EFFECT OF FEMORAL COMPONENT MALROTATION ON CONTACT STRESS IN TOTAL KNEE REPLACEMENTS

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INTRODUCTION

Proper internal/external rotational alignment of the femoral component is essential to the success of total knee replacements. In particular, femoral component external rotation has been found to reduce patellofemoral complications, currently the number one cause for revision (Berger *et al*., 1998). Since slight femoral external rotation may also reduce the need for lateral retinacular release, some surgeons routinely aim for 3º to 5º of such rotation (Agaki *et al*., 1999).

In addition to its effect on patellar tracking, femoral component rotational alignment may also affect the contact stresses exerted on the polyethylene tibial insert, thereby influencing wear. However, to our knowledge, no studies have investigated this effect over a large range of flexion angles.

This study uses computer simulation to predict how femoral component malrotation affects tibial insert contact stresses. A novel approach combines rigid body dynamics with elastic contact to study contact stresses during movement. The results suggest that a adding a small amount of femoral component external rotation to improve patellar tracking will not increase polyethylene contact stresses and consequently wear.

MODEL DEVELOPMENT

A hybrid rigid-deformable multibody dynamics model of the tibial and femoral components of a total knee replacement was created for this study. The femoral component was treated as a rigid body possessing six degrees of freedom relative to the fixed tibial component, with the medial and lateral contact surfaces being treated as deformable. Five radii of curvature (three for the femoral and two for the tibial component) were used to describe the surface geometry.

Two elastic half-space contact models were used to calculate tibiofemoral contact forces and stresses based on the interpenetration of the undeformed surfaces and their material properties (Johnson, 1985). The first was a Hertz model which assumed locally quadratic surface profiles in the region of contact. The second was a half-space boundary element model which made no assumptions about the contacting geometry by discretizing the contact region into elements. Checks were developed to ensure that the amount of penetration and conformity between the contacting surfaces remained small enough to warrant the use of elastic half-space theory. The entire multibody dynamics model was implemented in the commercial software Pro/MECHANICA MOTION.

The model was used to perform a one-second dynamic simulation of a 90° knee flexion motion. This was achieved by prescribing a sinusoidal sagittal plane rotation of the femur relative to the tibia, with the motion of the remaining five degrees of freedom being predicted by dynamic simulation. In addition to elastic contact forces, the motion was influenced by the major knee joint ligaments (minus the ACL) modeled as one or more bundles of nonlinear elastic springs (Blankevoort and Huiskes, 1996). Articular contact was maintained by a fixed downward vertical load of 1500 N applied at the midpoint between the posterior femoral condyles. Because the patella and limb segments were excluded in this initial study, all inertia in the model was from the femoral component alone.

Once a nominal dynamic simulation was developed, the femoral component was rotated about the long axis of the femur by ±10° to simulate the effects of internal/ external rotational malalignment.

RESULTS AND DISCUSSION

The nominal dynamic simulation predicted larger contact forces and stresses in the medial than in the lateral compartment, with the maximum stresses occurring near 90° of flexion (t = 0.5 sec; Fig. 1). A dramatic jump in contact stress occurred at a flexion angle of 17° (t = 0.15 and 0.85 sec) when the anterior-posterior curvature discontinuity in the femoral component was traversed. Although such discontinuities have been associated with excessive wear in industrial cam mechanisms, surface finishing of the femoral component may diminish this effect. Since the contact surfaces were quadratic by construction, stress results from both elastic contact models were nearly identical.

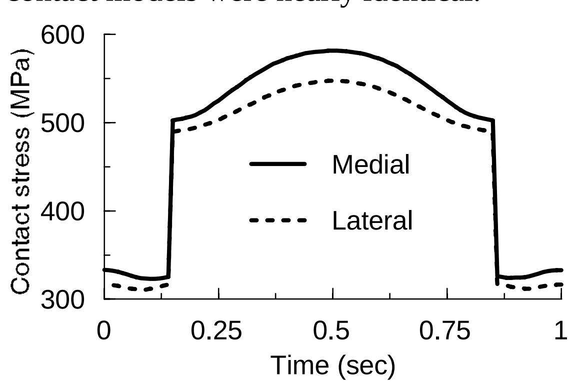

Figure 1: Average contact stresses for the nominal dynamic simulation.

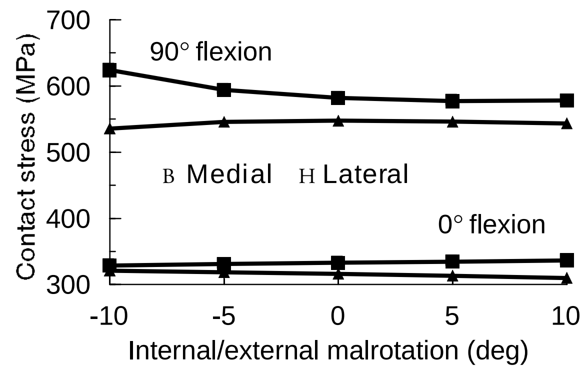

Figure 2: Sensitivity of contact stresses to femoral component malrotation.

The simulations with femoral component malrotation predicted contact stress sensitivity only for internal (i.e., negative) malrotation and only in highly flexed positions (Fig. 2). Even then, the magnitude of the sensitivity (+7% medially for 10° internal rotation) was small. The lack of appreciable sensitivity in extension agrees with published *in vitro* test results (Liau *et al.*, 1999).

These simulation results suggest that for this implant geometry, adding a small amount of femoral component external rotation to improve patellar tracking will not come at the expense of increased tibial insert contact stresses and wear. A more complete dynamic simulation validated against video fluoroscopic movement data and including the patella, limb segments, and muscles is being developed to confirm these findings.

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