Patellofemoral Forces in the Setting of Trochlear Dysplasia and Tibial Tubercle Lateralization: A Mathematical Model

Joseph William Anderson[1], Trisha Agrawal, Terry Bradly Clay[1], James R Slauterbeck[2], Dhananjay Tulsiram Tambe
[1]University of South Alabama, [2]University of South Alabama Orthopedics

INTRODUCTION:

Trochlear dysplasia and tibial tubercle lateralization are two significant underlying anatomic factors to consider in the evaluation of patients with patellar instability. Cadaveric and biomechanical studies have demonstrated that tubercle lateralization is associated with increasing patellofemoral forces and stress on the medial patellofemoral ligament (MPFL). Data suggests that MPFL reconstruction alone may be unable to restore physiologic patellofemoral kinematics and contact pressures in the setting of significantly increased tubercle lateralization. Since MPFL reconstruction is recommended as a treatment option for patellar instability, we have created a model that facilitates assessment of several anatomic features and the possible effectiveness of mitigation surgeries.

METHODS:

Several anatomic angles and associated force vectors were evaluated to assess mechanical stability of the patella. In these calculations, forces in multiple planes (including the quadriceps and patella tendon) were evaluated in relation to the sulcus angle (ϕ) and tibial tubercle lateralization (β) throughout varying degrees of knee flexion (θ), to evaluate laterally directed forces on the patella (F_L). As such, evaluating F_L allows for a representation of a laterally directed force exerted on the patella that must be resisted by the medial sided knee soft tissue structures, including the MPFL. Specifically, we look at the force vector changes of F_L in relation to varying degrees of trochlear dysplasia and tibial tubercle lateralization.

RESULTS:

Our mathematical model shows three key causes of patellar destabilization 1) flatter ϕ / sulcus angle, 2) wider β / tubercle lateralization, and 3) quadricep tension acting when the knee is extended. F_L represents potential destabilizing forces acting laterally on the patella. More positive values of F_L represents instability throughout varying degrees of knee range of motion and trochlear geometry. Conversely, greater negative values of F_L represent increasing patella stability.

When sulcus angles were held constant within normal ranges, increasing values of tubercle lateralization caused values of F_L to become more positive, which represented increasing instability (-26.8 at 0mm of tibial tubercle translation vs -15.1 at 25 mm translation; at 30° knee flexion and sulcus angle of 130°. Likewise, flatter trochlear grooves were associated with higher levels of instability (-26.8 at 130° sulcus angle vs -19.0 at 160° sulcus angle; at 30° knee flexion and tubercle translation at 0mm). More negative values of F_L (representing increasing stability) were noted with increasing degrees of knee flexion regardless of anatomic considerations. Additionally, the combination of increasing tubercle lateralization and flattening trochlear grooves showed significantly increased values of instability throughout knee flexion angles.

DISCUSSION AND CONCLUSION:

Increasing tibial tubercle lateralization and trochlear dysplasia are associated with patella instability. In addition, our model provides an interactive means to examine the effect of different parameters affecting patellar instability including geometry of the trochlear groove, location of the knee flexion axis, and quadricep muscle pull. Based on our results and comparison to biomechanical and cadaveric studies, we suggest that soft tissue procedures alone may not provide sufficient stability in the treatment of patellar dislocations in the setting of significant tibial tubercle lateralization.

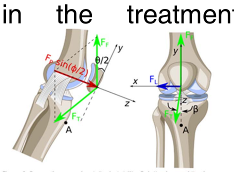

Figure 1: Force diagram of patellar instability. F_p is the force of the femur pushing on the patella (stabilizing force). F_l is the force of the patella pushing on the ligament (destabilizing force). F_F is the tension in the femur. F_T is the tension in the tibia. β is the tibial tubercle position. An increased offset of the tibial tubercle increases the destabilizing force indicating patellar instability

$$F_p = W\gamma(1 + e^{\frac{-(\theta-\mu)^2}{2\sigma^2}})$$

$$F_T = \frac{F_p sin(\frac{\phi}{2})}{2sin\,(\frac{\theta}{2})cos\,(\frac{\psi}{2})}$$

$$F_L = 2F_t sin(\frac{\theta}{2})sin(\frac{\varphi}{2}) - F_p cos(\frac{\phi}{2})$$

Figure 2: Mathematical equations representing varying force vectors across the knee

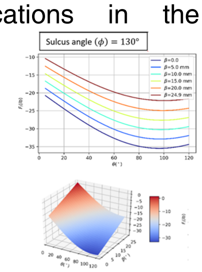

Figure 3: The effect of tibial tubercle lateralization (β) and varying knee flexion angles (θ) on laterally directed patella forces (F_L) when sulcus angles (ϕ) are held constant at 130°

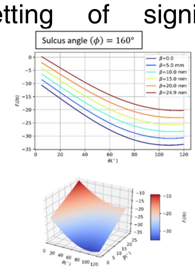

Figure 4: The effect of tibial tubercle lateralization (β) and varying knee flexion angles (θ) on laterally directed patella forces (F_L) when sulcus angles (ϕ) are held constant at 160°

Knee Flexion Angle (θ)	Tubercle Translation (β), mm					
	0	5	10	15	20	25
5°	-20.74	-18.72	-16.70	-14.64	-12.55	-10.39
10°	-21.98	-19.92	-17.85	-15.74	-13.60	-11.39
20°	-24.44	-22.23	-20.10	-17.90	-15.65	-13.34
30°	-26.80	-24.54	-22.27	-19.96	-17.61	-15.19
60°	-32.66	-30.15	-27.62	-25.05	-22.44	-19.74
90°	-35.40	-32.79	-30.17	-27.51	-24.79	-22.00

Table 1: The effect of tubercle translation and knee flexion on F_L. Sulcus angle was held constant at 130°.

Knee Flexion Angle (θ)	Sulcus Angle (ϕ)			
	130°	140°	150°	160°
5°	-20.74	-18.17	-14.84	-10.68
10°	-21.98	-19.55	-16.38	-12.36
20°	-24.44	-22.29	-19.42	-15.71
30°	-26.80	-24.92	-22.37	-19.01
60°	-32.66	-31.53	-29.91	-27.65
90°	-35.40	-34.83	-33.96	-32.69

Table 2: The effect of sulcus angle and knee flexion on F_L. Tubercle translation was held constant at 0 mm.