Control/Tracking Number: 22-A-300-OARSI
Activity: Abstract
Current Date/Time: 1/9/2022 9:43:53 PM

STATISTICAL SHAPE MODELING OF THE MENISCUS FROM THE OSTEOARTHRITIS INITIATIVE — A LARGE-SCALE, DATA-DRIVEN EVALUATION OF DEMOGRAPHICS AND CORRELATION TO OSTEOARTHRITIS INCIDENCE

Author Block: E. Xie, K. Gao, S. Majumdar, V. Pedoia; Univ. of California, San Francisco, San Francisco, CA

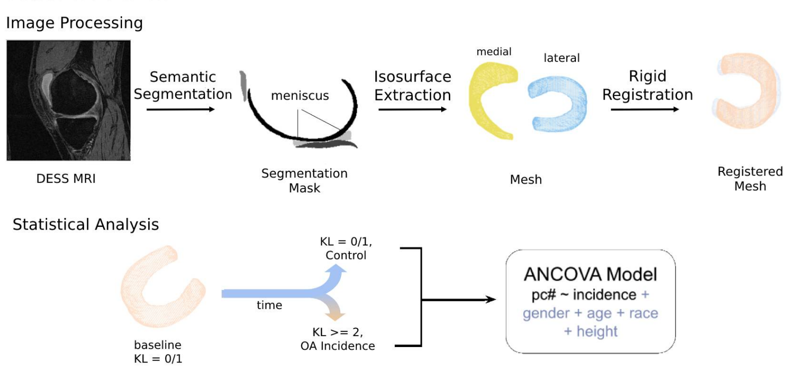
Abstract:
Purpose: Morphological meniscal features, such as tears and extrusion from the tibial plateau, are well-characterized and associated with knee osteoarthritis (OA) progression; however, the relationship between the geometric shape of the meniscus and OA incidence is unclear. This study uses statistical shape modeling (SSM) to identify variations in meniscus morphology and its associations with general demographics, such as sex, race, age, and BMI, and to determine shape features as precursors to the development of OA.
Methods: Baseline visits of the Osteoarthritis Initiative (OAI) dataset (n = 4,791 subjects) were processed to define the SSM (Fig. 1). All menisci were automatically segmented from DESS knee magnetic resonance images by a deep learning network with Dice overlap of 0.874 ± 0.0243. Lateral and medial menisci were separated and assessed independently. The surface topology of each volumetric segmentation was extracted using the Marching Cubes algorithm. Rigid registration minimized the average distance between vertices of each mesh and a healthy reference mesh, aligning all menisci in Euclidean space. Principal component analysis was used to reduce the dimensionality of the data to the 10 principal components (PC) capturing the most geometric variance. To analyze OA incidence, two groups were constructed for statistical analysis: a) Control (2,778 subjects; 1,536 female, age = 62 ± 17, body mass index [BMI] = 31.8 ± 14.9 kg/m^2): knees with Kellgren-Lawrence grade (KLG) of 0 or 1 throughout participation in the OAI, and b) OA Incidence (528 subjects; 383 female, age = 62 ± 17, BMI = 31.2 ± 12.6 kg/m^2): knees with KLG of 0 or 1 at baseline and subsequent development of OA (KLG > 1)

within 8 years. Partial correlation was used to analyze numerical variables such as age and BMI. One-way analysis of covariance was used to assess categorical variables such as OA incidence, sex, race, and right-left knee asymmetry. Asymmetry was determined by subtracting the PC shape values between right and left knees for each menisci and by comparing the difference with OA incidence. These analyses determined the shape features significantly associated ($p < 0.005$) with OA incidence.

Results: Shape features found to be significantly associated with key demographics are depicted in Fig. 2. In regards to OA incidence, four of 10 components describing medial meniscus shape and three of 10 components describing lateral meniscus shape were significantly different between control and OA incidence groups. Of the notable components in the medial meniscus, we found that the OA incidence group had wider overall structure (PC 2: $p < 0.0001$; % variance (v) = 5.82%), longer anterior root (PC 5: $p < 0.0001$; % v = 1.28%), and increased concavity of the posterior flap (PC 8: $p < 0.005$; % v = 0.45%). For the lateral meniscus, we observed that the OA incidence group had larger length-width ratio (PC 2: $p < 0.0001$; % v = 11.37%), inward angling of the anterior horn (PC 3: $p < 0.0001$; % v = 6.99%), and lesser height (PC 5; $p < 0.0001$; % v = 2.17%) (Fig. 3). For the medial meniscus, five of 10 shape asymmetries were found to be significantly associated with OA incidence, including features such as size (PC1: $p < 0.0001$); for the lateral meniscus, two shape asymmetries were found to be associated with OA incidence. In total, the components captured 90.17% and 87.71% of the variance of the medial and lateral menisci geometry, respectively (Fig. 4).

Conclusions: To our knowledge, this is the largest assessment of meniscus shape and first to utilize a fully automated method. An observation from the key demographics was that patients who were male, of higher BMI, or older had a larger (PC1) and wider (PC2) medial meniscus and larger lateral meniscus (PC1), which support findings in literature. For OA incidence, PCs that demonstrated the most variance were related to length-width ratios in both medial and lateral menisci, though to opposite effects. This may be related to a disproportion of medial compartment OA and resultant bulging in the lateral meniscus. Higher stresses in the medial knee may account for more asymmetric shapes that associate with OA incidence, and the agreement between the shapes and asymmetries on the lateral side may indicate that lateral shape variations as OA precursors may largely be attributed to asymmetry. This study identifies meniscus shapes strongly associated with key demographics and future development of OA. These findings may uncover relationships between meniscal morphology, biomechanics, and knee joint degeneration.

Figure 1. Fully automated image, mesh, and statistical processing pipeline. Meniscus is segmented from DESS MRI, transformed into mesh. Registration of meshes to a reference mesh allows all meniscus shapes to be directly compared. OA incidence and control groups were determined by KL grade at baseline and over time. Categorical variables such as incidence were analyzed with an analysis of covariance model.



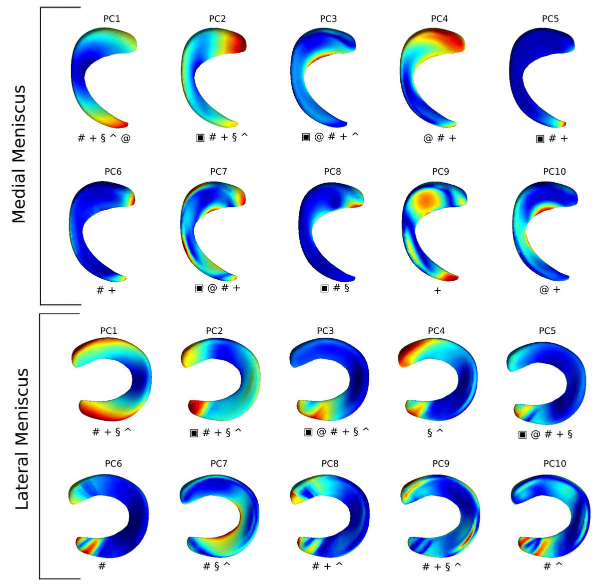


Figure 2. Mean meniscus shapes with a color overlay of the distance displaced at +3 standard deviations from the mean. The PC of each meniscus was compared with each variable below. Statistically significant variables are listed below its corresponding PC.

Significance Symbols:

▣ - OA incidence
@ - Asymmetry

- Sex
+ - Race
§ - Age
^ - BMI

Figure 3. Significantly different PCs between OA incidence and control groups. The top row portrays the shapes associated with OA incidence, while the bottom row portrays the shapes associated with the control. All shapes were generated to be ±3 standard deviations from the mean.

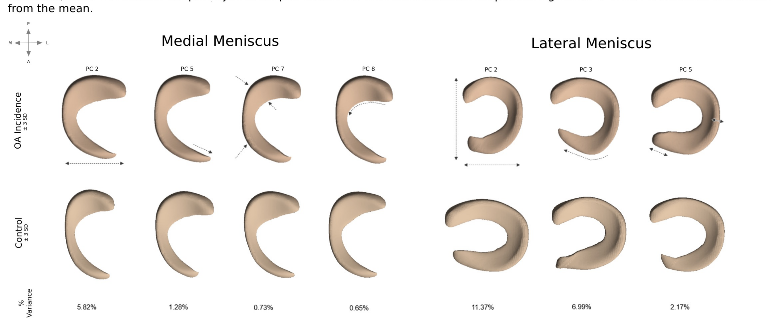
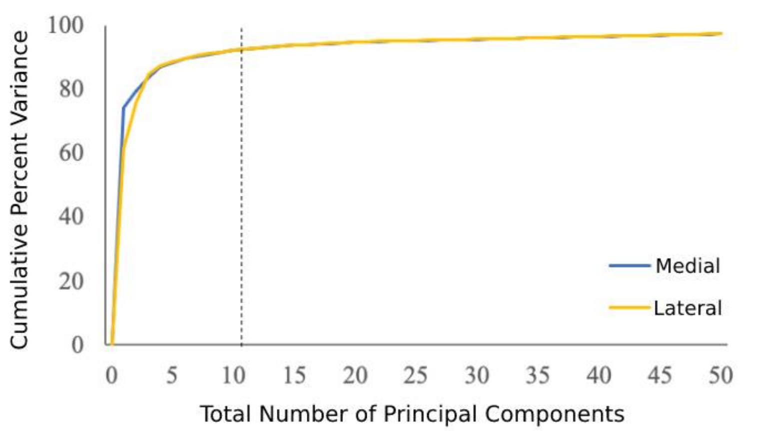


Figure 4: Cumulative % variance captured by increasing number of PCs.Ten PCs were sufficient to capture 90.17% and 87.71%.



Category (Complete): Imaging
Keyword (Complete): Meniscus ; MR Imaging ; Morphology ; Statistical Study
Presentation Preference (Complete): Podium Preference
Additional (Complete):

Type of Abstract (Required): Clinical Science

Are you age 40 or under and within 5 years of your research degree? (Required): No

Do you want to be considered for a Need Based Travel Assistance Award? (Required): Yes

(Tentative response based on information currently available) (Required): I am able to present in person

Payment (Complete): Your credit card order has been processed on Sunday 14 November 2021 at 12:56 PM.

Status: Complete

Osteoarthritis Research Society International
1120 Rt. 73, Ste. 200
Mt. Laurel, NJ 08054, USA
Ashton Hald

For any technical inquiries, click here to contact cOASIS Helpdesk or call 217-398-1792.

Feedback