Computational Evaluation of Predisposing Factors to Patellar Dislocation

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Disclosures:

Introduction: Patellar dislocation typically occurs during sports-related activities in young active people. The typical mechanism for injury has been described as internal femoral rotation with the quadriceps engaged, with dislocation occurring between 20 and 30° of tibiofemoral (TF) flexion [1]. After initial dislocation has occurred, the incidence of reoccurrence is high (44%) [2]. As such, dislocation can be a debilitating injury which often hinders or prevents further sporting participation. In the normal patellofemoral (PF) joint, passive patellar stability is provided by a combination of constraint from articular surface contact, and medial soft-tissue structures - notably the medial PF ligament (MPFL) which cadaveric studies have reported as providing between 50 to 60% of the medial restraining force on the patella [2, 3]. Predisposing factors for recurrent lateral patellar dislocation include increased femoral anteversion, trochlear dysplasia, increased quadriceps angle (Q-angle), vastus medialis obliquus (VMO) weakness and damage to the MPFL, which is commonly ruptured (up to 94%) during the initial incidence of patellar dislocation [4-6]. Surgical interventions to correct for recurrent lateral dislocation include MPFL reconstruction, tibial tubercle osteotomy and sulcus-deepening trochleoplasty [7]. However, relationships between patellar dislocation and PF anatomy, muscle loading and soft-tissue integrity are not fully understood, and hence surgical decision-making on a patient-specific basis has not been perfected. The objective of the present study was to determine the influence of several predisposing factors on PF mechanics for a patient with previous patellar dislocation and a size-matched control without patellofemoral pathology.

Methods: Magnetic resonance (MR) scans were taken from a patellar dislocation patient with trochlear dysplasia and a size-matched, healthy normal control. Femoral and patellar bone and cartilage was reconstructed from the scans and used to develop subject-specific three-dimensional (3D) finite element (FE) models of the PF joint of both the dislocation patient and the control (Figure 1). The FE models of the isolated patellofemoral joint were based on prior research that validated model-predicted, six-degree-of-freedom (6DOF) PF kinematics during a squat cycle [8]. The model included 2D fiber-reinforced membranes of the patellar tendon and quadriceps, divided into rectus femoris (RF), vastus intermedius (VI), vastus lateralis longus (VLL), vastus lateralis obliquus (VLO), vastus medialis longus (VML) and VMO. Quadriceps load was split between the various quadriceps heads in proportion to their physiological cross-sectional-area (VL:40%; RF+VI:35%; VM:25%) [9]. Analyses were performed under a quadriceps load of 400N for each subject at 10° intervals of TF flexion from full extension to 40°, with the patella kinematically unconstrained. PF 6-DOF kinematics, PF contact mechanics and contact forces were measured.

A series of perturbations were performed on the original models to simulate predisposing factors for patellar dislocation. Kinematics of the TF joint were modified to 5° and 15° of internal femoral rotation; the Q-angle was altered by laterally shifting the line of action of the quadriceps muscles; and quadriceps distribution was altered to simulate the
least stable end of the normal spectrum (VL:45%; RF+VI:35%; VM:20%) and a VM
relaxed condition (VL:47%; RF+VI:53%; VM:0%) [10]. Patellar mechanics were
compared across subjects, flexion angle, and loading conditions to provide
preliminary data on sensitivity of normal and dysplastic PF anatomy to
predisposing conditions.

**Results:**
The patella of dysplastic subject was consistently
more laterally positioned, relative to the femur, than the control from full
extension to 30° flexion (Figure 2). At 40° flexion, geometry of the trochlear
groove constrained the patella to a medial-lateral (M-L) position similar to
that of the control. The dysplastic subject consistently demonstrated higher
contact pressures and lower contact area than the control (Figure 3). Each
model perturbation (femoral internal rotation, increased Q-angle, VM
weakness/absence), for both dysplastic and control subjects, served to shift
the patellar position laterally and reduce patellar contact area. There were
substantial differences in sensitivity to predisposing factors between the
subjects; the control demonstrated most variability in patellar position at
full extension, with all perturbations converging to a similar M-L position at
40° flexion. The patella of the original dysplastic model tracked along the
lateral facet of the femoral condyles in early flexion before dropping into the
groove at 40° flexion, while perturbations were enough to prevent the patella
from achieving a stable position within the groove; patellae continued to track
along the lateral ridge, or dislocated laterally for all dysplastic
perturbations.

**Discussion:**
This study serves as a preliminary investigation
into the factors influencing patellar dislocation; the data thus far highlights
the increased sensitivity of dysplastic patients to predisposing factors for
patellar dislocation - dysplasia in conjunction with any of the perturbations
evaluated in this study prevented the patellar from settling into a stable
position in the initial 40° of flexion. The original dysplastic subject
demonstrated most lateral displacement at 20° flexion, in agreement with
clinical studies which report patellar dislocation typically occurring at
20-30° flexion when the patella is most influenced by PF congruency and sulcus
geometry. Ongoing work will assess additional dysplastic and control geometries
and aim to quantify the relative influence of anatomy and soft-tissue metrics
in determining risk of patellar dislocation on a subject-specific basis, and
ultimately, optimal patient-specific surgical intervention (trochleoplasty,
MPFL reconstruction, etc.) to reduce the potential for dislocation. The
computational environment is ideal for objectively evaluating the influence of
a specific factor or combination of factors as, unlike the clinical situation,
each factor can be perturbed and assessed without additional confounding
factors.

**Significance:**
This study is a preliminary step towards developing criteria to determine optimal
patient-specific surgical intervention required for recurrent lateral patellar
dislocation. The models demonstrate substantial difference in sensitivity
between anatomy to predisposing factors for patellar dislocation, with normal anatomy
robust to model perturbations, and dysplastic tending towards dislocation.

**Acknowledgments:**

**References:**

![Graph showing patella contact area](image)

**Figure 3:** Patella contact area for the control (solid line) and dysplastic (dashed line) subjects for each perturbation at 0°, 10°, 20°, 30°, and 40° of TF flexion; insets showing PF contact patch for the original model at 0, 20 and 40° flexion.
Figure 2: Patella medial-lateral position for the control (solid line) and dysplastic (dashed line) subjects for each perturbation at 0°, 10°, 20°, 30°, and 40° of TF flexion; insets showing patella position for the VM weak perturbation at 40° flexion (left) and original model at 0, 20 and 40° flexion (right).
Figure 1: Finite element model setup for a control (left) and dysplastic subject (right) showing femoral cartilage with PF contact at 40° flexion (bottom).

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