Cartilage Deformation under Load in a Human Cadaveric Hip Measured with 7.0T qMRI

L. L. Greaves[1], M. Gilbart[2], A. Yung[3], P. Kozlowski[3], and D. R. Wilson[2]

[1]Mechanical Engineering, University of British Columbia, Vancouver, British Columbia, Canada, [2]Orthopaedics, University of British Columbia, Vancouver, British Columbia, Canada, [3]Radiology, University of British Columbia, Vancouver, British Columbia, Canada

Introduction: Measuring load distribution in the hip joint is vital to understanding the biomechanics of joint injury, disease progression and surgical intervention. Few methods are available for measuring hip contact mechanics because approaches used in other joints such as the knee (e.g. pressure sensitive film) are less suitable in the spherical geometry of the hip and require disruption of important soft tissues. Recently quantitative MRI (qMRI) has been used to measure cartilage deformation in the knee[1]. However, cartilage deformation with load has not been measured in the hip. The objective of the current study was to assess the feasibility and repeatability of measuring cartilage deformation at the hip under a static physiological load with qMRI.

Materials and Methods: A human cadaveric hip (F,age 38) was stripped of all soft tissue to the level of the capsule which was left intact. The hip was then mounted in a custom MRI compatible pneumatic loading device **(Fig 1)**. Absence of pathology was verified using hip specimen traction and an arthroscope placed through a standard anterolateral portal in the capsule. The distal femur was potted and the pelvis was sectioned such that a physiological orientation simulating single leg stance[2] was obtained when the specimen was placed in the loading device. The capsule was covered with gauze soaked in a phosphate buffered saline solution with protease inhibitors (PBS+) to minimize degradation and maintain joint hydration.

MR imaging of hip cartilage was performed with a fat-suppressed 3D FLASH sequence using a 15 cm inner diameter quadrature volume coil on a 7T animal MRI scanner (Bruker Biospin,Ettlingen Germany) Imaging parameters were: TR/TE 25/4.6 ms; flip angle 20°, slice thickness 1 mm, in–plane resolution 0.11 mm, matrix 512 x 512, FOV 5.63 cm, 16 slices per image, time: 3 min 25 s. Slices were orthogonal to a plane running parallel to the rim of the acetabulum, and passed through the longitudinal axis of the anterior inferior iliac spine. We loaded the hip to 1980 N (2.5xBW, nominal 80 kg) of axial compression to simulate hip loads during single leg stance[2]. Images were obtained upon initial loading and every 15 min thereafter. For each time interval we subtracted the intensity of each pixel in the image from the corresponding pixel in the preceding image, producing a subtraction image. Deformation phase scanning was complete when the subtraction image showed only noise (i.e. the 2 source images were identical except for the background noise). The piston in the loading device was then retracted slightly for 8 hrs, with no cartilage thickness recovery in this time. Full retraction of the piston initiated the cartilage recovery phase and the specimen was scanned every hour until the recovery phase was complete, again using feedback from subtraction images. In the recovery phase, the loading device was filled with the PBS+ solution between scans, providing fluid for re-uptake. The specimen and loading device remained in the MRI scanner throughout testing. For each time interval during deformation and recovery phases, the osseous interfaces between the femoral and acetabular cartilage were segmented on a single (centre) slice (Analyze 7.0, Mayo Clinic, USA). The segmented acetabular cartilage was fitted to a circle and radial cartilage thickness measurements between the osseous surfaces of the femur and acetabulum were obtained in over 230 points in the anterosuperior (AS) region (Matlab 7.0, Mathworks, USA).

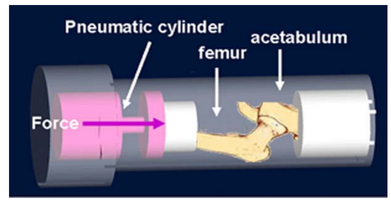

Figure 1: Custom MRI loading device

The precision of our cartilage deformation measurements was assessed by repeating the methodology described above every day for 5 days in the same specimen (F, age 47). To include error due to specimen placement in the loading device and MRI bore, we removed the specimen from the device daily and submerged it in the PBS+ solution overnight. Fiducial markers were used to locate the same slice each day. The cartilage was segmented as described above and cartilage thickness was measured each day at deformation time intervals 1 hr 45 min and 2 hr.

Results: Subtraction images showed the articular cartilage reached a steady-state thickness distribution after 3 hr 45 min of loading and 16 hr 30 min of recovery. Cartilage compressed by a mean of 0.71 mm (34%) **(Figures 2 and 3)**. Repeatability results showed a maximum difference in mean cartilage thickness of 0.13 mm (3.4%) over the 5 days, which occurred at the 1hr 45 min time interval.

Discussion: Cartilage deformation and recovery in the hip was successfully measured using MRI. Our finding of full cartilage thickness recovery in the hip after 16.5 hrs is consistent with a similar study in the knee joint[1]. We successfully measured cartilage deformation in the hip and observed an overall magnitude of deformation (0.71 mm) far greater than our in-plane resolution (0.11 mm) and our error due to repeatability (0.13 mm). Our results suggest that measuring hip cartilage deformation and recovery with MRI could be a powerful tool for investigating hip joint mechanics.

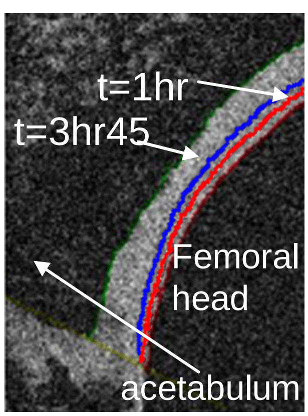

Figure 2: Lines show movement of femoral head causing cartilage deformation after 1 hour of load and at end state of deformation, time 3 hour 45 min

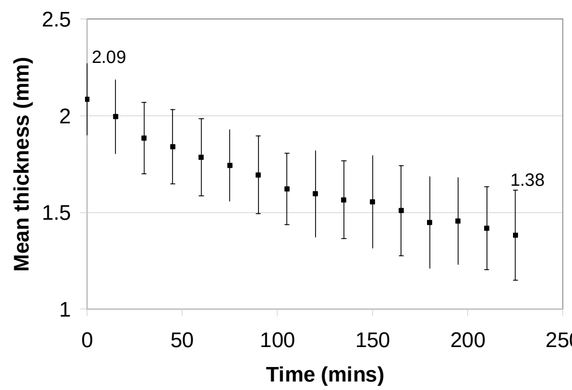

Figure 3: Mean cartilage thickness change as a function of time, measured in a single slice in the AS region of one hip (F, 38)

References: 1. Song et al. Osteoarthritis Cartilage.2006;14(8):728-37 2. Bergmann et al. J Biomech.2001;34:859-71