INFLUENCE OF QUADRICEPS MUSCLE FORCE DISTRIBUTIONS ON CARTILAGE STRESSES AT THE PATELLOFEMORAL JOINT DURING RUNNING

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INTRODUCTION

Several factors can influence the tracking of the patella, including soft tissue restraints, femoral internal rotation, and the geometry of the joint. Quadriceps muscle forces also influence the mechanics of the patellofemoral (PF) joint and are often the focus of physical therapy interventions, such as strengthening and stretching. However, the efficacy of such treatment strategies remains unclear.

Elias et al. (2006) and Dhaher & Kahn (2002) have shown the importance of the quadriceps force distribution on the medial-lateral force balance at the patella and the associated contact force and pressure. It is unknown, however, how the quadriceps force distribution influences the stresses throughout the PF joint cartilage.

The purpose of this study was to estimate the cartilage stresses within the PF cartilage during the stance phase of running (with the knee at 30° flexion) and determine the influence of altering the distribution of forces between the medial and lateral vasti to support the same net joint moment.

METHODS

Sixteen subject-specific finite element models of the PF joint were created from physically active volunteers (8 males and 8 females). The methods used to create these models are explained in detail in Besier et al. (2005). An open-MR scanner was used to obtain upright, weight-bearing images of each subject holding a squat at 30° flexion, which were used to orient the bones of the model (Figure 1).

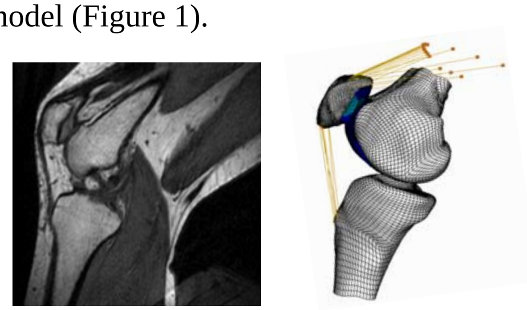

Figure 1. Weight-bearing MR image of the knee and corresponding finite element model.

The patellar tendon and quadriceps muscles were modeled as tension-only connector elements. The patellar tendon had a stiffness of 2000 N/mm. The quadriceps muscles were divided into functional groups which were activated independently. These included: vastus intermedius, rectus femoris, vastus lateralis, vastus lateralis oblique, vastus medialis, and vastus medialis oblique.

Muscle forces during running were estimated based on an EMG-driven musculoskeletal model (Lloyd & Besier, 2003) using joint kinematics and EMG data obtained from a gait analysis. Muscle forces when the knee was at 30° were used as input to the finite element model for the initial simulation. The forces in the oblique parts of vastus medialis and lateralis were determined based on their relative cross-sectional areas. Simulations were then performed in which the relative contributions of the vastus medialis and vastus lateralis muscles where perturbed while the same net joint moment was maintained. The size of the muscle force pertubations were determined by examining the variation in muscle forces across all subjects and perturbing by one and two standard deviations from the mean muscle force. Mean and peak hydrostatic pressure and octahedral shear stresses were determined for each simulation at the layer of cartilage closest to the bone.

RESULTS AND DISCUSSION

Across all subjects the total muscle force produced by the quadriceps during stance phase when the knee was flexed 30° was 1860 ± 660 N. Vastus medialis was responsible for producing 26 ±5% of the total quadriceps force, whereas vastus lateralis produced 43 ±6% of the net quadriceps force.

These muscle forces resulted in an average PF contact area of 345 ± 72 mm^2 and a PF joint reaction force of 2059 ± 788 N. Mean hydrostatic pressures at the layer of cartilage closest to the bone were 2.1 ± 1.1 MPa in the patella and 2.5 ± 1.1 MPa in the femur. Mean octahedral shear stresses within the cartilage were 1.1 ± 0.6 MPa in the patella and 0.8 ± 0.4 MPa in the femur. Peak cartilage stresses in the patella were ~4 times greater than the average stress for both hydrostatic pressure and octahedral shear stress. Peak stresses in the femoral cartilage were 4.5 to 7 times greater than the average shear stress and hydrostatic pressure, respectively.

Increasing the contributions from the vastus medialis and vastus lateralis did not have any sizeable effect (<2%) on the *average* stresses in the PF joint cartilage.

Peak cartilage stresses, however, were more sensitive to changes in the medial-to-lateral muscle force balance. Increasing the contribution from vastus lateralis had the greatest effect on both shear stress and hydrostatic pressure (Figure 2). Shear stresses in the patella cartilage were the most sensitive to changes in muscle force distribution.

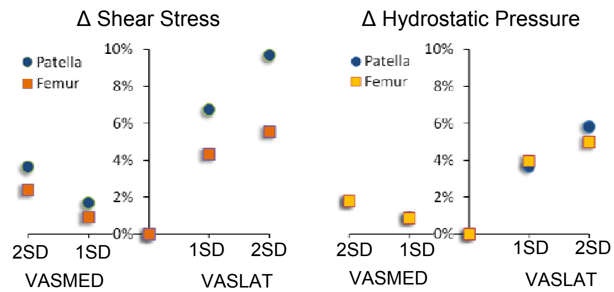

Figure 2. Percent change in cartilage stress with increasing contributions (1 or 2 standard deviations) from vastus medialis (VASMED) and vastus lateralis (VASLAT).

Cartilage stresses appear relatively insensitive to changes in the distribution of medial-to-lateral quadriceps forces, with the exception of shear stresses in the patellar cartilage. Due to its smaller physiological cross-sectional area, vastus medialis has less potential to influence cartilage stresses compared with vastus lateralis.

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