# CORRELATION OF PATELLOFEMORAL MALTRACKING AND ANTERIOR KNEE PAIN

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## INTRODUCTION

Patellofemoral disorders are a common cause of knee pain and disability in all age groups. The diagnosis of patellar malalignment and patellofemoral instability requires documentation of the changing relationships of the patella to the trochlear groove in all planes of knee motion [1,2]. While there have been many clinical and analytic studies of patellofemoral joint biomechanics, there is little documentation of correlation among features of the physical examination, imaging studies and patient pain and function.

The objective of our study is to improve the understanding of the relationship between patellofemoral joint (PFJ) pain and three-dimensional PFJ kinematics by developing clinical tools that objectively quantify patella tracking relative to the femur and evaluate PFJ pain. The specific aims of this study are the following: 1) to develop and apply an MRI-based method for measuring patellar kinematics during closed-chain (loaded) dynamic, knee motion and PFJ cartilage deformation; 2) to develop and apply a method for assessing pain magnitude and mapping pain distribution around the patellofemoral joint; 3) to investigate the correlation between patellar tracking patterns, PFJ cartilage deformation and pain patterns in symptomatic patients and compare patella tracking patterns between symptomatic and asymptomatic patients.

## METHODS/RESULTS

### A. QUASIDYNAMIC MRI ANALYSIS OF THE PATELLOFEMORAL JOINT

A feasibility experiment was performed to obtain closed chain, quasidynamic MRI of the patellofemoral joint to assess three-dimensional patellar alignment and tracking *in-vivo*. A healthy 26-year-old female without a history of patellar subluxation or previous knee injury was tested using a 3.0 Tesla MRI scanner (Siemens, Iselin, NJ) and a custom designed patellar surface coil. Initially a reference MRI scan (0.286mm/pixel, 512x512) of the knee was obtained with the knee fully extended and relaxed. To allow MRI images of the knee to be obtained during simulated closed chain weight bearing through a range of knee flexion angles, the subject was placed in a commercially available, MRI compatible device for loading the spine (Dynawell, Billdal, Sweden) that was modified to allow resistive quadriceps force at preset knee flexion angles (Figure 1). The subject was instructed to push her feet against the footplates to generate an equivalent ground reaction force of approximately 35% body weight (20 lbs. each leg) while the knees were maintained at 15°, 30°, and 45° of flexion angles. At each knee flexion angle, axial and sagittal fast-spin echo proton density weighted images and axial fat suppressed 3 dimensional spoiled gradient echo images were obtained through the patellofemoral joint. Review of the MRI with the knee extended (Figure 2a) demonstrated a small effusion and evidence of signal changes within the lateral patellar facet cartilage consistent with early chondromalacia. The patella was symmetrically oriented with respect to the intercondylar sulcus with nearly equal joint contact along the medial and lateral middle patellar facets. The lateral patellofemoral angle was normal at 5° and the congruence angle was 12° [3,4]. The sulcus angle was increased at 155° on this view. However, the increased angle does not connote hypoplasia of the intercondylar sulcus but instead reflects that when the knee is extended the patella articulates with the proximal aspect of the intercondylar sulcus where the sulcus angle is shallower. (Indeed the image of the flexed knee at 30° (Figure 2b) illustrates that with increasing knee flexion the patella articulates more distally with the femur where the intercondylar sulcus is deeper (sulcus angle = 130°).

Figure 1:
The Dynawell compression device simulates standing conditions. MRI compatible knee braces lock the knee at a known angle.

The quasi-dynamic MRI images of the knee revealed information not evident on a standard MRI of the knee (Figure 2b). At 30° knee flexion, with a 20 lb. simulated ground reaction force there was now asymmetric contact between the patellar facets and the intercondylar sulcus of the femur as a consequence

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**Figure 2a (left)**
transaxial section through patellofemoral joint of extended knee. e = effusion, yellow lines indicate lateral patellofemoral angle = 5°. PFJ contact is symmetric

**Figure 2b (right)**
transaxial section through patellofemoral joint of loaded knee at 30° flexion. e = effusion, yellow lines indicate lateral patellofemoral angle = 0°. PFJ contact is asymmetric shifted laterally

of external rotation of the patella about its superior-inferior axis resulting in medial lift off and lateral tilt. This aberrant patellar movement was best measured by the lateral patellofemoral angle, which was now parallel. The congruence angle was also slightly increased at 15°. As patellofemoral joint contact migrated laterally, signal changes in the lateral patellar facet cartilage and the corresponding cartilage of the intercondylar sulcus were apparent. These unexpected findings in this "normal" volunteer might explain the etiology of her small effusion, occasional anterior knee pain and subtle findings on physical exam.

This experiment proved the feasibility of obtaining closed chain, quasidynamic MRI of the knee to assess three-dimensional patellar alignment *in-vivo*. Furthermore it demonstrates the additional insights that might be gained by relating aberrant patellar movement and asymmetric patellofemoral joint contact to early changes in cartilage integrity and patellofemoral joint pain.

### B. DEVELOPMENT OF MRI SHAPE-MATCHING TECHNIQUE FOR MEASURING PATELLAR MOVEMENT

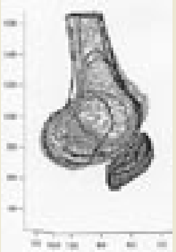

**Figure 3:**
Model femur and patella matched to the data from an MRI taken of the loaded knee

A cadaver knee was mounted in an MRI-compatible rig that allowed applied quadriceps loading at fixed knee flexion angles. One high-resolution (0.2734 mm in-plane 512 x 512, 1 mm thick contiguous slices) set of images was taken at a reference position, 0° flexion (Figure 3) and a high speed, low-resolution (0.625 mm in-plane, 4 mm thick contiguous slices) set of images was taken at 80° flexion. Segmenting the bone outlines on the MRI slices of the high-resolution scans and meshing the outlines using an interpolation routine generated geometric models of the patella, and femur (Figure 3). Bone outlines of the patella and femur were also identified in the low-resolution scans. A coordinate system consisting of proximal-distal, anterior-posterior and medial-lateral axes was identified in each bone [5] (Figure 4). The translation and rotation of the femoral and patellar coordinate systems for a specific knee flexion angle was found by applying the transformation matrix that related the 0° flexion reference position to the current flexed knee position. The transformation matrix was determined using a shape-matching algorithm.

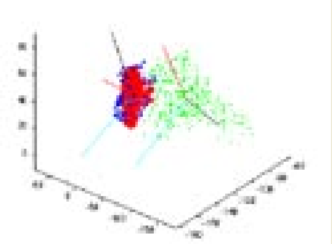

**Figure 4:**
Femur in green, Low-res. patella data in blue, Reference patella matched to low-res. patella in red, Knee joint at ~80°flexion, Patellar tilt = -2.47°, Patellar spin = 6.77°

## CURRENT WORK

Work is in progress to correlate surface tractions measured along the PFJ surface using a Tekscan thin film pressure transducer inserted into the PFJ to the deformation of the PFJ cartilage.

We are using a custom made, MRI compatible load frame that allows the Q-angle to be modulated by rotating the femur and tibia relative to the line of action of the Quadriceps tendon force, to load Veal cadaver knee joints. Quasi-dynamic loading of the PFJ is simulated by applying a 10 kg load to the quadriceps tendon over an array of fixed knee flexion angles from 90 to 120°. The thickness of the PFJ cartilage (given by the diameter of a circle tangent to both the superficial cartilage interface and subchondral bone contour) measured on high resolution MRI images of the PFJ will be mapped relative to bone surface contours of the patella and femoral condyles. The change in cartilage thickness between the loaded (10kg) and unloaded PFJ at each point along the bone surface will give the magnitude and distribution of cartilage deformation for each flexion angle. The profile of the magnitude of cartilage deformation calculated from changes in cartilage thickness under applied load for each knee flexion angle will be compared to the profile of surface tractions measured along the PFJ surface using a Tekscan thin film pressure transducer inserted into the PFJ. Further, the MR images obtained during these scans will be used to obtain patellar kinematics using the MRI shape-matching technique as outlined in section B of Methods/Results.

## DISCUSSION

A unifying theory explaining the relationships between tracking, compressive forces and pain in the patellofemoral joint does not yet exist. It seems clear that altering patellar-tracking mechanics can reduce pain. It also seems clear that decreasing joint reactive forces decreases pain. Whether the maltracking itself or the localized compressive forces from the maltracking are the primary problem remains to be learned. The following key limitations in our understanding of the relationship between patellofemoral tracking and anterior knee pain have been identified: 1) there is currently only one non-invasive MRI technique for measuring three-dimensional patellar tracking *in-vivo* and this technique has a number of limitations that may affect its sensitivity for measuring patellar tracking [6]; 2) the relationship between three-dimensional patellar kinematics and the development of anterior knee pain has not been established objectively; 3) the effect of surgery and physical therapy on altering three-dimensional patellar kinematics has not been quantified. Our study aims to address each of these limitations.

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