Variation in the shape of the human lateral meniscus

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Purpose

The knee has been the focus of much anthropological research due to its role in locomotion. The shape of the knee joint is important to its function. Analyses of shape variation in the knee have generally been limited to the bony condyles of the femur and tibia. The menisci contribute substantially to the effective distribution of loads and controlled mobility in the knee,[1-2] yet variation in their shape is poorly understood. Here we examine variation in the shape of the lateral meniscus in relation to biological sex and body size in a human cadaveric sample.

Sample

The knees of 61 cadaveric individuals (34 female, 27 male) were dissected to expose the menisci and their insertions. These individuals ranged in age from 56-97. Knees with total knee replacement or advanced osteoarthritis were excluded from the sample. Left knees were selected preferentially when both knees were appropriate for inclusion.

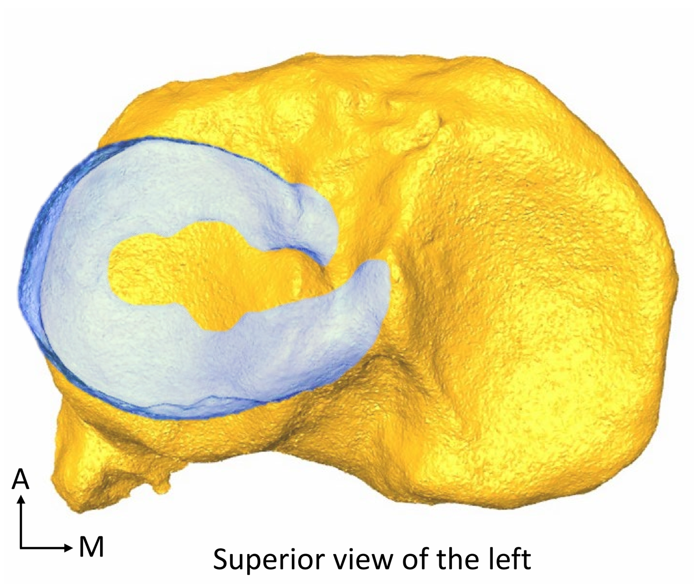
Methods

Surface Models

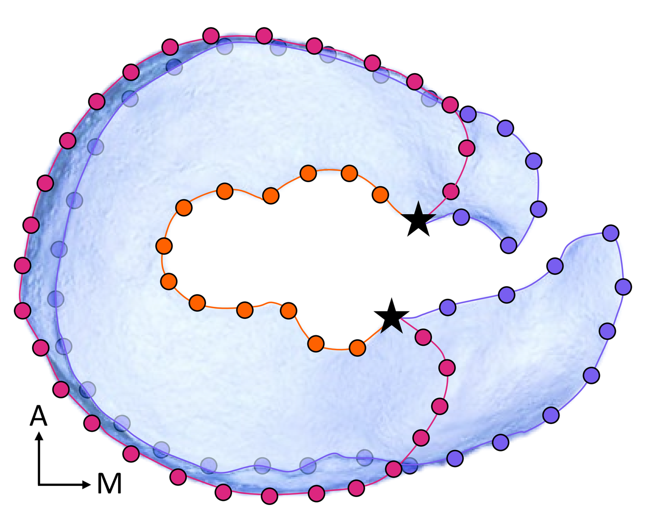
Photogrammetry and blue light scanning were used to generate surface models for each knee. Meniscal models were created by merging scans of the menisci with scans of the tibial plateau. Proximal tibiae from 38 individuals were photographed from 65 positions using a Canon Coolpix camera set to the macro setting. Photographs for each individual were masked and aligned to build a surface mesh using Agisoft Metashape.[3] Proximal tibiae from 23 individuals were mounted to a rotating stand and scanned using an Artec Space Spider; surface models were automatically reconstructed using the real-time fusion setting in Artec Studio 16.[4]

Shape Analysis

Landmarks (n=81) were placed along the inner, outer upper, and outer lower edges of each meniscus in Avizo.[5] The landmarks along each meniscal edge were then evenly distributed in MATLAB.[6] Following Procrustes superimposition, landmark configurations were analyzed using principal components analysis and resampling with replacement.



Superior view of the left proximal tibia (yellow) with the lateral meniscus (blue).

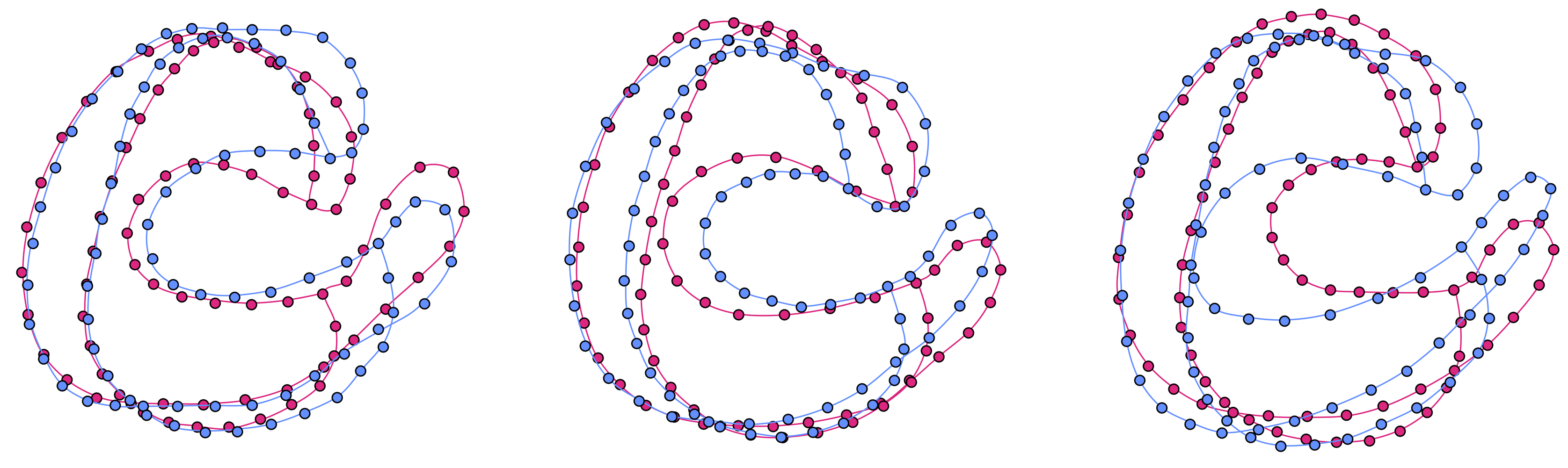


Lateral meniscus with landmarks along the outer upper (●), outer lower (●), and inner (●) margins as well as at their anterior & posterior meeting points (★).

Results

Shape Variation by Principal Component

The first three principal components (PCs) explain over 60% of variation in the shape of the lateral meniscus. Outlines demonstrating the variation in shape captured at two standard deviations positive (blue) and negative (magenta) for the first three PCs are included below. The shape of the lateral meniscus does not differ significantly in males (○)and females (▲)in this sample (p=0.34).



PC1
Percent variance: 37.9%

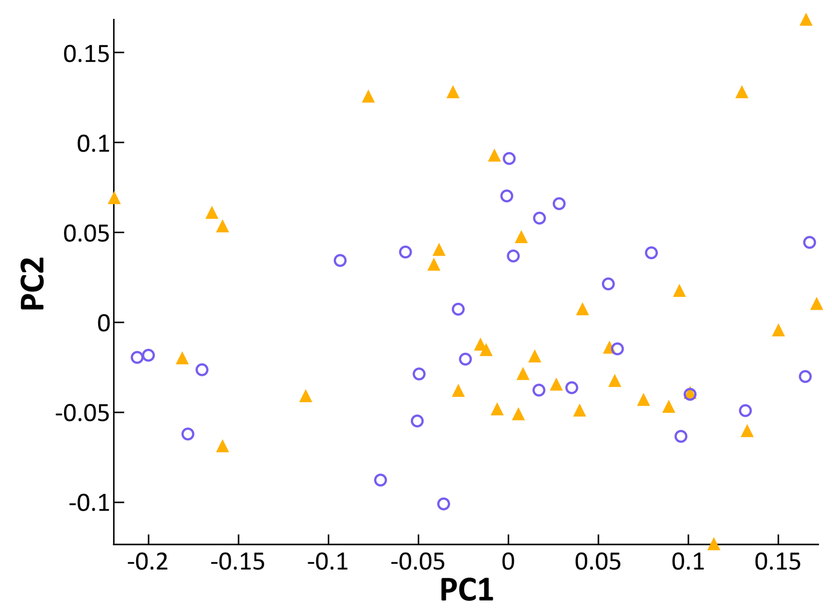
F & M shape significantly different?: No (p=0.59)

PC2
Percent variance: 12.9%

F & M shape significantly different?: No (p=0.45)

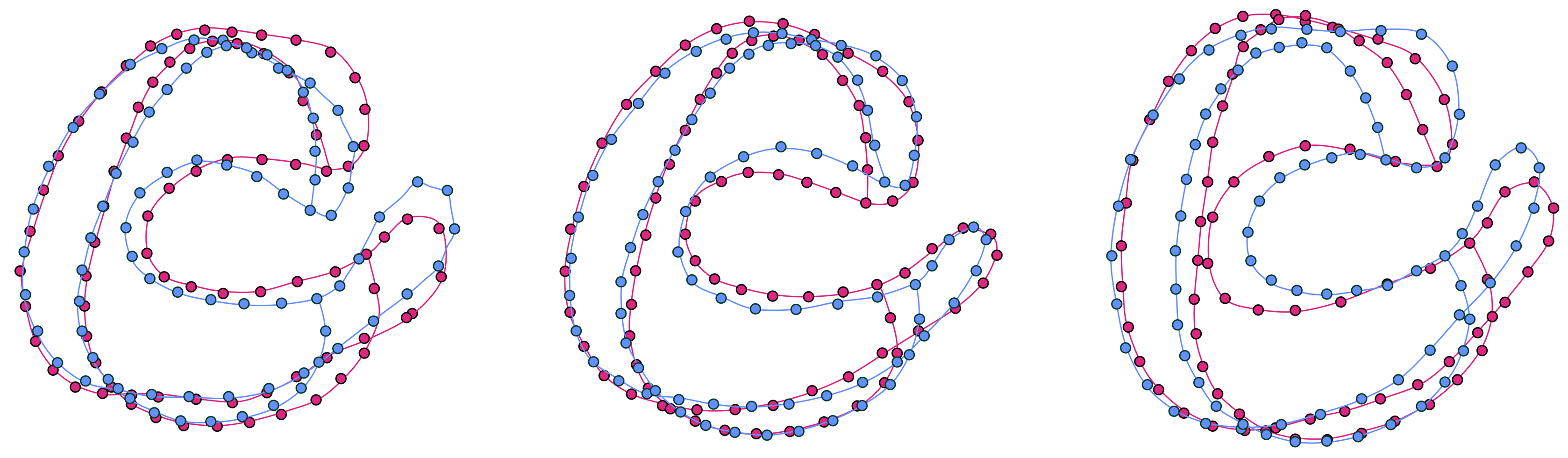
PC3
Percent variance: 9.5%

F & M shape significantly different?: No (p=0.82)



Shape Variation Associated with Body Size

The first three principal components explain over 60% of size-related variation in shape of the lateral meniscus. Outlines demonstrating size-related variation in shape at two standard deviations positive (blue) and negative (magenta) are included below. When mediolateral tibial breadth (MLTIB) is incorporated as a body size proxy, males (○) and females (▲) separate along PC2 (p<0.001). The size-related variation captured along this PC indicates that females have lateral menisci with more narrowly curving inner borders, superiorly extended upper lateral margins, and broader anteriorly-canted posterolateral insertions.



MLTIB PC1
Percent variance: 31.6%

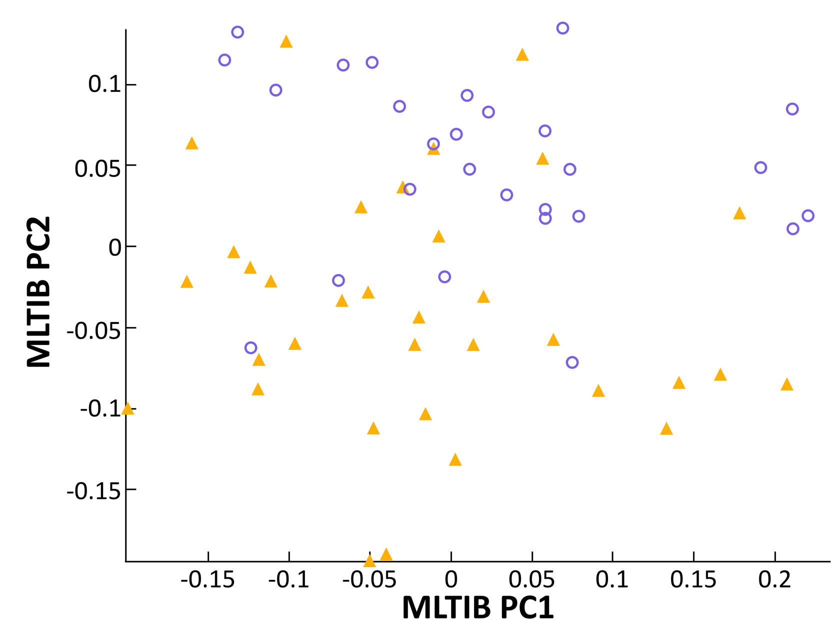
F & M shape significantly different?: No (p=0.12)

MLTIB PC2
Percent variance: 19.2%

F & M shape significantly different?: **Yes (p<0.001)***

MLTIB PC3
Percent variance: 10.4%

F & M shape significantly different?: No (p=0.56)



Conclusions

Body size and its relationship to biological sex play significant roles in observed variation in human lateral meniscal shape.

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References

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