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Patellofemoral Friction Syndrome: MRI correlation of morphologic and T2 cartilage imaging

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Abstract

OBJECTIVE—To investigate whether patellofemoral T2 cartilage changes are associated with lateral patellofemoral friction syndrome (PFS), as indicated by edema-like signal within the superolateral infrapatellar (Hoffa) fat pad.

METHODS—In this IRB-approved retrospective study of 510 consecutive patients, 49 patients with 50 knee MR imaging exams demonstrating normal or low-grade patellofemoral cartilage abnormalities (WORMS score ≥ 2) were included. 22 exams with PFS (cases) were compared with an age- and gender-matched cohort of 28 exams without PFS (controls). 3T MR imaging was performed with multi-echo, spin echo T2 mapping. Two readers measured in consensus malalignment parameters, including patellar height index, tibial tuberosity to trochlear groove distance (TT-TG), and sulcus angle. Bulk T2 cartilage values in the lateral and medial patellofemoral compartment, central weight-bearing medial and lateral femoral condyles were measured independently. Interobserver agreement was quantified using concordance correlation coefficients (CCC). Demographics, anatomic measurements, WORMS scores, and cartilage T2 values were compared between cases and controls using Fisher's exact test, Wilcoxon rank-sum, and mixed effects models.

RESULTS—Cases demonstrated higher patellar height index ($p=0.002$) and TT-TG ($p=0.02$). Interobserver agreement for T2 values was good overall (CCC range: 0.65–0.93). Cases

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demonstrated higher medial facet patellar bulk T2 (38.1 ± 7.5 ms) versus controls (33.6 ± 7.3 ms) ($p=0.02$); otherwise there were no significant differences in regional T2 values.

CONCLUSION—T2 mapping in patients with PFS demonstrates increased cartilage T2 in the medial patellar facet, possibly reflecting collagen alteration from early chondromalacia (softening) or increased water content related to altered contact pressures.

Keywords

cartilage; patellofemoral friction syndrome; patellar malalignment; T2 mapping

Introduction

Patellofemoral disorders are among the most frequent causes of anterior knee pain, and may in many cases be related to an underlying patellar tracking abnormality or patellofemoral impingement related to malalignment (1, 2). Chung et al, have previously described edema in the superolateral portion of the infrapatellar fat pad as a secondary sign of the patellar tendon-lateral femoral condyle friction syndrome (PFS) (3). This finding is increasingly recognized as a marker of patellofemoral malalignment and maltracking (4–6).

Because normal patellar alignment in relation to the trochlear groove has important implications for proper load bearing (7, 8), improper alignment or tracking are hypothesized to lead to chondromalacia, chondrosis, early osteoarthritis, synovial proliferation, subchondral bony changes, and fat pad impingement, all of which can cause pain, and eventually joint degeneration (9–11). Regional quantification of the transverse relaxation time constant (T2 mapping) offers a sensitive imaging method for early detection of changes in collagen anisotropy and hydration status (12). Recent results have suggested that T2 maps are more sensitive than standard morphological sequences for detecting early cartilage lesions (13, 14), and that elevated T2 values specifically in the patella may be a marker for increased risk of subsequent development of morphologic cartilage lesions (15–18).

Since superolateral Hoffa's fat pad edema is a frequent finding in patellar malalignment and maltracking, we hypothesized that higher T2 values in the patellar cartilage would be associated with MR imaging findings seen in PFS.

Materials and Methods

Subjects

With approval of the Institutional Review Board, the records of 510 consecutive patients referred for MRI for knee pain at a single institution over an 18-month period were reviewed retrospectively. Because the focus of this study was on biochemical changes preceding morphologic abnormalities, analysis was restricted to younger patients between the ages of 18–50 with normal or low-grade morphologic patellofemoral cartilage abnormalities (described below). Patients with high grade patellofemoral cartilage abnormalities were excluded because of technical difficulty measuring T2 values when little cartilage is present. Patients with a clinical history of trauma or prior surgery, or major internal derangement such as an anterior cruciate ligament tear, were excluded as such factors can influence the

presence of edema or abnormal signal in Hoffa's fat pad (19). A total of 21 patients (8 men, 13 women) with 22 knee MR imaging exams demonstrated PFS and met inclusion criteria, comprising the case group; an age and gender-matched cohort of 28 patients (17 men, 11 women) without evidence of PFS comprised the control group.

Morphologic Imaging

3T MR imaging (Siemens Verio, Erlangen, Germany) of the knees was performed using intermediate-weighted images with and without fat saturation (TR/TE 3000–3100/27–35) in the axial, sagittal, and coronal planes. The presence of superolateral Hoffa fat pad edema (a marker for PFS) was determined in consensus by two readers (TKS and RST, each with 1 year of musculoskeletal imaging experience) based on the presence of increased signal intensity on both sagittal and axial fat saturated intermediate-weighted sequences (axial TR/TE 3100/35 ms, sagittal TR/TE 3000/37 ms). The patellar tendon:patellar length ratio (PTPL, Insall-Salvati ratio) was calculated on sagittal intermediate weighted imaging (TR/TE 3000/27 ms); trochlear sulcus angle and tibial tuberosity to trochlear groove distance were measured on the axial fat suppressed sequence according to the previously described methods by one reader (RST) (4).

Morphologic cartilage assessment was based on an 8-point scale adopted from the Whole-Organ Magnetic Resonance Imaging Score (WORMS) (20) for cartilage, and was evaluated in consensus (TKS and RST). The WORMS scoring system incorporates 14 features (e.g. articular cartilage integrity, subarticular bone marrow abnormality, marginal osteophytes, synovitis/effusion, etc.)—because complete scoring is laborious and this study focused solely on patients with low grade cartilage abnormalities, only the articular cartilage integrity was assessed. Briefly, cartilage was scored as follows: 0=normal thickness and signal; 1=normal thickness but increased signal on T2-weighted images; 2.0=partial-thickness focal defect <1 cm in greatest width; 2.5=full-thickness focal defect <1 cm in greatest width; 3=multiple areas of partial-thickness (Grade 2.0) defects intermixed with areas of normal thickness, or a Grade 2.0 defect wider than 1 cm but <75% of the region; 4=diffuse (<75% of the region) partial-thickness loss; 5=multiple areas of full-thickness loss (grade 2.5) or a grade 2.5 lesion wider than 1 cm but <75% of the region; 6=diffuse (<75% of the region) full-thickness loss.

Morphological assessment was carried out in the lateral and medial patellar facets, lateral and medial trochlear facets, and central medial and lateral femoral condyles. Only patients with cartilage WORMS scores ≤2 in the patellofemoral compartment were included in the study. As defined by Peterfy et al, anatomical borders for the anterior (trochlea) and central portions of the femur were defined by anterior and posterior margins of the meniscus; the medial border of the lateral condyle on an axial image demarcates the lateral and medial trochlea; finally, the patellar median ridge defines the medial and lateral facets, with the ridge itself considered part of the medial facet (20).

T2 Mapping

T2 maps were constructed using multi-echo, spin echo sagittal T2 acquisitions with varying TEs (TR = 1650 ms, TE = 12.9, 25.8, 38.7, 51.6, 64.5, and 77.4 ms). In-line software (*syngo*

MapIt, Siemens, Erlangen Germany) was used for parametric analysis that calculates T2 relaxation times on a linear fit applied to the logarithm of signal intensity decay. Colored T2 maps were generated after manual segmentation of the cartilage on the MRI series with TE = 12.9 from the multi-echo T2 acquisition, and the segmentation was applied to the corresponding T2 relaxation time map. Segmentation was performed in the sagittal plane for all measurements, with one representative slice through each region chosen for analysis. Two readers (TKS and RST) independently measured bulk cartilage T2 maps in the lateral and medial patellar facets, lateral and medial trochlear facets, and central weight bearing medial and lateral femoral condyles (5 medial femur measurements were excluded because of higher grade (grade 5) cartilage defects, precluding T2 analysis).

Statistics

Demographic differences in age and sex were compared using Wilcoxon rank-sum and Fisher's exact test, respectively. Differences in anatomic measurements were compared using Wilcoxon rank-sum. Interobserver variability in T2 measurements was quantified using the concordance correlation coefficient (CCC), which reflects inter-rater agreement by examining the extent to which pairs of observations fall along the 45° line (21). By convention, CCCs of 0.81–1.00 indicate excellent agreement; CCCs of 0.61–0.80, substantial agreement; CCCs of 0.41–0.60, moderate agreement, CCCs of 0.21–0.40, fair agreement; and CCCs of 0–0.20, slight to poor agreement (22). Differences in T2 values were compared between cases and controls using mixed effects models with a random intercept for patients to account for the correlation between readings from the same patient. Multiple regression and Pearson's correlation were used to determine associations between anatomic measurements and T2 values. Differences were considered significant at the $\alpha = 0.05$ significance level. The statistical analysis was performed using Stata 11.1 (StataCorp, College Station, TX).

Results

Demographic and anatomical data are summarized in Table 1. Cases and controls were demographically similar in terms of age and gender. Anatomic measurements of the patellofemoral joint showed increased patellar height indices, increased tibial tuberosity to trochlear groove distance, and a trend toward increased sulcus angle among patients with PFS.

Despite restricting inclusion criteria to normal or low-grade cartilage abnormalities, cases demonstrated higher cartilage WOMS scores in the lateral trochlear facet, central medial femur, and central lateral femur (Table 2). Scores were not statistically different in the medial patellar, lateral patellar, or medial trochlear facets between cases and controls.

For T2 mapping, bulk average T2 relaxation times of cartilage in the medial and lateral patella, medial and lateral trochlea, and central aspects of the medial and lateral femoral condyles are summarized in Table 3. Patients with evidence of PFS demonstrated higher cartilage T2 values in the medial patellar facet than those patients without evidence of PFS (38.1 vs 33.6 ms, $p = 0.02$). Figure 1 shows the T2 map of the patellofemoral cartilage of a patient without PFS; in contrast, Figure 2 shows an example of a patient with PFS and

elevated T2 values in the medial patellar facet. Other regions measured demonstrated no statistically significant difference in cartilage T2 values between groups. The concordance correlation coefficient was lowest in the medial femoral condyle (CCC = 0.65), but otherwise correlation coefficients were excellent (Table 3).

Next, multiple linear regression analysis was carried out to examine how anatomic measurements were associated with T2 values in the medial patellar cartilage. Of the variables measured (PTPL ratio, TT-TG, and sulcus angle), only PTPL ratio was associated with significantly higher T2 values in the medial patellar facet ($p = 0.03$). Pearson's r for this correlation was moderate ($r = 0.31$).

Discussion

Elucidating the precise biomechanical and pathophysiologic mechanisms responsible for pain in patients with patellofemoral disorders is complicated by the complexity of the joint and the variety of factors, both static and dynamic, which contribute to stability. Abnormalities in factors such as bony alignment, joint geometry, soft tissue restraints, neuromuscular control, and excessive functional demands may combine to overwhelm the physiologic tolerance of the joint tissues (23). Anatomy associated with patellofemoral malalignment, particularly patella alta, may increase the risk for cartilage damage in the lateral patellofemoral joint (24, 25), presumably on the basis of resultant abnormal contact area and contact pressure (26). However, there is growing interest in detecting patients at risk for patellofemoral cartilage damage before morphological changes become apparent on conventional MRI in the hopes of offering earlier therapeutic interventions that could maintain cartilage and joint integrity.

T2 mapping has emerged as one of several biochemical imaging techniques for cartilage, and in particular exploits early alterations in the collagen organization and tissue anisotropy that lead to increased water mobility and hence, increased T2 values (25, 27). Recent studies have shown increase in T2 values in the tibiofemoral cartilage in patients with OA (28, 29), and higher T2 values in longitudinal cohorts associated with progression of morphologic cartilage abnormalities (30). Increase in patellar cartilage T2 values has also been suggested to reflect early damage not yet identifiable by conventional MRI (17, 18) and in those patients at risk for developing osteoarthritis (16, 31). However, a recent study of asymptomatic patients showed that patellar cartilage T2 relaxation times in subjects with OA risk factors did not significantly differ from subjects without OA risk factors over 2 year follow-up (32).

Our results show that patients with superolateral Hoffa's fat pad edema in a pattern consistent with lateral patellofemoral friction syndrome exhibit quantitatively higher T2 relaxation values in the medial patellar facet. The difference in T2 relaxation values in the medial patella exist without significant morphological cartilage differences in this group of patients with normal or only low grade cartilage abnormalities. Of the anatomic measurements, the patellar height index is most strongly associated with elevated T2 values.

Although focal areas of increased T2 values have been observed in previous studies of patellar cartilage (18), we believe this is the first investigation that attempts to correlate potential patellofemoral malalignment with quantitative T2 differences in discrete regions of the joint. It has been suggested that a mechanical etiology for pain in patients with patellofemoral maltracking results from increased stress transmitted through cartilage to nociceptors in the underlying subchondral bone (9). Consistent with this theory are observations that patients with patellofemoral pain exhibit a baseline reduction in patellar cartilage thickness, and a reduced capacity to mechanically absorb loading stresses after exercise; however, no differences in T2 relaxation values were found between patients with and without patellofemoral pain (24). We hypothesized such increased stress would manifest as increased T2 signal in the patellofemoral compartment, given that T2 mapping techniques are sensitive to changes in tissue anisotropy that reflect effects of compressive forces (33, 34). While we expected higher values in the lateral aspect of the patellofemoral joint to be associated with patients exhibiting signs of PFS, other investigators have found that deformational changes are greatest in the medial patellar facet after load-bearing exercise in normal subjects (35). This observation raises the possibility that T2 values in the medial patellar facet are higher in patients with PFS because of increased water content as a result of decreased loading stresses relative to those patients without PFS.

This study has several limitations, including its retrospective nature and inability to blind readers to the presence of superolateral Hoffa's fat pad edema while performing WORMS assessment and segmentation of T2 maps. Additionally, subjects without Hoffa's fat pad edema in the comparison group were not true controls, in that their exams were also performed for knee pain. Because many of these patients were referred for MRI from primary care clinics or physicians outside our institution, it was difficult to determine from the available clinical records precise nature of the knee pain that resulted in the MRI request. It is certainly possible that a subgroup of these patients had underlying abnormalities in patellofemoral tracking which were not radiologically manifested. Thus, the difference in patellar cartilage T2 values between patients with PFS and truly asymptomatic controls may be larger than that observed in this patient cohort.

T2 cartilage segmentation is a time-consuming process; in this preliminary study, we restricted segmentation on T2 maps to a single representative slice for each compartment. In future studies full segmentation across each anatomic compartment should be performed so that the mean T2 value more completely reflects the state of cartilage in that compartment. Finally, we were limited to identifying patients with patellofemoral maltracking/impingement based on secondary static MRI findings of PFS, and were unable to discriminate between anterior knee pain and generalized knee pain in the majority of clinical records we reviewed. MRI findings do not necessarily predict the severity of patient symptoms (36), and patellar malalignment does not consistently result in patellofemoral pain or cartilage damage (37, 38). However, dynamic/kinematic imaging studies have shown that patellofemoral tracking is altered in a subset of patients with anterior knee pain (39). Whether and how T2 cartilage changes are associated with dynamic abnormalities is unknown.

In conclusion, our results support the hypothesis that early patellofemoral cartilage damage occurs in patients with patellofemoral friction syndrome. Specifically, patients with PFS demonstrated higher T2 values in the medial patellar facet. Future studies should be correlated with clinical findings or with dynamic-kinematic imaging for maltracking, and validated with longitudinal cohorts.

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Fig. 1.
38-year-old man with knee pain. T2 mapping of the medial patellar cartilage shows relatively low bulk T2 value (27.1 ms).

Fig. 2. 26-year-old woman with knee pain. Axial proton-density weighted images with fat suppression (TR/TE 3100/35 ms) demonstrate A) edema in the superolateral aspect of Hoffa's fat pad (arrow), indicative of patellofemoral friction syndrome (PFS), and B) morphologically normal cartilage in the patella. C) T2 mapping of the medial patellar facet shows elevated bulk T2 (39.1 ms) compared to patients without PFS.

Table 1

Demographic data and morphological measurements in cases and controls

	Age (years)	# female	PTPL ratio	TT-TG (mm)	Sulcus Angle (degrees)
Controls	31.0 ± 10.2	11/28 (39%)	1.16 ± 0.13	11 ± 3	134 ± 7
Cases	33.9 ± 12.8	13/21 (62%)	1.30 ± 0.12	13 ± 3	138 ± 9
p-value	0.62	0.15	0.002	0.02	0.07

PTPL ratio: patellar tendon to patellar length ratio (Insall-Salvati method), TT-TG: tibial tuberosity to trochlear groove distance.

Values expressed as mean ± standard deviation

Comparison p-value for Wilcoxon rank-sum (age, PTPL ratio, TT-TG, and sulcus angle) and Fisher exact test (gender).

Table 2

Whole-Organ Magnetic Resonance Imaging Score (WORMS)

	MP	LP	MFa	LFa	MFc	LFc
Controls	0.25 ± 0.56	0.36 ± 0.68	0.09 ± 0.47	0 ± 0	0.25 ± 1.0	0 ± 0
Cases	0.5 ± 0.67	0.41 ± 0.67	0.14 ± 0.35	0.14 ± 0.35	1.57 ± 2.07	0.68 ± 1.20
p-value	0.09	0.66	0.22	0.05	0.002	0.003

MP: medial patella, LP: lateral patella, MFa: medial femur anterior (medial trochlea), LFa: lateral femur anterior (lateral trochlea), MFc: medial femur central, LFc: lateral femur central.
Values expressed as mean + std deviation for that region, which was determined in consensus.
Comparison p-value for Wilcoxon rank-sum.

Table 3

T2 values in cases and controls by cartilage region.

	MP	LP	MFa	LFa	MFc	LFc
Controls	33.6 ± 7.3	38.7 ± 8.8	51.1 ± 11.6	49.4 ± 8.7	40.8 ± 6.0	44.8 ± 6.6
Cases	38.1 ± 7.5	38.9 ± 8.6	44.9 ± 9.4	52.1 ± 10.2	46.0 ± 14.2	47.4 ± 8.9
p-value	0.02	0.88	0.06	0.24	0.08	0.26
CCC	0.84	0.86	0.93	0.87	0.65	0.80

MP: medial patella, LP: lateral patella, MFa: medial femur anterior (medial trochlea), LFa: lateral femur anterior (lateral trochlea), MFc: medial femur central, LFc: lateral femur central.

Comparison p-value for Wilcoxon rank-sum. CCC: concordance correlation coefficient.

T2 values expressed in ms, mean ± standard deviation.