In Vivo UHMWPE Contact Mechanics During A Deep Knee Bend for Subjects with PCR and PS TKA

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INTRODUCTION:

Abrasive/adhesive wear and fatigue damage have become limiting factors in the long-term performance of ultra-high molecular weight polyethylene (UHMWPE) joint replacement components, and have been in part attributed to high joint contact stresses. The objective of this study was to determine the in vivo contact mechanics during a deep knee bend for patients with posterior cruciate retaining (PCR) and posterior stabilized (PS) total knee arthroplasty (TKA) and to evaluate any demonstrable differences.

METHODS:

To accomplish this objective, video fluoroscopy was utilized to determine tibio-femoral kinematics during a deep knee bend for forty-three TKAs. The kinematic analysis was then used to drive a sagittal plane finite element model of the joint to determine contact mechanics (Sarojak, 1998). In this study, thirteen patients had PCR TKA with a relatively unconstrained tibial insert, eleven patients had PCR TKA with a semi-constrained insert, and nineteen patients had PS TKA. Total knee arthroplasty was performed by a single surgeon for each of the three knee types. Each TKA was clinically successful. Non of the patients had liga-mentous pain/ laxity. Finite Element Model Plane strain finite element models were created to represent the sagittal profiles of the femoral and tibial components of each of the three total knee devices. The 4-noded quad elements representing the tibial insert were given nonlinear UHMWPE material properties, and the femoral surface was modeled as a rigid surface (DeHeer, 1992). The compressive loading cycle for each analysis varied from 1X-3X body weight (Komistek, 1998). Results from the quasi-static analyses for each patient were output at 0, 30, 60, and 90 degrees. The contact area, peak surface normal contact pressure, and peak subsurface stress values were monitored during the analyses.

Figure 1. Peak contact pressure as a function of flexion angle for the unconstrained tibial insert (13 subjects).
DISCUSSION:

The more conforming designs (PS and semi-constrained inserts) had slightly lower contact stresses and larger contact areas. However, the significant differences in contact stresses were seen to be a result of abnormal kinematic conditions. Large anterior-posterior motion created potential for edge loading of the tibial insert and sharply increased stresses, well beyond the polyethylene yield strength. Edge loading occurred in the unconstrained PCR insert and somewhat in the PS insert, but did not occur in the semi-constrained PCR insert. These locations correspond to retrieved components. Combining in vivo kinematic analysis with finite element simulations has demonstrated the significance of tibio-femoral kinematics in wear or fatigue damage of UHWMPE tibial components.

RESULTS:

Average stress results for the semi-constrained insert and the PS devices were similar, with average results for the unconstrained insert higher as expected due the lack of tibio-femoral conformity. Both the unconstrained tibial insert and the PS insert showed statistically significant differences in standard deviations when compared to the semi-constrained insert (Figures 1 and 2). The varied results at 0 and 30 degrees from the unconstrained insert (Figure 1) are a result of abnormal tibio-femoral positions that result in edge loading and increased polyethylene stresses (Figure 3).

Figure 2. Peak contact pressure as a function of flexion angle for the semi-constrained tibial insert (12 subjects).

Figure 3. Anterior contact position developed on the unconstrained insert at 30 degrees flexion.

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References:


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