# METHODS TO DETERMINE *IN VIVO* CARTILAGE STRESS IN THE PATELLOFEMORAL JOINT FROM WEIGHT-BEARING MRI

Thor Besier[1], Garry Gold[2], Christine Draper[1], Chris Powers[3], Scott Delp[1,4], and Gary Beaupré[4]

Departments of Mechanical Engineering[1], Bioengineering[1], and Radiology[2], Stanford University, Stanford. CA.
[3]Department of Biokinesiology and Physical Therapy, University of Southern California, LA.
[4]VA Palo Alto Rehabilitation R&D Center, Palo Alto, CA
besier@stanford.edu

## INTRODUCTION

Elevated cartilage and subchondral bone stresses have been suggested as a possible cause of pain in subjects with patellofemoral (PF) syndrome (Powers, 1998). To test this hypothesis, *in vivo* cartilage stress needs to be estimated in subjects with and without patellofemoral pain. Given knowledge of joint loads, articulating geometries, cartilage thickness and tissue material properties, the finite element (FE) method provides a framework to calculate cartilage stress. Medical imaging techniques, such as magnetic resonance (MR) imaging, can provide subject-specific inputs to the FE model such as cartilage thickness and geometry. The purpose of this research was to estimate patellofemoral joint cartilage stress distribution and deformation using weight-bearing MR images as input to a FE model.

## METHODS

We have developed a low-friction backrest for stabilizing subjects during upright, weight-bearing scans of the knee in a 0.5T open-configuration MR scanner (Gold et al., 2004). MR images were acquired from the right knee of a single healthy male subject using an open configuration scanner (0.5T GE SP/i MR GE Medical Systems, Milwaukee, WI). The subject had no previous history of patellofemoral pain and informed consent was gained prior to participation. The subject was asked to maintain a squatting posture with the knee at 60 deg (Fig. 1).

**Figure 1:** MR compatible back rest allows subject to assume ~0.45 body weight of load per knee.

A 3D fast spoiled gradient echo (SPGR) sequence was employed to obtain 2 mm contiguous sagittal plane images of the patellofemoral joint. The 0.5T scan took 2 min using the following parameters: TR = 33ms, TE = 9ms, Flip Angle = 45°, NEX = 1, FOV = 20x20cm, matrix dim = 256x160, interpolated to 256x256.

A separate, sagittal plane scan of the subject's knee was also taken in a standard 1.5T closed MR magnet to obtain images of the cartilage in its undeformed state (SPGR sequence, 1.5 mm slices, scan time 10:25 min). The MR images were manually segmented to obtain point cloud representations of the femur and patella bone and articular cartilage. The point clouds were then converted into triangulated surfaces using a commercial software package (Raindrop Geomagic, Research Triangle Park, NC). The bone surfaces from the 1.5T scan were then registered to the bone surfaces in the 0.5T weight-bearing scan. This transformation was used as a boundary condition in the FE model to place the undeformed cartilage into the same position and same flexion angle as the deformed, weight-bearing state. Distance maps could then be calculated to compare the undeformed and deformed cartilage contact surfaces, as well as the cartilage thickness (Fig. 2a). NURBS surface representations of the undeformed patella and femoral cartilage were then created and hexahedral meshes of the cartilage were generated using Patran (MSC.Software Corp., Santa Ana, CA) (Fig. 2b).

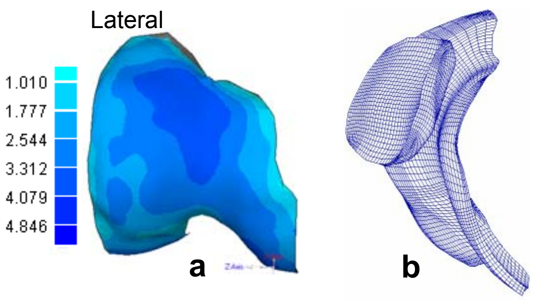


**Figure 2:** a) Femur cartilage thickness map. b) FE mesh of patella and femoral cartilage with a total of 11,550 elements. Typical element size ~1.5 $mm^3$.

FE analyses were performed using ABAQUS (ABAQUS Inc., Pawtucket, RI) and included surface to surface contact (friction coefficient of 0.001) Cartilage was modelled as a linear elastic solid with Young's modulus of 6 MPa and Poisson's ratio of 0.47. The subchondral surface of the patella and femur were both treated as rigid and the back of the femoral cartilage fixed. A displacement was then applied to the patella cartilage to reproduce the position of the patella in the weight-bearing scan. The hydrostatic pressure distribution on the subchondral cartilage surface was determined.

## RESULTS AND DISCUSSION

For this subject, hydrostatic pressure was highest on the lateral condyle of the femur (Fig. 3a). Shear stresses were highest at the subchondral bone surface, at the periphery of PF contact (not shown).

A deformation map of the patella cartilage showed a band of higher deformation across the width of the patella with the greatest deformation centered on each facet (Fig. 3b).

This study demonstrates a technique for calculating in vivo stresses based on MR images obtained during an upright, weight-bearing activity representing bilateral squatting. This activity is often used during the clinical evaluation of subjects with PF pain. Future studies will examine age and activity-matched subjects with and without PF pain to determine if subjects with PF pain have elevated cartilage stresses.

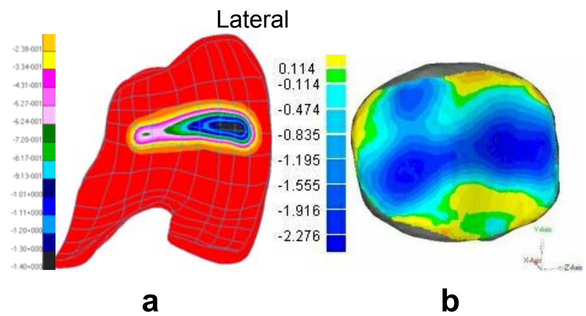


**Figure 3.** a) Hydrostatic pressure distribution on the subchondral cartilage surface. Peak pressure clearly indicated on the lateral femoral condyle. b) Patella cartilage deformation map.

## REFERENCES


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