Quantification of knee joint contact area using weight-bearing MRI for subjects with osteoarthritis
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Introduction
Osteoarthritis (OA) is a potentially debilitating disease with approximately one third of older adults exhibiting signs and symptoms of knee OA (1). In order to better understand progression of this pathology, a more accurate understanding of knee kinematics is needed. Magnetic resonance imaging (MRI) allows for precise measurement of the bones and cartilage in the knee joint and is not subject to the same limitations of external markers (skin motion) or fluoroscopy (radiation exposure). The use of an open upright MRI scanner allows for full weight-bearing at the knee and a more accurate representation of knee joint kinematics and their effect on the progression of knee OA. The goal of this study is to quantify changes in tibiofemoral contact area at varying stages of knee OA using a novel MRI technique.

Methods
Barrance and colleagues (2,3) have developed a novel method to quantitatively measure kinematics, cartilage proximity and contact area in the tibiofemoral joint using MRI acquired from weight-bearing individuals. For this study, 4 healthy control subjects and 8 individuals with OA (divided by KL score based on radiograph) were recruited after approval for this study was obtained from the University of Delaware Human Subjects Review Board. All subjects were required to complete an informed consent form prior to participating. Scans were performed in an open MRI scanner (Upright MRI, Fonar Corporation) with the subject nearly vertical (85°) against the table while knees were fully extended. Thirty sagittal image slices, spaced 3.3 mm between centers, with 3 mm slice thickness and a 25 cm field of view, were acquired for each knee. The total imaging time for each knee, including localizer scans, was approximately 6.5 minutes.

Distal femoral and proximal tibial bone surfaces as well as medial and lateral compartment cartilage surfaces were digitized on an LCD screen (Wacom, Vancouver, Washington) using IMOD software (University of Colorado). Cartilage proximity was calculated using surface interpolation and closest point distance computation implemented in Matlab. Regions of contact were defined over areas of femoral cartilage that lay within a threshold distance of 2 mm from the tibial cartilage, and centers of contact were calculated as the centroid of all points within this region. Femoral and tibial coordinate systems were assigned using anatomical landmarks and joint kinematics were calculated as the relative translations and rotations. Positions of coordinate systems were maintained between scans by using the Trimmed Iterative Closest Point algorithm (4) to match bone surfaces.

Results
Subjects were split equally into three groups based on each subject’s medial KL grade: healthy (KL=0), mild OA (KL=1-2), severe OA (KL=3-4). The subject-specific three-dimensional models yield distinctly different contact area estimates and centroid locations for each subject studied (Figure 1). Estimates of average medial condyle contact area for the healthy group were 521.5 ± 35.1 mm², 418.5 ± 63.1 mm² for the mild OA group, and 539.0 ± 72.6 mm² for the severe OA group.

Discussion
In this study, a novel weight-bearing MRI technique was used to quantify the changes in contact area during nearly upright standing in subjects with varying degrees of knee OA. Approximately 50% body weight was borne by each knee during the upright scan. It is hypothesized that the decrease in contact area in the mild OA group might be due to neuromuscular adaptation that the subject adopts in an attempt to decrease knee pain. Cartilage may not be able to adjust to the new loading pattern and therefore deteriorates quickly (5). In a larger cohort of subjects, we have also observed increased co-activation of hamstrings and quadriceps for subjects with moderate OA relative to those with severe OA and healthy counterparts (6). Perhaps this altered muscle activity promotes an increased net joint compressive force and subsequent cartilage deterioration. Strategies may be modified again by the time OA becomes severe, potentially resulting in increased contact area. Such questions are being addressed in an ongoing longitudinal study.

In future work, centroid location and kinematic changes at the tibiofemoral joint will be analyzed with the progression of OA in the upright weight-bearing position as well as during partial weight-bearing at three knee flexion angles (0, 15, 30°). From this information we will be able to interpolate tibio-femoral joint kinematics across a range of flexion angles and couple them with estimates of joint contact force based on motion analysis and musculoskeletal simulation to determine how cartilage thickness and applied loads are related. Area estimates will also be normalized by tibio-femoral geometry to account for differences in subject size.

Figure 1: Visualization of the superior surface of a healthy subject’s tibia. The circles represent the centroid of the contact between the tibia and femur for each of the condyles. The colored area represents the distance between that point on the tibial cartilage and the nearest point on the femoral cartilage in mm. Points are considered to be in contact if the distance is 2 mm or less. The orientation of the tibia is determined by identifying several landmarks on the MRIs during the digitizing process and creating a joint coordinate system.

Figure 2: Comparison of medial condyle contact area estimates and medial OA severity. Average medial contact area decreased by 19.7% in the mild OA group compared with the healthy group while the severe OA group increased 3.3% over the healthy subject group.

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References
(2) Barrance, P.J. and T.S. Buchanan. ASME Summer Bioengineering Conference. 2006a.
(3) Barrance, P.J. et al. World Congress of Biomechanics. 2006b.