INTRODUCTION

Patellofemoral pain (PFP) is the most common overuse injury of the lower extremity. It has been hypothesized that PFP is the result of increased pressure on highly innervated subchondral bone. A recent finite element (FE) modeling study has suggested that persons with PFP demonstrate elevated hydrostatic pressure and octahedral shear stress in patella articular cartilage. It is unclear however how cartilage stress influence stress within the pain-sensitive subchondral bone layer. The purpose of the current study was to test the hypothesis that females with PFP exhibit elevated patella bone stress compared to pain-free controls.

METHODS

To date, seven females with PFP, and 7 pain-free females have participated in this on-going study. Subjects were matched based on age, weight, height, and physical activity level.

Input parameters for the FE model included: 1) PFJ geometry, 2) elastic modulus of patella, 3) weight-bearing PFJ kinematics, and 4) quadriceps muscle forces (Fig. 1). PFJ geometry was obtained from sagittal plane, water-fat IDEAL magnetic resonance imaging (MRI) acquired with a 3.0T MRI scanner (General Electric Healthcare; Fig. 1A). Voxel-wise bone density of patella was estimated from IDEAL in-phase MRI with the assistance of a calcium hydroxyapatite phantom and the voxel-wise elastic modulus was consequently computed. The elastic modulus of each element was calculated by retrieving the elasticity of the closest voxel to the element’s centroid. The patella was then divided into 200 linear material regions based on the elastic modulus distribution of the patella (Fig.1B). The FE mesh of cartilage and bone was then registered to the position of each structure on the weight-bearing MRI (Fig.1C). Quadriceps muscle forces were estimated using a previously described EMG driven model (Fig.1D).

For each model, the femur and tibia were modeled as rigid structures and the cartilage of the patella and femur was modeled as homogeneous isotropic tetrahedral continuum elements (elastic modulus of 4 MPa and Poisson ratio of 0.47). The patella was modeled as heterogeneous isotropic tetrahedral continuum elements with Poisson ratio of 0.3. Quadriceps muscles were divided into 3 functional groups (rectus femoris/vastus intermedius, vastus medialis, and vastus lateralis) made up of 6 equivalent uniaxial connector elements. The patellar tendon was modeled as 6 uniaxial, tension-only elements with stiffness of 4334 N/mm.

The peak and average stresses at the cartilage-bone interface were quantified in terms of 2 invariants: 1) von Mises stress, and 2) compressive stress. To establish a clinically meaningful measure of average stress, only elements with a stress higher than the 90th percentile were considered while computing the average stress. This threshold was used to identify
the highest risk for bone initial failure. As an indirect assessment of the validity of each FE simulation, the estimated contact area and final patella position predicted by the models were compared to the actual contact area and patella position measured from the weight-bearing MRI using previously published procedures.

Independent t tests were used to compare 1) peak and average von Mises stresses, and 2) peak and average compressive stresses between the PFP and control subjects. The significance level was set as 0.05.

RESULTS AND DISCUSSION

In general, more concentrated stress was observed on the lateral facet of the patella in the PFP subjects while a more evenly distributed stress pattern was observed in the control subjects (Fig. 2). When compared to the pain-free controls, individuals with PFP exhibited significantly greater peak and average von Mises stress as well as peak and average compressive stress (Table 1).

Contact areas estimated by the model were within 19.3 mm² (5.0 %) of contact areas measured from the weight-bearing MRI. In addition, the average lateral patella displacement predicted by the FE models were within 0.02 (3.0 %) of those measured from the weight-bearing images.

Previous literature has reported that elevated bone stress is associated with bone tissue damage. We propose that the elevated bone stress observed in the current study may contribute to bone tissue injury (e.g., MRI-detected bone marrow lesions) and patellofemoral symptoms in persons with PFP.

Future efforts will focus on increasing the sample size and relating stress values to pain, function, and location of BML’s to better understand the underlying pathomechanics of this poorly understood clinical condition.

![Figure 2: von Mises stress distribution of PFP and control subjects is demonstrated in a posterior view of patella. L and M indicate lateral and medial.](image)

REFERENCES


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| Table 1: Peak and average von Mises stress and compressive stress at the cartilage-bone interface of patella |
|-----------------------------------------------|---------------|-------------|
| PFP | CONTROL | P value |
| Peak von Mises Stress (MPa) | 5.58±1.22* | 3.52±0.81 | 0.003 |
| Average von Mises Stress (MPa) | 3.75±0.98* | 2.16±0.69 | 0.004 |
| Peak Compressive Stress (MPa) | 5.64±2.25* | 3.06±1.07 | 0.018 |
| Average Compressive Stress (MPa) | 2.13±0.57* | 1.12±0.30 | 0.001 |

Values are presented as mean±SD. * indicates a significant difference from the control group.