Introduction: The meniscus is a load sharing structure and acts as a cushion to distribute knee stresses. Loss of the meniscus substantially increases contact stresses and is associated with early onset osteoarthritis. Therapeutic replacement could restore load bearing and contact conditions but may suffer from attachment technique issues. We developed a computation model of the knee to study the effect of meniscal attachment technique on knee-contact biomechanics.

Materials and Methods: A solid mesh was generated in Hypermesh (Altair Engineering Inc) from the surface geometry obtained by segmenting an MRI of a normal knee using MIMCS (Materialise). The femoral and tibial cartilage were meshed with linear elastic isotropic hexahedral elements with a stiffness of 15 MPa. The medial meniscus was meshed as an orthotopic elastic material with a stiffness of 20 MPa in the radial and vertical directions, a stiffness of 150 MPa in the circumferential direction, and shear modulus of 58 MPa to simulate the circumferential organization of the collagen fibers. The attachments of the meniscal horns were simulated using linear springs based on the stiffness of commercially available suture materials: no attachment, suture constructs (mean stiffness, 1–50 N/mm), and bone plug anchorage. The knee was loaded in full extension with an axial load of 600N (representing body weight). Contact area, contact stresses, and meniscal horn displacement were computed during the applied load using a commercial finite element analysis package (MSC.MARC, MSC.Software).

Results:

Changes in contact area and stresses due to total meniscectomy were compared to published experimental results and were within the reported ranges. In the intact condition, femoral contact area was 289 mm² and peak stresses reached 2.93 MPa, (average, 1.04 MPa). With total meniscectomy, femoral contact area decreased by 26% with a concomitant increase in mean contact stresses (36%) and peak contact stresses (17%).

Replacing the meniscus without suturing the horns did little to restore femoral contact area because the horns separated easily under load (>4mm displacement) and circumferential stiffness was insufficient to maintain meniscofemoral contact. Suturing the horns increased contact area and reduced peak/mean contact stresses. Horn displacement ranged from 2.5mm to <1mm (suture stiffness 1 to 50N/mm, respectively). Increasing suture stiffness correlated with increased contact stresses as greater tibiofemoral load was transferred to the meniscus. A small incremental benefit was seen of simulated bone plug fixation over the stiffest suture construct.

Discussion: Meniscectomy reduced femoral contact area and increased contact stresses within the range experimentally reported which validated the model. The method of horn fixation appears critical to restoring normal conditions. Suturing the horns with high tensile stiffness sutures approximated the contact conditions generated while using bone plugs for fixation. Suturing the rim was also tested but did not appear to substantially affect contact conditions.

These specific results may only apply to this particular knee anatomy, but the trends are broadly applicable. Only the medial compartment was simulated: the lateral compartment has a substantially different geometry and may result in different contact conditions. This simulation resembles a meniscal autograft condition in that the replacement meniscus was identical to the original meniscus. In meniscal replacement (either allograft or artificial) the shape is almost never the same.

This model may also be useful in predicting the effect of biomaterial mechanical properties and meniscal replacement shape on knee contact conditions.