Evaluation of the relationship between meniscal T2* metrics and tibial bone shape

Erin C. Argentieri[1,3], Ek Tsoon Tan[1], Garry Gold[2], Sharmila Majumdar[1], Hollis G. Potter[1], Matthew F. Koff[1]
[1]Department of Radiology and Imaging, Hospital for Special Surgery, New York, New York, USA; [2] Stanford University, [3]University of California San Francisco

Introduction: Features of tibial bone morphology such as medial compartment slope and spine volume have a significant impact on overall joint mechanics and have been implicated as risk factors for sustaining non-contact ACL-injuries[1,2]. While previous studies found that meniscal T2* metrics prolong in the setting of degeneration[3,4] and that qMRI metrics of articular cartilage are influenced by tibiofemoral bone morphology[5], to date, no previous studies have attempted to evaluate the relationship between meniscal T2* metrics and tibial bone morphology. Therefore, the objective of this study was to determine the relationship between meniscal T2* metrics and tibial bone shape characterized via principle component analysis (PCA), with the hypothesis that tibial bone shape would be predictive of compartment and region specific meniscal T2* metrics.

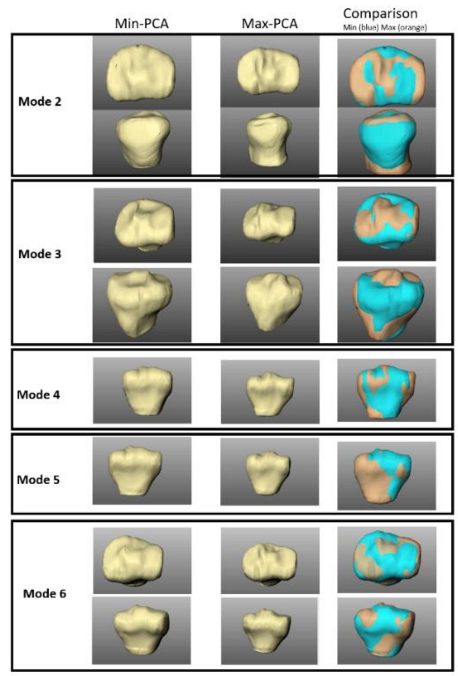

Figure 1: visual characterization of tibial PCA modes

Methods: These data were collected as a part of a larger overall IRB-approved multi-institutional study within elite NCAA athletes. Clinical 3T MRIs were acquired on 39 knees (23 subjects) using an 8-channel phased array knee coil (Invivo). Medial and lateral menisci were manually segmented (MeVisLab) from three-dimensional, Cones UTE sequences (TEs: 5 echoes between 0.03-24ms, TR: 188ms, voxel size: 0.63x0.63x3mm^3, RBW: ±83.3kHz, Flip-Angle: 16°). Mean and median meniscal T2* metrics were calculated via a mono-exponential fit of signal intensity to corresponding echo time (Matlab, Natick, MA). Eu) were used for bone segmentation. Segmentation of tibial bone was performed automatically via a fully convolutional neural network (V-Net) and were used to produce 3D triangulated meshes of tibial bone. The V-Net model achieved 0.98 ± 0.01 Dice Score coefficient in the unseen test set for tibia segmentation. Principal component analysis (PCA) was then performed to simplify the complexity of those surface data for interpretation/characterization over PC modes. 3D models for each of the modes were visualized for characterization using custom MeVisLab software (Figure 1). *__Statistical Analysis__*: Multiple linear regression and ANOVA analyses were performed to evaluate the influence of tibial bone shape (PC modes), BMI, and sex on compartment specific meniscal T2* metrics. Significance was set at $p<0.05$.

Results: __PCA Characterization__: Percent variance captured by first 6 tibial modes: 83.3039% (Table 1; Figure 1) **Lateral meniscus: *__Mean T2*:__*** PCA-modes 1-6, and BMI combined to explain 35.77% of the variance in mean T2* metrics, and an ANOVA found that this effect was significantly different from zero, (p = .034, R^2 = 0.36). ***__Median T2*:__*** PCA-modes 1-6, and BMI combined to explain 45.94% of the variance in median T2* metrics, and an ANOVA found that this effect was significantly different from zero, (p = .003, R^2 = 0.46). **Medial meniscus: *__Mean-T2*:__*** PCA-modes 1-6 and BMI combined to explain 35.77% of the variance in mean T2* metrics explained 37.92% of the variance in mean T2* metrics (p = .022, R^2 = 0.38). ***__Median-T2*__***: BMI and PCA-modes 1-6 explained 49.11% of the variance in median T2*, and an ANOVA found that this effect was significant (p = .001, R^2 = 0.49).

Discussion: PCA-modes 1-6 and BMI significantly impacted both medial and lateral meniscal T2* metrics. Modes 2-6 largely characterized tibial spine morphology and compartment slope. Additionally, CSA of the distal ACL insertion on the anterior medial tibia was evident in PCA-mode 4 and related to medial meniscal T2* metrics within this cohort. Interestingly, medial meniscal T2* metrics were better explained by included PCA-modes as compared to lateral T2*, which may suggest that the features of joint morphology that are associated with ACL-injury risk (medial slope, medial spine volume, ACL-CSA)[6,7,8] are also associated with acute meniscal injury or longitudinal meniscal degeneration. While the results of the current study are based on a population of young and elite athletes, tibial bone shape is a non-modifiable factor in joint biomechanics, which may suggest that these data could inform similar models across more heterogeneous cohorts.

Mode #	Lateral PCA characterization/description	Medial PCA characterization/description
1	total volume	total volume
2	circumferential rim curvature & tibial spine height	plateau concavity
3	Tibial spine width	posterior medial tibial slope, ACL insertion CSA
4	tibial spine peak to peak distance & tibial spine vault depth	lateral tibial compartment width
5	tibial spine slope	tibial spine slope
6	tibial spine volume	tibial spine volume & posterior lateral plateau slope

Table 1: descriptive characterization of tibial PCA modes

Conclusion: Evaluation of the relationship between meniscal T2* metrics and tibial PCA modes may allow for the development of individual risk equations for both acute meniscal injury as well as longitudinal degenerative processes.

References: (1) Sturnick 2014; (2) Beynnon 2014; (3) Koff 2014; (4) Williams 2012, (5) Gao 2021 (6) Beynnon 2022 (7) Whitney 2014 (8) Vacek 2016

Features of tibial bone morphology such as tibial slope and tibial spine volume have a significant impact on overall joint mechanics and, results of the current study indicate that these features of tibial bone shape impact both medial and lateral meniscal T2* metrics.

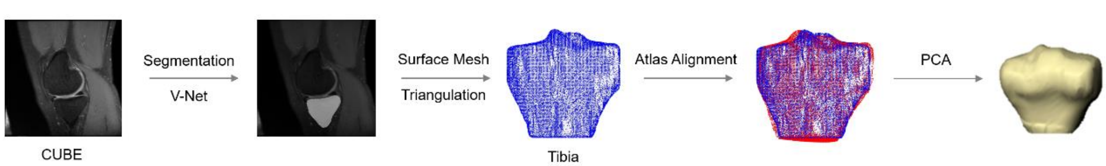

Figure 2: V-Net Automatic segmentation to PCA pipeline