

# Patella Shape is Associated with Patellar Dislocation and Cartilage T1ρ Relaxation Times

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**INTRODUCTION:** A patellar dislocation is a traumatic event associated with pain, impaired function, and tissue injury including bone and cartilage. Although approximately 50% of patients experience progressive cartilage degradation and eventually develop patellofemoral osteoarthritis [1], little is known about the interaction between patella dislocations and cartilage degradation. As an initial step toward understanding the mechanisms that can lead to post-traumatic osteoarthritis after patellar dislocation, the current study investigated the structural shape features of patellar anatomy that contribute to patellar dislocations and cartilage degradation. Cartilage properties were characterized by MRI-based T1ρ relaxation times and patellar shape was characterized by modes of variation derived from a statistical shape model (SSM).

**METHODS:** With IRB approval, 19 subjects being treated for a single patellar dislocation (8 males, age =  $26.82 \pm 8.85$  years, BMI =  $27.82 \pm 6.76$  kg/m<sup>2</sup>, 11 females, age =  $18.44 \pm 4.8$  years, BMI =  $26.01 \pm 7.51$  kg/m<sup>2</sup>), 18 being treated for multiple dislocations (5 males, age =  $19.18 \pm 6.36$  years, BMI =  $22.6 \pm 4.16$  kg/m<sup>2</sup>, 13 females, age =  $20.49 \pm 6.88$  years, BMI =  $27.95 \pm 9.27$  kg/m<sup>2</sup>), and 19 healthy controls (10 males, age =  $20.69 \pm 7.79$  years, BMI =  $23.95 \pm 4.09$  kg/m<sup>2</sup>, 9 females, age =  $19.68 \pm 5.69$  years, BMI =  $23.68 \pm 2.24$  kg/m<sup>2</sup>) participated in this study. MRI sessions (Prisma, Siemens) included a 3D water excitation DESS scan for segmentation of the cartilage surfaces (slice thickness of 0.7 mm), a T1ρ relaxation time scan (fat saturated scan, slice thickness = 4 mm, spin lock times = 0, 10, 30, and 70 ms, spin-lock frequency = 500 Hz), and a 3D non-fat saturated SPACE scan to create a surface model of the patella. Images from the DESS scan were rigidly registered to the first echo of the T1ρ images, using piecewise rigid registration and T1ρ relaxation times were mapped to the patellar cartilage. Long T1ρ relaxation times indicate a low concentration of proteoglycans within cartilage [2]. For this study, T1ρ relaxation times were averaged across the entirety of the patella cartilage. Automated segmentations of the patella bones from the SPACE images were reconstructed and a template patella surface model was identified through an iterative process using the sum of registration errors to evaluate each candidate surface [3]. This template was then deformably registered to each patella reconstruction using the coherent point drift method to ensure a dense point correspondence across subjects [4]. Next a generalized Procrustes analysis was used to remove the size variations between subjects, and the resulting surface distribution was analyzed using principal component analysis (PCA) to create a SSM [5]. Orthonormal shape modes and PC scores, which represent the contribution of each mode to an individual's bone shape, were extracted from the SSM. PC scores from the first ten modes of variation were compared between the three groups (controls, single dislocations, and multiple dislocations) using an ANOVA and Student-Newman-Keuls tests to identify shape features associated with patellar dislocation. The PC scores were further correlated against T1ρ relaxation times for the control group using linear regression to identify shape features associated with cartilage degradation. The regression analysis focused on the control group to relate anatomy to cartilage properties in the absence of a traumatic injury and inflammatory response. Statistical significance was set at  $p < 0.05$ .

**RESULTS:** Significant ( $p < 0.05$ ) differences in PC scores between control and dislocation groups were found for shape modes 2 and 5 (Figure 1). The common feature related to dislocation for the two modes was a medially positioned patellar ridge (lower PC scores for both modes), creating a relatively long lateral patellar facet. The same modes were the only two significantly correlated with control group T1ρ values ( $r^2 > 0.25$ ), but in opposite directions (Figure 2). The primary characteristic associated long T1ρ relaxation times was a hooked lateral patella, which was identified for higher PC scores for mode 5 and lower PC scores for mode 2.

**DISCUSSION:** Two features of the patella were identified that place a knee at risk of patellar dislocation and cartilage degradation. A medially positioned patellar ridge creates the risk of patellar dislocation and a hooked patella creates the risk of patellar cartilage degradation. A medially positioned ridge indicates patellofemoral contact is concentrated along the lateral facet with limited articular constraints applied by the trochlear groove in the contact region. A hooked patella indicates patellofemoral compression acting on the lateral facet which causes the patella to adaptively wrap around the femoral condyle. By focusing on cartilage properties of the control group, the study isolated a biomechanical mechanism of cartilage degradation, separate from the response to trauma that can dominate the acute phase of injury.

**SIGNIFICANCE/CLINICAL RELEVANCE:** These parameters of patellar anatomy, related to patellar dislocation and cartilage degradation, can be used to assess the risk of a patient experiencing a first or sequential patellar dislocation, and the risk of dislocation leading to progressive cartilage degradation. Further understanding of the biomechanical mechanisms related to anatomy could help develop strategies to stabilize the patella and preserve cartilage.

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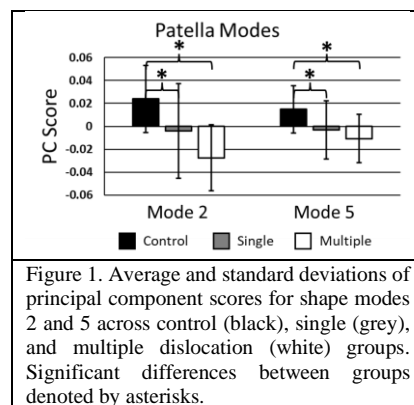


Figure 1. Average and standard deviations of principal component scores for shape modes 2 and 5 across control (black), single (grey), and multiple dislocation (white) groups. Significant differences between groups denoted by asterisks.

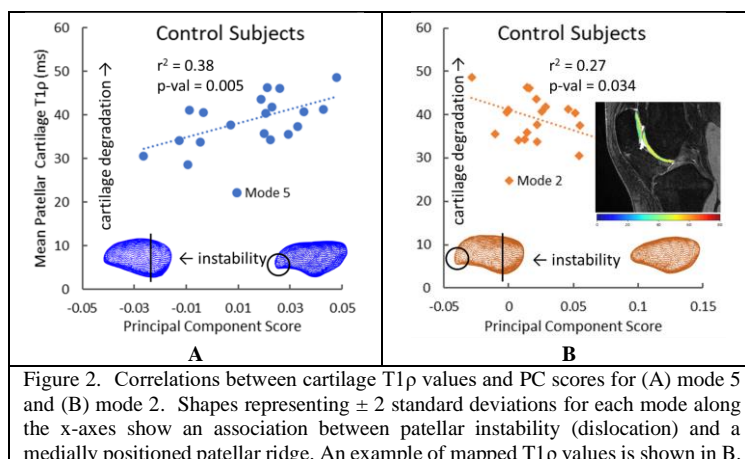


Figure 2. Correlations between cartilage T1ρ values and PC scores for (A) mode 5 and (B) mode 2. Shapes representing  $\pm 2$  standard deviations for each mode along the x-axes show an association between patellar instability (dislocation) and a medially positioned patellar ridge. An example of mapped T1ρ values is shown in B.