DETERMINING GEOMETRIC AND BONE POSE DIFFERENCES BETWEEN KNEES WITH AND WITHOUT PATELLAFEMORAL INSTABILITY USING STATISITCAL SHAPE MODELLING

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Summary

Traditional methods for diagnosing patellofemoral instability have often used simple 2D metrics. Though 3D geometry of the knee has been investigated previously, the extent has been limited to either just the femur, or only healthy knees. The present study looks to investigate geometric and bone pose differences between stable and unstable knees using statistical shape modelling.

Results show features associated with patella femoral instability such as greater external rotation of the tibia, flatter trochlear groove, and more patella alta within the unstable group.

Introduction

During normal knee flexion and extension, the patella tracks along the trochlear groove allowing for force transfer from the quadriceps to the tibia. However, due to muscular imbalance, soft tissue properties, bone geometry [1,2], or the complex interactions among these factors, the patella may track outside the groove and dislocate. This increased risk of patellar dislocation is diagnosed as patellofemoral instability (PFI)[3].

Traditional methods for diagnosing risk of PFI have used simple 2D measurements from x-ray or slice images from MR or CT imaging. However, these methods are limited by the angle the images are viewed from [3]. More recent studies have investigated 3D geometry using 3D printing or statistical shape modelling (SSM) which can be used to quantify and visualise variations in geometry. However, these studies have only investigated the femur [4] or only stable knees [5].

Purpose: To identify key geometric and pose differences between stable and unstable (PFI) knees using statistical shape modelling.

Methods

CT scans of full knee joints were obtained at the Yale School of Medicine and segmented to produce 3D meshes of stable (n=31) and unstable (n=29) knees. All bones were fully ossified. The in situ anatomic coordinate systems (ACS) were obtained for each femur, tibia, and patella [6,7]. Each bone was then aligned based on their respective ACS and point correspondence was obtained via geodesic Bayesian coherent point drift. All meshes were scaled based on tibial size and a mean geometry for each group and overall mean were obtained. Bone meshes were transformed back to their in situ positions and aligned such that the tibial ACS is the origin.

A principal component analysis (PCA) was conducted on the full joint, and each bone separately. An SSM was then created based on the PC scores from the first 8 PCs in each PCA, only the first is discussed in this abstract. The PC scores for each PCA were compared between groups using MANOVA with post-hoc one-way ANOVAs. Bone pose was analysed based on the ACS's split into translation and rotation components.

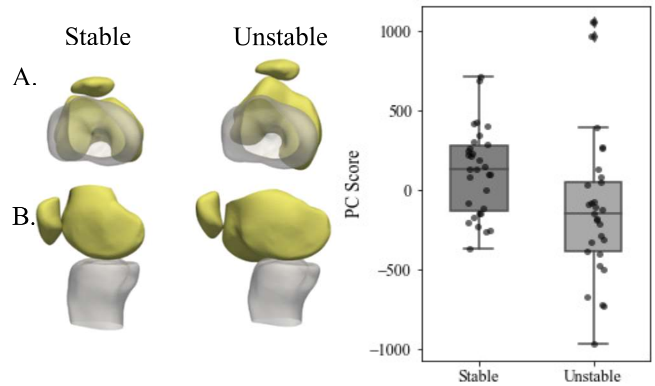

Figure 1: Left: An SSM depicting ±2 SD of PC1 from the full knee PCA. The left column depicts features associated with stable knees and the right, unstable. Row **A** is viewed distally, and row **B** is viewed medially. **Right:** Depicts the PC scores for PC1 for stable and unstable knees ($p = 0.012$)

Results and Discussion

Results appear consistent with previous findings [3] and are listed below. Bone pose is stated relative to the tibia and features listed are associated with PFI. (**Figure 1.** Unstable)

Femur: Anteriorised, internally rotated, and over extended. Flatter trochlear groove, and narrower intercondylar notch.

Tibia: Elevated medial condyle, depressed lateral condyle, and medialised tuberosity.

Patella: Lateralised, proximalised and anteriorised. More dominant lateral facet relative to medial.

Of note, the tibial morphology shows a slightly medialised tibial tuberosity, but the tuberosity is lateralised relative to the femur due to external tibial rotation. It is possible that external tibial rotation leads to a medially directed patellar tendon force, pulling the tuberosity medially. Though further investigation is required to better understand this result.

Conclusion

Geometric and pose differences consistent with PFI features were observed in this SSM. The results highlight that both geometry and joint orientation may contribute to PFI.

Acknowledgments
This research was supported by NSERC.

References
[1] Amis. (2007) *Sports Med Arthrosc*, **15**(2), [2] Levy et al. (2021) *AJSM*, **49**(6), [3] Barras & Diduch, (2024) *KA*, [4] Nagawa et al. (2024) *Sci Rep,* **14**(1), [5] Clouthier et al. (2019) *Med Eng & Phys,* **66,** [6] Miranda et al. (2010) *J Biomech,* **43**(8), [7] Rainbow et al. (2013) *J Biomech,* **46**(12)