Introduction: Recent interest in knee joint contact pressure experimental models has increased. It has been shown that increased peak contact pressure is a harbinger of future degenerative change. Most of these studies have been done in static models using animal or human cadaveric specimens. One recent article, by Cottrell et al., reported on a dynamic model using sheep cadaveric knees stripped of almost all soft tissue attachments. The purpose of this study was to develop a soft tissue sparing human gait model that can be used to measure knee joint contact pressure and kinematics dynamically to test surgical manipulations of the knee.

Methods: Eighteen fresh frozen cadaver knees were examined arthroscopically to rule out significant arthritic, meniscal or ligamentous pathology, yielding six acceptable knees. These six knees were prepared for testing in a modified MTS machine (fig 1). Knees were potted, retaining all capsular and ligamentous structures, and the quadriceps mechanism, in similar fashion to our prior work. The modified MTS machine provided axial, tibial rotation/torque, anterior-posterior and knee flexion control. Control of the 4 channels followed a modified ISO standard for knee implant wear testing. Free medial-lateral movement and free valgus/varus angulation of the knee were allowed. Quadriceps load was applied by 2 tension springs. The motion of the tibia with respect to the femur was measured using a 6 degree of freedom Polaris optical system. This allowed direct measurement of tibiofemoral motion independent of the MTS control and measurements. Femoral-tibial pressure and contact area were measured in each knee with dynamic pressure sensors in the intact knee. Tekscan pressure sensors (model 4000) were tethered in an inframeniscal position via suture to extra-articular bone anchors as previously reported. Changes in the motion, pressure and resultant force were statistically compared using a paired t test at p<.05 for each increment of the gait cycle independently.

Results: Knee kinematics followed a normal gait pattern (figure 2). Variations in motion among knees had an average standard deviation of 0.8 degrees for flexion, 1.4 degrees for ab/adduction and 1.3 degrees for tibial rotation. Complete pressure data was acquired in only 4 knees due to failure of the sensor or of the sensor’s fixation. Although there was no statistical difference between the medial and lateral loading distribution during the gait cycle, there is a trend that more medial loading occurred near full extension but more lateral loading later in stance (figure 3, here only stance phase is plotted). The 3 peaks in peak pressure correspond to the 3 axial load peaks applied during the gait motion cycle (figure 4). Statistically the peak medial pressure was greater than the lateral only during 15 to 17% of the gait cycle (at maximum flexion during early stance phase). The average contact area was 286 mm² in the medial compartment and 325 mm² in the lateral compartment during the stance portion of the gait cycle (figure 5). Statistically there was no difference between the amount of contact area in the medial and lateral compartments through the gait cycle.

Discussion: In a human knee cadaveric model we are able to measure knee joint contact pressure and knee kinematics during simulated stance phase of gait in both the medial and lateral compartments with minimal soft tissue stripping, maintaining the collateral ligaments, cruciates, and the meniscal-capsular attachments. Our results are reproducible and present a new standard for knee contact pressure measurement when testing manipulation of the human knee in a cadaveric model.

The study’s limitations include the use of a cadaveric model, limited sample size and the amount of soft tissue dissection needed for sensor implantation. We feel that these limitations are acceptable as this model is a vast improvement over previously reported models in the literature. The variation in knee motion among knees, as seen by a 1 to 1.5 degree standard deviation, is not due to variations in MTS control. Instead it reflects variations in the alignment of the motion sensors on the femur and naturally occurring variations between cadaver knee specimens. This verifies our ability to repeatedly pot and position the femur and tibia.

Our pressure sensor placement includes measurement of the loading beneath the menisci. Therefore the observed equality of the contact area and total force between compartments may be thought to be due to the sample size, the inclusion of the meniscal loading or may in fact be what is observed to occur in vivo as shown by Zhao et al. Of interest, during stance the peak contact pressure medially is greater than that in the lateral compartment when higher compressive loading occurs. As it is accepted that peak contact pressure is a predictive factor for degenerative change, this finding corresponds clinically to the greater incidence of medial compartment osteoarthritis.

This model shares many strengths with the model presented by Cottrell, et al, mainly that it is a dynamic model. This model surpasses that of Cottrell, et al by keeping intact more soft tissue constraints and being a human knee model, rather than an animal model. As Cottrell, et al and others have noted, knee contact mechanics rely on magnitude, incidence of medial compartment osteoarthritis. We feel that by retaining more soft tissue integrity our model more closely resembles what happens in the native knee, and is more representative of normal knee kinematics during testing. Our model lends itself to testing of both intra-articular and extra-articular manipulation of the knee joint and as such has many potential applications.

In conclusion we have presented a novel model for dynamic testing of knee joint contact pressure and kinematics in a human cadaveric model. This model will be applied to future studies of the knee joint.

References:

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