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 propensity of total knee systems for these types of wear is often assessed by evaluating the contact stresses and contact areas of each system. Previously, researchers have used experimental and analytical methods to determine joint contact characteristics. Most of these studies, however, have included simplified loading conditions, such as only compressive loading with a fully aligned tibio-femoral position. Retrieval studies, however, have demonstrated the many clinical locations for tibial insert wear, such as the posterior edge, due to the varied in vivo loading conditions. 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.

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. The femoral articular geometry was similar for each of the devices. Total knee arthroplasty was performed by a single surgeon for each of the three knee types. Each TKA was clinically successful, and had Hospital for Special Surgery (HSS) scores in the excellent category. None of the patients had ligamentous pain / laxity. (Note: Study had IRB approval, and each patient has an informed consent).

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. The UHMWPE material model used was previously validated. Relative kinematics from the mediolateral condyle of the implant were used to drive the simulation, specifically the flexion-extension angle and the anterior-posterior displacement. The compressive loading cycle for each analysis was determined through a static analysis of the deep knee bend (varied from 1X–3X body weight). 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. The insert geometry was assumed to be new (no wear or deformation) and perfectly aligned with the tibial baseplate (position reference from the fluoroscopic data).

Results  Contact stress and area parameters were determined for each subject.

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). The PS insert showed edge loading and increased stresses in 3 subjects at 0 degrees and the deep knee bend occurred at both the anterior and posterior edges of the implant.

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 UHMWPE tibial components.

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

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.