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Recreational runners with patellofemoral pain exhibit elevated patella water content

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ABSTRACT

Increased bone water content resulting from repetitive patellofemoral joint overloading has been suggested to be a possible mechanism underlying patellofemoral pain (PFP). To date, it remains unknown whether persons with PFP exhibit elevated bone water content. The purpose of this study was to determine whether recreational runners with PFP exhibit elevated patella water content when compared to pain-free controls. Ten female recreational runners with a diagnosis of PFP (22 to 39 years of age) and 10 gender, age, weight, height, and activity matched controls underwent chemical-shift-encoded water-fat magnetic resonance imaging (MRI) to quantify patella water content (i.e., water-signal fraction). Differences in bone water content of the total patella, lateral aspect of the patella, and medial aspect of the patella were compared between groups using independent t tests. Compared with the control group, the PFP group demonstrated significantly greater total patella bone water content (15.4 ± 3.5% vs. 10.3 ± 2.1%; $P = 0.001$), lateral patella water content (17.2 ± 4.2% vs. 11.5 ± 2.5%; $P = 0.002$), and medial patella water content (13.2 ± 2.7% vs. 8.4 ± 2.3%; $P < 0.001$). The higher patella water content observed in female runners with PFP is suggestive of venous engorgement and elevated extracellular fluid. In turn, this may lead to an increase in intraosseous pressure and pain.

1. Introduction

Patellofemoral pain (PFP) is the most common overuse injury in runners, and accounts for 25% of injuries treated in orthopedic clinics [1]. In spite of the high prevalence of PFP in persons who are physically active, little is known about the mechanism(s) underlying the development of PFP. It has been hypothesized that PFP is the result of chronic overloading of highly innervated subchondral bone [2]. For example, previous work from our group has shown that individuals with PFP exhibit greater patellofemoral joint stress during weight-bearing activities when compared to persons without pain [3]. Elevated loading of the patellofemoral joint has been hypothesized to result in articular cartilage breakdown [4], elevated subchondral bone metabolic activity [2], and increased bone water content [5].

Hejgarrd and Arnoldi [6] have reported that elevated intraosseous pressure within the patella is associated with pain in persons with patellofemoral joint osteoarthritis. Elevated intraosseous pressure is thought to be the result of systemic increases in bone water content (i.e., venous stasis) [7], and/or focal accumulation of extracellular fluid within the trabeculae (i.e., bone marrow lesions) [8]. Given that mechanical nociceptors are sensitive to pressure, intraosseous hypertension could create a noxious environment for the highly-innervated subchondral bone [6].

To date, it is unknown whether persons with PFP exhibit elevated bone water content. Such information is relevant as the presence of elevated bone water content could explain the tendency of persons with PFP to exhibit increased symptoms following a bout of repetitive loading (i.e., running). Using a chemical-shift-encoded water-fat magnetic resonance imaging (MRI) protocol [9,10], the purpose of this preliminary study was to compare patella water content between female runners with and without PFP. We hypothesized that the PFP group would demonstrate elevated patella water content when compared to the control group. Information obtained from this investigation may provide 1) potential insight into the cause of patellofemoral symptoms in runners, and 2) the feasibility of measuring water content in bone marrow in this population.

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Table 1
Subject characteristics (mean ± standard deviation).

	Patellofemoral pain group (n = 10)	Control group (n = 10)	P-value
Age, years	25.1 ± 4.7	25.8 ± 6.1	0.78
Height, m	1.7 ± 0.1	1.7 ± 0.1	0.97
Weight, kg	59.7 ± 9.3	59.8 ± 7.1	0.45
Activity level, MET.min/week	2166.0 ± 969.1	1944.0 ± 859.0	0.59
Distance of running, miles/week	15.0 ± 6.3	15.5 ± 6.9	0.88
Anterior Knee Pain Scale[a]	89.0 ± 5.7	N/A	
Duration of symptoms, months	57.6 ± 28.8	N/A	

[a] A score of 100 on the Anterior knee Pain Scale indicates no anterior knee pain or disability.

2. Materials and methods

2.1. Subjects

Twenty female subjects were recruited for this study (10 with a diagnosis of PFP and 10 pain-free controls; Table 1). The data presented here for subjects in the PFP group have been reported in a previous publication [11]. All subjects were recreational runners who ran at least 6 miles per week. Individuals with PFP were admitted to the study if their pain originated from behind the patella (i.e., retropatellar pain), and reported an insidious onset of symptoms of at least 3 months in duration. All subjects in the PFP group reported symptoms with running. Prior to participation, all subjects were informed of the nature of the study and signed a human subjects' consent form approved by the Health Sciences Institutional Review Board of the University of Southern California.

Subjects were screened through physical examination to rule out concomitant sources of pain. This process included palpation of the soft tissues around the patellofemoral joint to identify the location of pain. If the source of pain was localized to the quadriceps tendon, patellar tendon, patella bursa, patella fat pad, tibio-femoral joint, or the lateral and medial joint line, the subject was disqualified from the study. Persons with PFP also were excluded from participation if they reported having any of the following: 1) history of knee surgery, 2) history of traumatic patellar dislocation, or 3) implanted biological devices that could interact with the magnetic field.

Subjects in the control group were age, height, weight, and activity matched (<10% difference) to those in the PFP group. Subjects' physical activity levels were determined based on the World Health Organization's Global Physical Activity Questionnaire. This questionnaire has been reported to provide a valid and reliable estimate of physical activity [12]. Subject selection for the control group was based on the same criteria as the experimental group except that these subjects had no history of PFP.

2.2. Image acquisition

Prior to the MRI assessment, subjects were asked to refrain from sport or vigorous activity for 1 day. In addition, subjects refrained from weight-bearing for 1 hour prior to imaging. This was accomplished by having subjects sit in a chair, and was done to control for potential load-induced increases in bone water content [13]. For subjects in the PFP group, imaging was performed on the symptomatic side. For subjects with bilateral pain, the more painful side was evaluated. The limb evaluated in the control subjects was matched to that of their counterpart in the PFP group.

MRI scanning was performed on a 3.0 Tesla General Electric scanner (Excite HD, GE Healthcare, Milwaukee, WI, USA) with an 8-element knee coil. An investigational version of GE Healthcare's water-fat MRI technique (i.e., IDEAL) was utilized [10]. Briefly, this form of MRI technique exploits the differences in resonance frequency (e.g. chemical-shift) to accurately separate on a voxel-wise basis the component signals of protons from unbound free water and fat from the underlying tissue. A subsequent water fraction map can then be computed for quantitative analysis. The quantitative accuracy of the IDEAL method in measuring water and fat fractions has recently been validated in the bone marrow against MR spectroscopy [14]. Current literature has also demonstrated that the IDEAL technique provides a strong reproducibility in fat fraction estimation [15].

A 3-dimensional multi-echo spoiled-gradient-echo pulse sequence that incorporated signal relaxation compensation (e.g. T1, T2*) [16,17] and a 6-peak fat spectrum in the IDEAL reconstruction algorithm [17] was utilized in this study. The scan parameters were: TR = 20.2 ms, 1st TE = 1.68 ms, echo spacing = 0.98 ms, 6 echoes, echo train length = 2, flip angle = 5°, slice thickness = 2 mm, FOV = 160 × 160 mm, matrix = 224 × 224, BW = ±125 kHz, scan time = 9 minutes 50 seconds. Each subject was positioned supine with full knee extension during the MRI examination.

2.3. Image analysis

Since the IDEAL technique was originally designed to measure organ steatosis, the default reconstruction software provided by GE Healthcare automatically returned individual series of water-only, fat-only, and fat fraction maps (fat/[fat + water]x100%) (Fig. 1). For purposes of this study, we performed additional post-processing analysis using ImageJ software (National Institutes of Health, Bethesda, MD, USA). First, the subchondral bone region on the fat fraction maps (defined as the bright region under articular cartilage) was manually contoured on all image slices containing the patella (Fig. 1 C). A single region of interest was then identified on each image slice.

The average fat fraction of each region of interest was obtained by averaging the signal intensities of all voxels within the region of interest. The water fraction of each region of interest was then

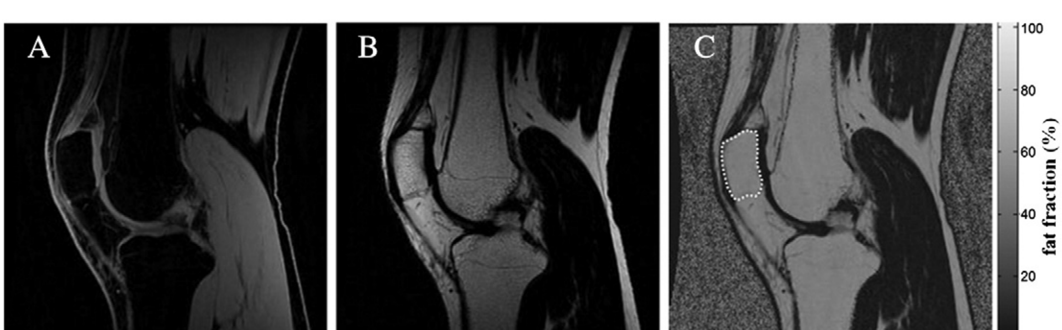

Fig. 1. Default output of IDEAL water-fat MRI: (A) water-only image; (B) fat-only image; (C) fat fraction map. A region of interest was contoured on the fat fraction map (dashed line), and the average water fraction of the region of interest was calculated as 100-fat fraction (%).