Knee Joint Contact Stresses on the Tibial Cartilage before and after Horizontal Cleavage Lesion Surgery

Rajshree Mootanah, PhD1, Sally Arno2, Christelle Esposito3, Franziska Reisse4, Diagarajen Carpanen5, Christopher Bell, MSc2, Peter S. Walker, PhD2, Howard Hillstrom, PhD4.

1Anglia Ruskin University, Chelmsford, United Kingdom, 2NYU Hospital for Joint Diseases, New York, NY, USA, 3Ecole des Mines d’Albi-Carmaux, Albi, France, 4Hospital for Special Surgery, New York, NY, USA.

Disclosures:

Introduction: Horizontal cleavage lesion (HCL) is a degenerative horizontal tear in the meniscus and is associated with an increased incidence of cartilage damage[1] and symptomatic osteoarthritis (OA) [2, 3]. OA is associated with increased knee joint contact stress, is irreversible with current treatments [4](Zhang, 2010) and poses a heavy health economic burden. HCL cannot be repaired and most often requires partial meniscectomy[5]. Both HCL[3, 6] and OA[7] usually occur in older individuals, thereby posing an increasing health economic burden. HCLs are commonly located beneath[8]the medial[9] meniscus. To understand the effect of surgical treatments of the most common type of HCL, the aim of this study was to investigate knee joint contact stress with 1) an intact meniscus, 2) the meniscus with a medial HCL, 3) the meniscus that has undergone partial meniscectomy, and 4) a total meniscectomy.

Methods: High-resolution magnetic resonance images of a cadaveric knee joint were acquired and segmented in Mimics software (Materialise, Belgium) to create three-dimensional (3D) representations of the bones and soft tissues. A 17-mm HCL lesion was simulated by splitting the medial posterior area of the meniscus into two horizontal layers. A solid 3D non-manifold assembly model of the knee joint was created in Mimics software and exported to ABAQUS V6.11-2 finite element (FE) package (HKS, USA).

Bones and soft tissues were meshed with tetrahedral and hexahedral elements, respectively. Homogenous, isotropic material properties with linear elastic behavior were used to represent bones and cartilages; the meniscus material properties were transversely isotropic; the ligaments were modeled, using the Holzapfel anisotropic material model[10]. Each meniscal horn was attached to the tibial plateau, using 1D linear springs with a stiffness of 2000N/mm[11]. The MCL, LCL, ACL and PCL were assigned Young’s Moduli values of 81, 104,165 and 40 MPa, respectively, at 15° flexion, which corresponds to the end of weight acceptance, when forces in the knee joint are very high. This was based on an iterative ligament tuning process carried out in a parallel model validation study until FE-predicted kinematics of the tibia with respect to the femur (in all six degrees of freedom - DOF), matched those collected in vitro from the same cadaveric knee during a 65° flexion-0° extension.

Frictionless contact elements were used between the split meniscus surfaces. The distal tibia of the FE model was fixed in all 6 DOF, an axial load of 500N was applied along the femoral axis to replicate cadaveric tests carried out at New York University. Pressure distributions on the tibial cartilage were obtained in vitro, using Tekscan Iscan sensors. FE analyses were run for the above four cases and peak pressure and shear stress values in the tibio-femoral compartments were compared.

Results: Table 1 presents the pressure distributions and peak pressure and shear stress values in the knee joint for the four outlined cases. Peak pressure values in both medial and lateral compartments were lowest in the intact knee. An HCL resulted in increase in peak pressures of 0.8% and 0% in the lateral and medial compartments, respectively. A partial meniscectomy increased peak pressure by 1.6% and 4.7% in the lateral and medial compartments, respectively. A total meniscectomy increased peak pressure by 78% and 52% in the lateral and medial compartments, respectively.

An HCL increased peak shear stress by 0% and 6.9% in the lateral and medial compartments, respectively. A partial meniscectomy increased peak shear stress by 17.9% and 5.0% in the lateral and medial compartments, respectively. A total meniscectomy increased peak shear stress by 87.7% and 7.9% in the lateral and medial compartments, respectively. Shear stress values were higher in the deeper zone of the cartilage than on the surface. With an intact meniscus, FE-predicted and in vitro-measured peak pressure values were 1.24 MPa and 1.46 MPa, respectively, in the lateral compartment and 1.06 MPa and 1.08 MPa, respectively, in the medial compartment.

Discussion: An FE model of the human knee joint was developed and used to predict peak stress in the tibio-femoral joint with an intact meniscus and a meniscus with an HCL, before and after surgical treatments. In vitro-measured and FE-predicted peak pressure values were close in magnitude, although the cadaveric knee specimen was not used to create the FE model; however, these results show that the FE model predicted sensible results. Peak shear stress in the medial compartment increased by 6.9% following an HCL and decreased again following a partial meniscectomy. Indeed, a recent study showed that HCL caused a decrease of anterior-posterior stability and changes in contact position[12]. Total meniscectomy resulted in an increase in peak pressure and shear stress that were 49 and 4.9 times higher than those with partial meniscectomy. These results suggest the
need to preserve as much healthy meniscus tissue as possible during a partial meniscectomy; this may minimize cartilage damage and the risk of developing OA. In this study, the HCL size was quite small (17 mm long); higher peak pressure and stress values are anticipated for larger HCLs, as indicated by the stress values associated with total meniscectomy. The FE model appears promising and was able to simulate intact, HLC, and partial and total meniscal removal. Based on pressure data from the sample knee, the FEA was able to predict an accurate value for the peak contact pressures at the one condition of testing. In future, comparative data will be obtained for different flexion angles, loading conditions and experimentally induced meniscal tears.

**Significance:** These results suggest that larger removal of meniscal tissues would increase the exposure of the cartilage to higher stress. Although shear stress, a major contributing factor to OA, cannot be measured physically, it can be predicted by the FE model. This research is clinically important because the FE model can be developed into a surgical planning tool for specific meniscal lesions to reduce joint stress, which is important for lowering the risk of developing OA.

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**References:**
7. Valkenburg H, 1980
Table 1: Peak pressure and shear stress values in the medial and lateral compartments of the tibio-femoral joint with: 1) intact menisci, 2) HCL, 3) partial meniscectomy, and 4) total meniscectomy. M = medial, L=Lateral, A= Anterior, P= Posterior.

<table>
<thead>
<tr>
<th>1. Intact Meniscus</th>
<th>2. HCL, no flap removed</th>
<th>3. Partial meniscectomy</th>
<th>4. Total meniscectomy</th>
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<tr>
<td><strong>Peak pressure</strong></td>
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<td>Medial (FE): 1.06 MPa</td>
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<td>Medial (FE): 1.11 MPa</td>
<td>Medial (FE): 1.61 MPa</td>
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<td>Lateral (in vitro): 1.46 MPa</td>
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<td>Medial (in vitro): 1.08 MPa</td>
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<td><strong>Shear stress</strong></td>
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<td>Medial (FE): 1.01 MPa</td>
<td>Medial (FE): 1.08 MPa</td>
<td>Medial (FE): 1.06 MPa</td>
<td>Medial (FE): 1.09 MPa</td>
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