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Exercise-Induced Changes in Femoral Cartilage Thickness in Patients With Patellofemoral Pain

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Context: Rehabilitative exercises alleviate pain in patients with patellofemoral pain (PFP); however, no researchers have analyzed the cartilage response after a bout of those athletic activities in patients with PFP.

Objective: To determine if a single session of rehabilitative exercises alters femoral cartilage morphology.

Design: Crossover study.

Setting: Research laboratory.

Patients or Other Participants: Twelve participants with PFP (age = 21.0 ± 2.0 years, height = 1.72 ± 0.1 m, mass = 68.7 ± 12.6 kg) and 12 matched healthy participants (age = 21.3 ± 2.8 years, height = 1.71 ± 0.1 m, mass = 65.9 ± 12.2 kg) were enrolled.

Intervention(s): Participants completed treadmill running, lower extremity strengthening exercises, and plyometric exercises for 30 minutes each.

Main Outcome Measure(s): Patient-reported outcomes on the visual analog scale, Anterior Knee Pain Scale (AKPS), Knee injury and Osteoarthritis Outcome Score (KOOS), and Knee Injury and Osteoarthritis Outcome Score for Patellofemoral Pain and Osteoarthritis were collected. Femoral cartilage ultrasonographic images were obtained at 140° of knee flexion. Ultrasound images were segmented into medial and lateral images using the intercondylar notch. Medial and lateral cartilage cross-sectional area (mm^2) and *echo intensity* (EI), defined as the average grayscale from 0 to 255, were analyzed by ImageJ software. The difference between loading conditions was calculated using repeated-measures analysis of variance. The Spearman correlation was calculated to find the association between the cartilage percentage change (Δ%) and patient-reported outcomes.

Results: Pain increased in the PFP group after all loading conditions (P values $< .007$). No differences were found in cartilage cross-sectional area or EI alteration between or within groups (P values $> .06$). The KOOS was negatively associated with the Δ% of the lateral femoral cartilage EI after plyometric loading ($\rho = -0.87$, $P = .001$), and the AKPS score was positively correlated with the Δ% of lateral femoral cartilage EI ($\rho = 0.57$, $P = .05$).

Conclusions: Ultrasound imaging did not identify cartilaginous deformation after all loading conditions. However, because lateral cartilaginous EI changes were associated with the AKPS and KOOS score, those questionnaires may be useful for monitoring changes in femoral cartilage health.

Key Words: anterior knee pain, diagnostic ultrasound, patient-reported outcomes

Key Points

- Patients with patellofemoral pain did not show altered cross-sectional area or echo intensity (EI) of femoral cartilage compared with healthy individuals at baseline.
- Lateral femoral cartilage EI decreased after the loading conditions, and the Δ% of lateral femoral EI was correlated with the Knee injury and Osteoarthritis Outcome Score and Anterior Knee Pain Scale score.
- The Knee injury and Osteoarthritis Outcome Score and Anterior Knee Pain Scale score may be useful for monitoring early changes in femoral cartilage health among individuals with patellofemoral pain.

Patellofemoral pain (PFP) is a prevalent lower extremity disorder often observed in physically active individuals.[1] Although PFP frequently arises during adolescence, it is a lifelong condition for many patients.[2] Unfortunately, prolonged symptoms of PFP may contribute to the development of patellofemoral osteoarthritis (PFOA), increasing the health care burden for affected people.[3] Individuals with PFOA experience joint deformation and increased pain on joint compression that occurs with knee flexion.[4] Symptomatic PFOA may also contribute to the development of tibiofemoral osteoarthritis (TFOA), which indicates an urgent need for the early diagnosis and management of PFP to mitigate the knee joint osteoarthritis risk.[5]

Patients with PFP experience peripatellar pain or retropatellar pain (or both) during activities such as squatting, running, and jumping,[6] which often leads to the reduction or cessation of physical activity participation.[7] The aforementioned activities are known to be beneficial to overall health but can increase stress on the patellofemoral joint, especially in individuals with PFP.[8] During closed kinetic chain activities such as running or jumping, the femoral cartilaginous surface glides behind the patella, thereby interrelating the femoral and patellar cartilage. In PFP, patellofemoral cartilage loading increases or decreas-

es, ultimately leading to reduced deformative behavior of patellofemoral cartilages.[8,9] This increased patellofemoral joint stress during weight-bearing exercises is similar to that observed in individuals with PFOA, suggesting a possible continuum from PFP to PFOA.[10]

The current standard for diagnosing osteoarthritis is plain radiography to examine the joint space width and presence of osteophytes. In addition to these measures, cartilage health can be assessed through thickness measures using magnetic resonance imaging (MRI). Although useful, MRI is a costly alternative to radiographs. Diagnostic ultrasound (US) may provide a valid,[11] cost-effective alternative to MRI. Furthermore, diagnostic US provides a real-time image that may aid in the assessment of femoral cartilage thickness, a benefit that MRI does not offer.

The measurement of cartilage thickness is important for the diagnosis and progression of osteoarthritis, yet early-stage osteoarthritis shows cartilage compositional changes before the loss of cartilage thickness.[12] Cartilage undergoes remodeling throughout life, but the ability of osteoarthritic cartilage to regenerate is compromised due to its reduced extracellular matrix quality combined with a quick turnover rate.[13,14] Radiographs cannot detect these biochemical alterations in the cartilage; MRI can but at a high cost to the health care system.[15] Similar to its ability to provide cost-effective cartilage thickness measures, diagnostic US can detect alterations in cartilage composition. Diagnostic US can be used to measure *echo intensity* (EI), which quantifies the amount of water present in the articular cartilage, as determined by the brightness of the image.[16] A hypoechoic (dark) zone is often found in early osteoarthritic cartilage, indicating an altered echotexture and increased water content in the cartilage.[17]

Researchers[19] have suggested that the femoral cartilage is significantly deformed after joint loading on MRI[18] and diagnostic US in healthy individuals. Despite the possible link between PFP and both PFOA and TFOA, not many authors have studied the deformative characteristics of femoral cartilage in patients with PFP. Therefore, our purpose was to quantify the deformative behavior of femoral cartilage after different movements. We additionally sought to determine the association between the percentage change (Δ%) in femoral cartilage cross-sectional area (CSA) and EI alteration after loading conditions with patient-reported outcomes (PROs) and pain. We hypothesized that individuals with PFP would show less Δ% in femoral cartilage than people without pain after loading conditions. We also hypothesized that the Δ% of quantitative US measures would be associated with PROs and pain.

METHODS

Before the study, the protocol was approved by the institutional review board at the University of North Carolina at Charlotte (IRB 17-0548). We used G*Power software (version 3.1.9.3; Kiel University) and the results of a previous investigation[19] to determine the number of participants required to detect changes in femoral cartilage thickness after knee joint loading physical activities. Using parameters $\alpha = .05$ and $1 - \beta = 0.8$ with a moderate effect size ($d = 0.5$), we found that 8 participants per group would be necessary to adequately power this study. To account for potential participant dropouts, we enrolled 12 participants per group.

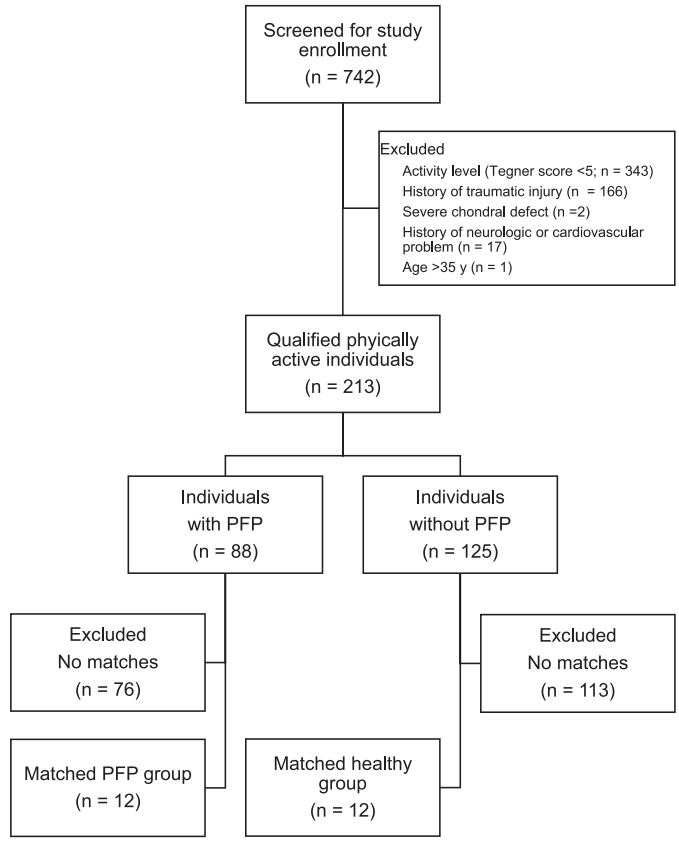

Figure 1. Consolidated Standards of Reporting Trials (CONSORT) flow chart. Abbreviation: PFP, patellofemoral pain.

Participants

A total of 24 individuals (n = 12 with PFP, n = 12 healthy) between the ages of 18 and 35 years were recruited from the university campus via flyers and campus-wide email in January 2018. All participants were *physically active*, defined as performing activities that are included in the Tegner Activity Scale of ≥5 for at least 30 minutes on ≥3 days per week. Recruits were excluded if they had a (1) severe osteochondral defect in either knee; (2) history of cardiovascular, neurologic, or balance disorder that precluded safe participation in exercise; or (3) body mass index of >40 kg/m^2. Furthermore, healthy participants were not permitted to have a history of orthopaedic injuries or surgeries (including fractures or other conditions necessitating medical intervention or limiting engagement in physical activity for >1 day) to either limb or the low back. Patients with PFP similarly could not have a history of orthopaedic injury or surgery other than that related to their PFP.

Patients with PFP were required to have (1) retropatellar pain during at least 2 of the following activities: prolonged sitting, stair ascent or descent, squatting, hopping, kneeling, running, and jumping; (2) pain with compression of the patella; and (3) pain on palpation of the patellar facets.[20] Twelve participants with PFP were enrolled, and 12 matched healthy individuals were enrolled after the screening procedure (Figure 1). Participants were matched based on age (±3 years), Tegner Activity Scale score (±1), and body mass index (±5%). All participants provided written informed consent before enrollment.

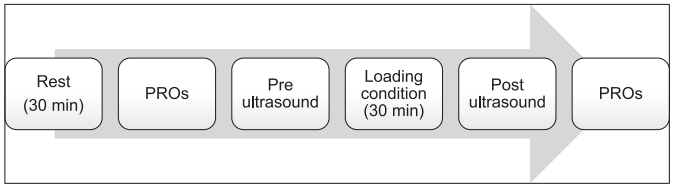

Figure 2. Testing overview. Loading conditions = running, strength training, or plyometrics. Abbreviation: PROs, patient-reported outcomes.

Patient-Reported Outcomes

The Anterior Knee Pain Scale (AKPS), Knee injury and Osteoarthritis Outcome Score (KOOS), and Knee injury and Osteoarthritis Outcome Score for Patellofemoral Pain and Osteoarthritis (KOOS-PF) were used to quantify self-reported symptoms and perceived knee function. The AKPS is considered a criterion standard for evaluating the severity of PFP, and it is a valid and reliable 13-question survey scored 0 to 100, with lower scores indicating worse symptoms and function.[21] The KOOS contains 5 subscales related to pain, symptoms, function during daily living and sports, and quality of life specifically for those who are at risk of posttraumatic osteoarthritis. It is scored 0 to 100, with lower scores indicating worse symptoms and dysfunction.[22] The KOOS-PF is the most recently designed responsive questionnaire specifically aimed at assessing the function of individuals affected with PFP and osteoarthritis.[23] To test participants' pain level, we used the visual analog scale: the individual selects a value on a 10-cm straight-line continuous scale that indicates the severity of pain. All PROs were completed at each session.

Overview of Testing Procedure

Testing Protocol. Participants reported to the research laboratory on 3 occasions and completed 1 exercise condition on each occasion. Each session was conducted at the same time of day, and sessions were separated by 1 week. All sessions began with the participant sitting on a treatment table with the knees fully extended for 30 minutes to mitigate the cartilage compression that occurred while walking to the laboratory.[19] The PROs were collected at the end of the cartilage decompression and at the end of the testing session (Figure 2). The order of conditions was randomized for all participants by means of a randomization table generated before the start of the study.

Ultrasound Imaging of the Femoral Articular Cartilage. Identical procedures were performed before and after the various loading conditions. Participants sat on a treatment table with their back against a wall and the test knee flexed to 140°. A LOGIQe US system (General Electric Co) with a 12-MHz linear probe was used to collect a femoral cartilage image. The machine is calibrated annually by an independent technician who specializes in diagnostic and therapeutic modality calibration, safety, and maintenance.

A clear paper with a 1-cm grid was placed on the US screen to center the intercondylar notch for consistency. Three images were collected per collecting time point (preloading and postloading). The depth was set to 2.5 cm, and gain was fixed at 34 for reproducibility. The US probe was placed transversely in line with the femoral condyles above the superior pole of the patella, as previously reported.[19] A transparent grid was secured to the computer screen to improve reproducibility. The center of the transparent grid was matched to the midline of the monitor, and the intercondylar notch was centered using the grid.

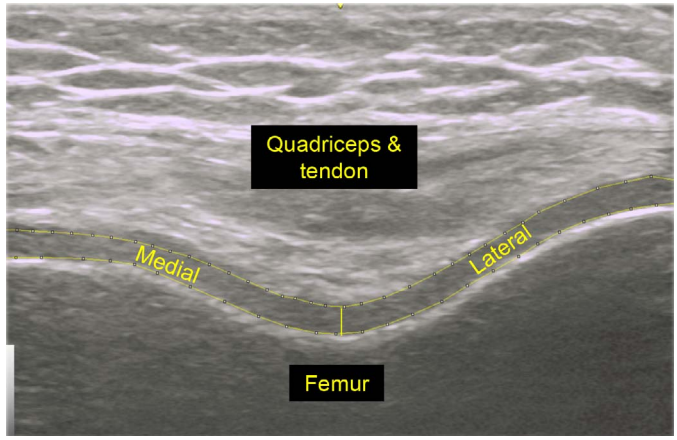

Figure 3. Femoral cartilage cross-sectional area. Medial and lateral cartilage are separated by the intercondylar notch.

Loading Conditions. Participants performed the assigned loading condition immediately after the pre-US imaging. They were allowed to stretch before the loading conditions, which consisted of strengthening exercises, plyometric exercises, and treadmill running (Supplemental Figure 1). All loading conditions were designed to be completed within 30 minutes. For strength training, individuals performed a series of exercises designed to mimic a rehabilitation session for patients with PFP. They included body weight squats, step-downs, and similar weight-bearing exercises to improve lower extremity muscle strength.[24] The plyometric exercise loading condition involved single- and double-legged landings and drop vertical jumps, mimicking the explosive exercises that may provoke PFP symptoms. Lastly, participants jogged on a treadmill for 30 minutes at a self-selected comfortable jogging speed that they could sustain for 30 minutes.

Femoral Articular Cartilage Image Analysis

All US images were processed using ImageJ software (version 1.52a; National Institutes of Health). Before data collection, we tested reliability. Three knee cartilage images were collected from 6 volunteers using identical procedures to the current study. Reliability images were captured on 2 occasions separated by 5 days. Intraclass correlations (ICCs) determined using a 2-way random-effects model with 95% CIs for CSA and EI were excellent ($ICC_{CSA} = 0.98$ [0.85, 0.99]; $ICC_{EI} = 0.96$ [0.72, 0.99]).

Femoral cartilage was manually divided into medial and lateral sections according to the intercondylar notch, which is the deepest point of the cartilage surface, and each section's CSA was measured (Figure 3).[25] For the lateral compartment in Figure 3, for example, the cartilage borders were traced laterally from the intercondylar notch to the edge of the image along the femur. Tracing continued along the edge of the image superiorly to the quadriceps and tendon and then medially to return to the intercondylar notch. Furthermore, the average water content level within

Table 1. Descriptive Characteristics of the Study Population at Baseline

Characteristic	Group, Mean ± SD		*t* Value	*P* Value
	Patellofemoral Pain	Healthy		
Age, y	21.0 ± 2.0	21.3 ± 2.8	0.25	.80
Height, m	1.72 ± 0.1	1.71 ± 0.1	0.09	.92
Mass, kg	68.7 ± 12.6	65.9 ± 12.2	0.53	.60
Symptom duration, mo[a]	54.0 ± 34.7			

[a] Statistically significant difference ($P < .05$).

each of the medial and lateral sections was measured by mean *EI*,[26] which is defined as the average grayscale from 0 to 255. A lower EI appears darker and indicates greater water content within the region of interest.[27] The regions of interest for quantifying EI were the same as those for quantifying CSA. Three images per time point (preloading and postloading) and loading condition (strength exercise, plyometric exercise, and jogging) were obtained, and the CSA and EI values were averaged for each time point and loading condition for statistical analysis. We calculated the Δ% from baseline to postloading to determine the alteration of the cartilage segment using the following equation:

$$\text{Percentage } (\Delta) = \left(\frac{\text{Mean}_{\text{post}} - \text{Mean}_{\text{pre}}}{\text{Mean}_{\text{pre}}}\right) \times 100$$

Statistical Analysis. Mann-Whitney U tests were used to compare the mean ranks of the pain and PRO differences between groups. The difference scores for the Mann-Whitney U tests were computed by subtracting the premeasure values from the postmeasure values to represent within-session changes. We chose the Mann-Whitney U test because pain and PROs were categorical values. We used the 2-way repeated-measures of analysis of variance for cartilage CSA and EI and determined the effect of time (before and after), different preloading conditions (strength exercise, plyometric exercise, and jogging), and a time × group interaction. In the presence of significant interactions, the Tukey post hoc analysis was applied. The Cohen d effect size and associated 95% CIs were calculated to quantify the magnitude of change in cartilage alterations and PROs (<0.2, *weak*; 0.21–0.5, *small*; 0.51–0.8, *medium*; and >0.8, *large*). Lastly, Spearman ρ correlation analysis was performed to determine the association between the Δ% of cartilage CSA and EI and changes in PROs. Statistical significance was set a priori at $\alpha < .05$, and all statistical procedures were carried out using SPSS (version 26; IBM Corp).

RESULTS

No differences in height, body mass, or age were observed between groups at baseline (*P* values > .05; Table 1). The symptom duration was longer in the PFP group than in the healthy group ($P < .001$). No participants dropped out. As a result, data from 24 participants were included in the assessment.

The pain level increased in the PFP group after all loading conditions compared with the healthy group (*P* values < .002; Table 2). We found no differences in PROs after any loading conditions (*P* values > .05; Table 2). Finally, no differences in cartilage CSA or EI alteration were statistically significant between or within groups (*P* values > .06; Table 3).

The associations between the Δ% of cartilage CSA and EI and changes in PROs are shown in Table 4. The KOOS was negatively associated with the Δ% of the EI in the lateral femoral cartilage after the plyometric loading condition ($\rho = -0.87$, $P = .001$) in patients with PFP. After strengthening exercises, the decreased AKPS score was positively correlated with the Δ% of the lateral femoral cartilage EI ($\rho = 0.57$, $P = .05$) in patients with PFP. No significant associations were found between the Δ% of femoral cartilage and PROs after running in both groups.

DISCUSSION

The main purpose of our research was to determine if patients with PFP would demonstrate lesser Δ% in femoral

Table 2. Effects of Loading Conditions on Pain and Patient-Reported Outcomes

Variable / Exercise	Group				*U* Value	*P* Value
	Patellofemoral Pain		Healthy			
	Mean Rank	Sum of Ranks	Mean Rank	Sum of Ranks		
Visual analog scale						
Plyometric[a]	17.42	209.00	7.58	91.00	13.00	.001
Strengthening[a]	16.33	196.00	8.67	104.00	26.00	.007
Running[a]	17.17	206.00	7.83	94.00	16.00	.001
Anterior Knee Pain Scale score						
Plyometric	10.92	131.00	14.08	169.00	53.00	.29
Strengthening	11.29	135.50	13.71	164.50	57.50	.41
Running	13.17	158.00	11.83	142.00	64.00	.67
Knee injury and Osteoarthritis Outcome Score						
Plyometric	12.08	155.00	12.92	145.00	67.00	.79
Strengthening	11.67	140.00	13.33	160.00	62.00	.59
Running	13.13	157.50	11.88	142.50	64.50	.67
Knee injury and Osteoarthritis Outcome Score for Patellofemoral Pain and Osteoarthritis						
Plyometric	12.92	155.00	12.08	145.00	67.00	.79
Strengthening	12.08	145.00	12.92	155.00	67.00	.79
Running	13.04	156.50	11.96	143.50	65.50	.71

[a] Indicates a significant difference ($P < .05$).

Table 3. Repeated-Analysis-of-Variance Measures of Medial and Lateral Cartilage Cross-Sectional Area and Echo Intensity Before and After the Loading Conditions

Variable	Group, Mean ± SD				
Exercise	Patellofemoral Pain		Healthy		
	Before	After	Before	After	*P* Value
Cross-sectional area, mm^2					
Plyometric					
Medial	27.41 ± 6.69	26.98 ± 6.01	29.14 ± 8.92	27.86 ± 7.42	.43
Lateral	28.58 ± 6.96	28.43 ± 6.55	30.47 ± 8.99	28.43 ± 8.43	.11
Strengthening					
Medial	28.14 ± 5.59	26.63 ± 5.24	29.04 ± 8.33	28.42 ± 8.17	.49
Lateral	28.85 ± 5.40	27.98 ± 5.92	30.95 ± 8.85	29.42 ± 8.43	.53
Running					
Medial	28.27 ± 6.35	27.38 ± 7.13	29.80 ± 9.11	30.15 ± 9.47	.13
Lateral	28.39 ± 6.33	28.05 ± 6.86	31.50 ± 9.79	29.44 ± 9.15	.06
Echo intensity, 0–255					
Plyometric					
Medial	109.99 ± 4.73	109.84 ± 5.53	110.56 ± 9.95	111.00 ± 8.72	.70
Lateral	109.11 ± 5.00	108.25 ± 4.85	108.54 ± 9.02	107.95 ± 8.51	.88
Strengthening					
Medial	110.62 ± 4.98	108.79 ± 5.41	110.02 ± 9.29	110.88 ± 9.45	.06
Lateral	108.56 ± 4.81	107.75 ± 4.60	108.32 ± 8.34	109.85 ± 8.18	.07
Running					
Medial	111.62 ± 7.42	111.75 ± 5.87	108.79 ± 8.94	112.34 ± 10.91	.11
Lateral	109.60 ± 6.12	110.32 ± 5.24	107.83 ± 9.62	111.58 ± 9.36	.09

cartilage CSA and EI than individuals without PFP after various loading conditions. Secondarily, we tested if the Δ% of femoral cartilage CSA and EI was associated with changes in PROs.

Pain severity increased after all loading conditions for patients with PFP. Interestingly, other PROs, including the AKPS, KOOS, and KOOS-PF, did not show changes after the 30-minute loading conditions. Although the aforementioned PROs are valid and reliable[21–23] for quantifying subjective ratings of knee pain and function in individuals with PFP, they do not appear optimized to detect short-period (30-minute) changes in self-perceived pain and function. Another possible reason for nonsignificant changes in most questionnaires was that the participants were physically active, performing at least 30 minutes of exercise more than 3 times a week. Thus, 30 minutes of loading conditions may have been insufficient to induce functional decreases despite increased pain. Researchers[28] have suggested that self-reported disability and performance-based assessments of pain and function are influenced by different characteristics in patients with low back pain. Specifically, pain intensity, health-related quality of

Table 4. Spearman ρ Correlations Between % Cartilage Cross-Sectional Area (CSA) and Echo Intensity (EI) and Patient-Reported Outcome Changes ρ

	Group, Δ%							
	Patellofemoral Pain				Healthy			
Exercise	CSA		EI		CSA		EI	
Patient-Reported Outcome	Medial	Lateral	Medial	Lateral	Medial	Lateral	Medial	Lateral
Plyometric								
VAS	–0.30 (0.34)	–0.26 (0.41)	0.04 (0.90)	–0.47 (0.12)	0.26 (0.42)	0.19 (0.55)	–0.07 (0.84)	–0.07 (0.84)
AKPS	0.02 (0.95)	–0.04 (0.90)	–0.39 (0.20)	0.25 (0.43)	0.01 (0.98)	–0.28 (0.39)	0.04 (0.91)	0.02 (0.96)
KOOS	–0.08 (0.80)	–0.26 (0.41)	–0.36 (0.25)	–0.87 (0.001)[a]	0.25 (0.43)	0.20 (0.52)	–0.08 (0.82)	–0.05 (0.87)
KOOS-PF	–0.12 (0.72)	0.40 (0.19)	0.04 (0.90)	0.42 (0.18)	–0.23 (0.47)	–0.21 (0.51)	0.16 (0.63)	0.17 (0.59)
Strengthening								
VAS	–0.39 (0.21)	–0.29 (0.36)	0.04 (0.91)	–0.15 (0.63)	0.40 (0.19)	0.36 (0.26)	0.05 (0.88)	0.11 (0.74)
AKPS	–0.29 (0.35)	0.13 (0.68)	0.17 (0.59)	0.57 (0.05)[a]	–0.37 (0.24)	–0.29 (0.36)	0.05 (0.88)	–0.02 (0.95)
KOOS	0.28 (0.37)	0.02 (0.96)	–0.05 (0.87)	–0.04 (0.89)	0.40 (0.19)	0.36 (0.26)	0.05 (0.88)	0.11 (0.74)
KOOS-PF	–0.28 (0.39)	–0.21 (0.52)	0.35 (0.27)	0.16 (0.61)	–0.56 (0.06)	–0.37 (0.24)	–0.07 (0.83)	–0.12 (0.71)
Running								
VAS	0.28 (0.38)	0.15 (0.64)	–0.22 (0.49)	–0.19 (0.57)	–0.26 (0.41)	–0.22 (0.50)	–0.06 (0.85)	–0.37 (0.24)
AKPS	–0.31 (0.33)	–0.18 (0.57)	–0.12 (0.72)	0.15 (0.64)	0.06 (0.86)	0.24 (0.46)	–0.39 (0.22)	–0.18 (0.58)
KOOS	–0.004 (0.99)	0.45 (0.14)	0.02 (0.95)	0.33 (0.30)	–0.06 (0.86)	–0.24 (0.46)	0.39 (0.22)	0.18 (0.58)
KOOS-PF	0.17 (0.59)	–0.12 (0.70)	0.04 (0.89)	–0.37 (0.24)	0.32 (0.31)	–0.04 (0.89)	–0.34 (0.27)	–0.03 (0.92)

Abbreviations: AKPS, Anterior Knee Pain Scale score; KOOS, Knee injury and Osteoarthritis Outcome Score; KOOS-PF, Knee injury and Osteoarthritis Outcome Score for Patellofemoral Pain and Osteoarthritis; VAS, Visual Analog Scale.

[a] Statistically significant correlation ($P < .05$).

life, and depression were significant contributors to self-reported disability. In our study, the self-reported visual analog scale detected an increase in pain, but the function-based AKPS, KOOS, and KOOS-PF assessments did not detect any changes in PROs. Therefore, the previously reported disparity in what self-reported versus performance-based assessments are quantifying may also be true in patients with PFP. Future investigators should consider including depression and quality-of-life measures to understand PFP.

Contrary to our hypothesis, individuals with PFP did not demonstrate deformative characteristics of femoral cartilage compared with the healthy control group. Earlier authors[9] reported that individuals with PFP showed reduced baseline patellar cartilage thickness and decreased deformation of patellar cartilage after acute knee joint loading. Substantial differences in the material properties of patellar and femoral cartilage should be noted.[29] Patellar cartilage is thicker than femoral cartilage but has a lower compressive aggregate modulus and higher permeability to fluid flow, explaining the earlier fibrillation of patellar cartilage than femoral cartilage.[29] Further work is needed to confirm the deformative characteristics of femoral cartilage in patients with PFP through other imaging methods (eg, MRI) because individuals with PFP are at risk of TFOA.

It is imperative to assess the femoral cartilage because PFP may indicate poor femoral cartilage health. The Δ% in femoral cartilage CSA was not associated with the pain level or PROs after any loading condition in individuals with PFP. Our results complement those of a preceding study[30] in which the researchers identified nonsignificant associations between cartilaginous abnormalities and clinical symptoms. Perhaps the pain reported by our participants originated in a structure other than the femoral cartilage. Joint effusion, osteophytes in the patellofemoral compartment, and the infrapatellar fat pad have all been reported sources of pain in patients with PFP.[30] We did not address these pain-inducing factors and tissues, but they should be considered in future explorations of diagnostic US in patients with PFP.

Contrary to our finding, previous authors[31] demonstrated that individuals with a history of anterior cruciate ligament tear showed less Δ% in femoral cartilage after walking, which was significantly correlated with worse subjective function (ie, lower KOOS). The different findings between the 2 studies may be due to the patients' demographic differences. Despite the participants' ages being similar between the earlier work[31] and ours (age = 22 ± 4 years versus 21 ± 2 years, respectively), our participants did not sustain a traumatic anterior cruciate ligament tear, which has been reported to initiate the degenerative process.[32] Perhaps it was too early to detect cartilaginous changes in all of our participants with PFP. Although the average symptom duration of our participants was 54 months, the range was 18 to 125 months. Participants whose symptoms had lasted closer to 18 months may not have had PFP long enough to display cartilaginous changes. The exact timing of the transition between PFP and PFOA remains unknown but warrants further investigation.

Researchers[25] examining individuals with a history of anterior cruciate ligament reconstruction described EI alteration of the medial femoral cartilage, whereas individuals with PFP showed EI changes in the lateral femoral cartilage. A laterally tilted and tracking patella is common in patients with PFP, and thus, unsurprisingly, these patients may have altered EI in the lateral region of femoral cartilage after loading conditions.[33] Our results supported this previous finding of negative Δ% scores in the lateral cartilage EI after both plyometric and strengthening loading conditions and significant correlations with changes in the KOOS and AKPS score, respectively. Interestingly, the KOOS increased after the plyometric loading condition, and the AKPS score decreased after the strengthening loading condition. Perhaps participants felt better after the plyometric loading condition and worse after the strengthening exercises. Most participants in the current study were active at a recreational level of sport with a Tegner Activity Scale score of 6 to 7. These scores reflect involvement in recreational and competitive sports that are often associated with strength training. Therefore, the participants may have applied more effort to these exercises due to increased familiarity with strength training compared with plyometrics. More effort may have resulted in greater symptoms (lower AKPS scores) after the strengthening exercise. Regarding the plyometric exercise, we expected this would increase symptoms, as is commonly reported in a clinical setting among patients with PFP. However, the KOOS improved, suggesting fewer symptoms, after plyometric exercise. Despite ample instructions and familiarization time with the exercises, it is possible that a lack of familiarity with plyometrics may have influenced this outcome. The AKPS and KOOS ask patients to rate their symptoms during a variety of similar tasks, including running, jumping, and squatting. The fact that the association with the lateral cartilage EI was present for only 1 PRO scale for each loading condition despite the similar questions suggests that more research is needed to confirm the present association between EI and the AKPS score and KOOS.

We acknowledge several limitations in our study. We did not rule participants in or out based on clinical criteria (eg, knee joint swelling or patellar tilt), which made it difficult to generalize the outcomes to patients showing other signs and symptoms. Participants did not reach 140° of knee flexion during the loading conditions. Patellofemoral contact area changes throughout knee-flexion range of motion, potentially increasing the joint contact pressure due to the reduced contact area in the intercondylar notch at full knee flexion.[34] Also, patellofemoral cartilage contact area increases while weight bearing, but we collected sonographic images while participants were seated. Thus, it is unlikely that we assessed the femoral cartilage where the patellofemoral joint undergoes the greatest stress because the transverse imaging of the knee joint may show only the most anterior portion of the femoral cartilage. Ultrasonography of the knee joint lacks the ability to provide a thorough view of the entire joint, unlike MRI. Therefore, future researchers should use MRI for individuals with PFP after an acute bout of loading conditions. In addition, we could not quantify the amount of loading applied to the joint because participants were asked to perform the loading conditions based on repetitions or time. This may have increased the variability of responses in the Δ% of cartilage CSA and EI along with the PROs. Hence, future authors should consider controlling the loading conditions. Lastly, although we matched age and body mass index

between groups, older age or higher body mass index may increase the odds of a progressive loss of patellar cartilage. We recommend that future researchers assess the effect of age and body mass index on cartilaginous response after loading conditions.

CONCLUSIONS

Ultrasound imaging showed potential use in monitoring the lateral femoral cartilage EI in patients with PFP. This was the first sonographic research to analyze cartilage CSA and EI changes after exercises in patients with PFP. As cartilaginous EI changes were associated with the AKPS score and KOOS, those questionnaires might be useful in monitoring early changes in femoral cartilage health among patients with PFP.

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SUPPLEMENTAL MATERIAL

Supplemental Figure.

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