly improved the accuracy of component alignment in the coronal and sagittal planes. However, the potential for error for alignment in the axial plane (rotational alignment) is still high (Chauhan et al., 2004, Matziolis et al., 2007, Siston et al., 2005, Insall et al., 1976, Fehring, 2000). Rotating-platform mobile bearings compensate for malrotation between the tibial and femoral components (Buechel and Pappas, 1989). It has been suggested that rotating–bearings may also reduce the patellofemoral maltracking resulting from femoral component malposition conditions (Stiehl et al., 2001).

We previously reported on a computer model of open-kinetic chain knee extension (Kessler et al., 2008). While we demonstrated substantial patellar maltracking associated with femoral component malalignment, in that study we could not demonstrate that a rotating-platform bearing improved patellofemoral maltracking. The biomechanics of weight-bearing closed-kinetic chain knee extension (such as a deep knee bend) are significantly different and much more clinically relevant. Patellar kinematics and stresses differ substantially between weight-bearing and non-weight-bearing conditions (Cohen et al., 2001, Powers et al., 2003, Doucette and Child, 1996).

In this study we analyzed the effect of a rotating–bearing on patellofemoral maltracking during a clinically relevant simulated weight-bearing deep knee bend. We validated our computer model with experimentally measured patellar forces in addition to knee kinematics. Given that femoral component malrotation would alter

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patellar kinematics and forces under closed-kinetic chain conditions, our primary hypothesis was that a rotating–bearing design would reduce the changes in patellar kinematics and forces induced by femoral component malrotation. Our secondary hypothesis was that increasing the conformity of the rotating–bearing design would result in a further reduction of the changes in patellar kinematics and forces induced by femoral component malrotation.

2. Methods

2.1. Cadaver model

Experimental data from a previously reported cadaver study were used to generate and validate the model (Browne et al., 2005). Briefly, normal fresh-frozen cadaver lower extremity specimens were surgically implanted with Scorpio CR (Stryker Orthopaedics, Mahwah, NJ) components. The femur was implanted perpendicular to the mechanical axis of the femur in the coronal and sagittal 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 the 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 sagittal planes. The bony attachments of the collateral ligaments, posterior cruciate ligaments, patellar tendon, and quadriceps tendon were digitized using an electromagnetic tracking stylus (3SPACE FASTRACK, Polhemus, Colchester, VT). The alignment of the implants relative to bony landmarks was also digitized using registration marks machined on the components. The knees were mounted in a dynamic quadriceps-driven closed-kinetic chain knee simulator based on the Oxford knee rig design (Fig 1A) (D'Lima et al., 2000, Petersilge et al., 1994, Zavatsky, 1997). Threaded rods were cemented into the femoral and tibial shafts for fixation to the testing rig. The femoral rod was connected to the "hip" section through a joint that permitted rotations about all three axes. The hip section was free to slide vertically on two rails. A vertical load (nominally 100 N) was applied through the hip section to generate a peak flexion moment of approximately 40 N-m, comparable to that reported during stair climbing after TKA (Andriacchi et al., 1997, Andriacchi et al., 1982). An electric motor applied tensile force (reaching a maximum of between 800 and 1000 N) on the quadriceps tendon by means of a nylon strap to extend the knee against gravity (simulating a weight-bearing deep knee bend). The tibial rod was connected to the "ankle" section via a joint that permitted rotations about all three axes. The ankle section was fixed in the translational degrees of freedom. Standard dome-shaped patellar components were mounted on a custom triaxial load cell for measuring patellar compressive forces and shear. Electromagnetic tracking sensors (3SPACE FASTRACK, Polhemus, Colchester, VT) mounted on the femur, tibia, and patella were used to monitor knee kinematics. Knee kinematics were calculated using a previously reported joint coordinate system (Grood and Suntay, 1983).

2.2. Computer model

A musculoskeletal model, replicating the dynamic quadriceps-driven weight-bearing knee flexion in the cadaver study, was constructed using a knee implanted with posterior cruciate-retaining arthroplasty components (Fig 1B, LifeMOD™/KneeSIM, LifeModeler Inc, San Clemente, CA). KneeSIM is a musculoskeletal modeling environment that uses the MSC.ADAMS rigid body dynamics solver to compute knee kinematics and forces during a deep knee bend. CAD models of the femoral, tibial, and patellar components were aligned in 0° of flexion, adduction, and external rotation. The soft tissues (collateral ligaments, posterior cruciate ligaments, patellar tendon, and quadriceps tendon) were modeled as nonlinear 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.

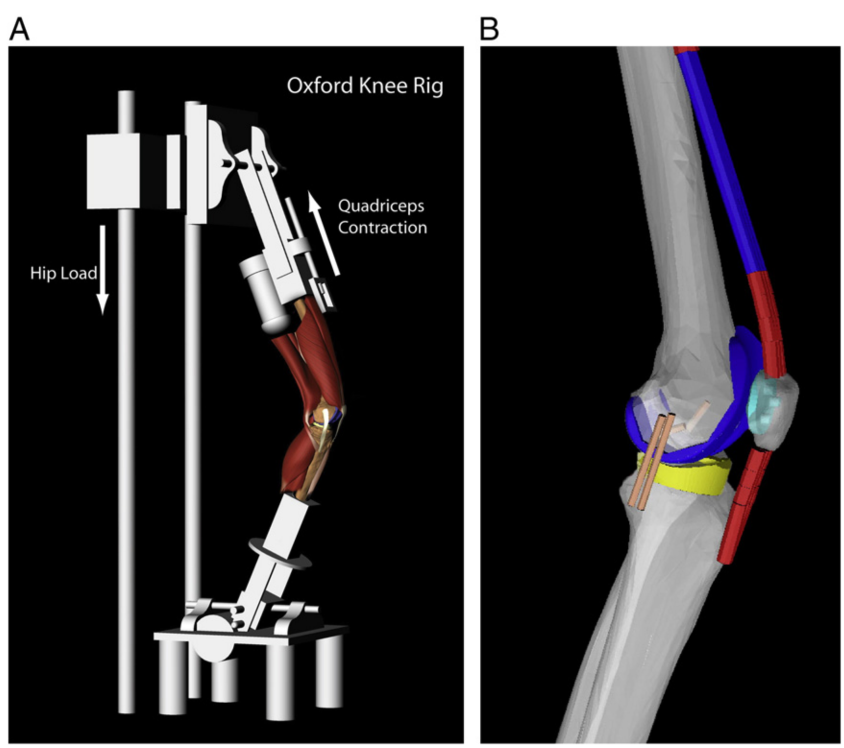

Fig. 1. Computer rendered images of a knee implanted with tibial, femoral, and patellar components. A: Oxford knee rig and B: KneeSIM model. The model includes ligaments and incorporates wrapping of quadriceps around the trochlea and patellar tendon over the tibial insert.