Variation in Human Meniscal Root Orientation

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Purpose

The menisci play a fundamental role in the effective transmission and distribution of loads in the knee during locomotion. The meniscal roots are critical for both the positioning and function of the menisci. Compressive forces during loading are transformed into tensile stresses in the circumferential fibers of the meniscal body periphery; the circumferential fibers of the meniscal body continue into the insertional ligaments which transmit this tensile load to the bone.[1-4] Despite the crucial function of meniscal roots in the knee, variation in the orientation of these insertional ligaments is not well understood. Here I quantify three-dimensional variation in the orientation of the meniscotibial roots of the menisci in modern humans.

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.

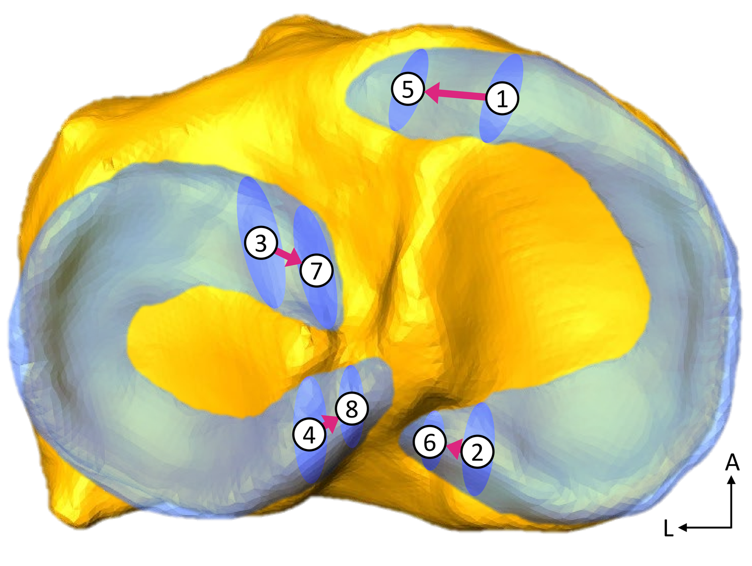
Methods

Surface Models

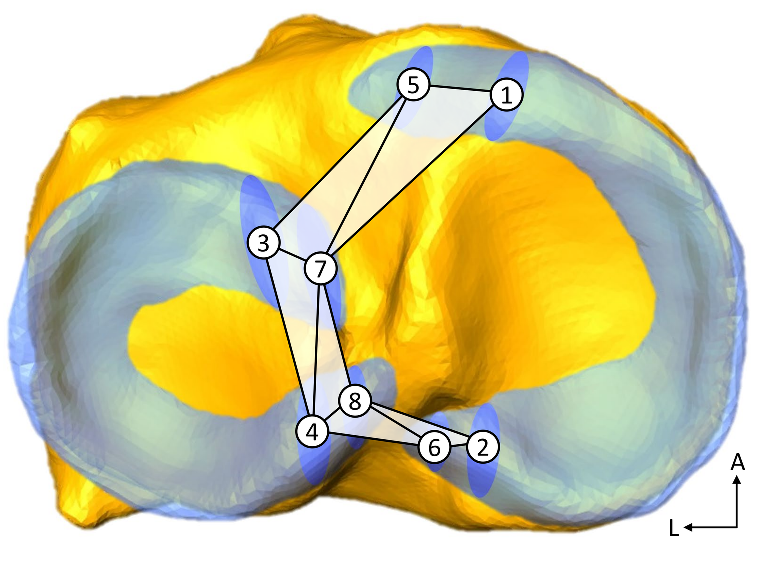
Photogrammetry and blue light scanning were used to generate surface models for each knee. Meniscal models were created by merging scans of the menisci with scans of the tibial plateau. Proximal tibiae from 38 individuals were photographed from 65 positions using a Canon Coolpix camera set to the macro setting. Photographs for each individual were masked and aligned to build a surface mesh using Agisoft Metashape.[5] 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.[6]

Meniscal Root Orientation

Meniscal root cross-sections were created in Avizo.[7] Proximal cross-sections were taken where each of the four meniscotibial roots crosses the condyle border; distal cross-sections were taken close to each root's attachment site. The centroids of each cross-section were collected as landmarks; all individuals were then Procrustes aligned relative to the proximal cross-section centroids in MATLAB.[8] Unit vectors were determined from the proximal point to distal point of each aligned root. Mean orientation, concentration, and ovalness for each root were calculated using the Directional package in R.[9] Both von Mises-Fisher (vMF, "symmetric") and Kent ("asymmetric") distributions were considered; the results of the most appropriate maximum likelihood estimation for each root are reported here.



Left proximal tibia with meniscal root cross-section locations

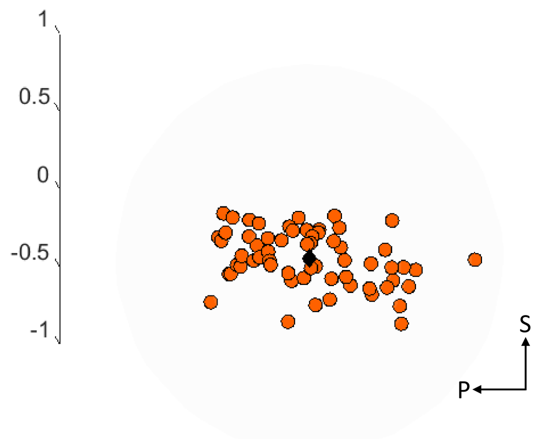


Left proximal tibia with root cross-section centroid landmarks

Results

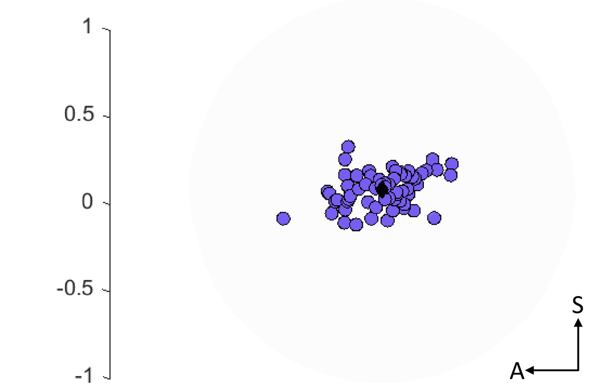
Three-dimensional variation in orientation was found to differ significantly for all meniscotibial roots in the human knee ($p<0.001$.) While the orientation distributions of the posteromedial (PM) and posterolateral (PL) roots were roughly rotationally symmetric about their means, the orientation distributions of the anteromedial (AM) and anterolateral (AL) roots were more elliptical. The PM root was found to have the highest degree of variation in its orientation, and the AM root was found to have the least variation. In addition to showing the least scatter in its orientation overall, the AM root also has the most elliptical orientation distribution. No significant differences were found in the mean orientation or concentration parameter for any root when analyzed by biological sex.

Anterolateral (AL) Root

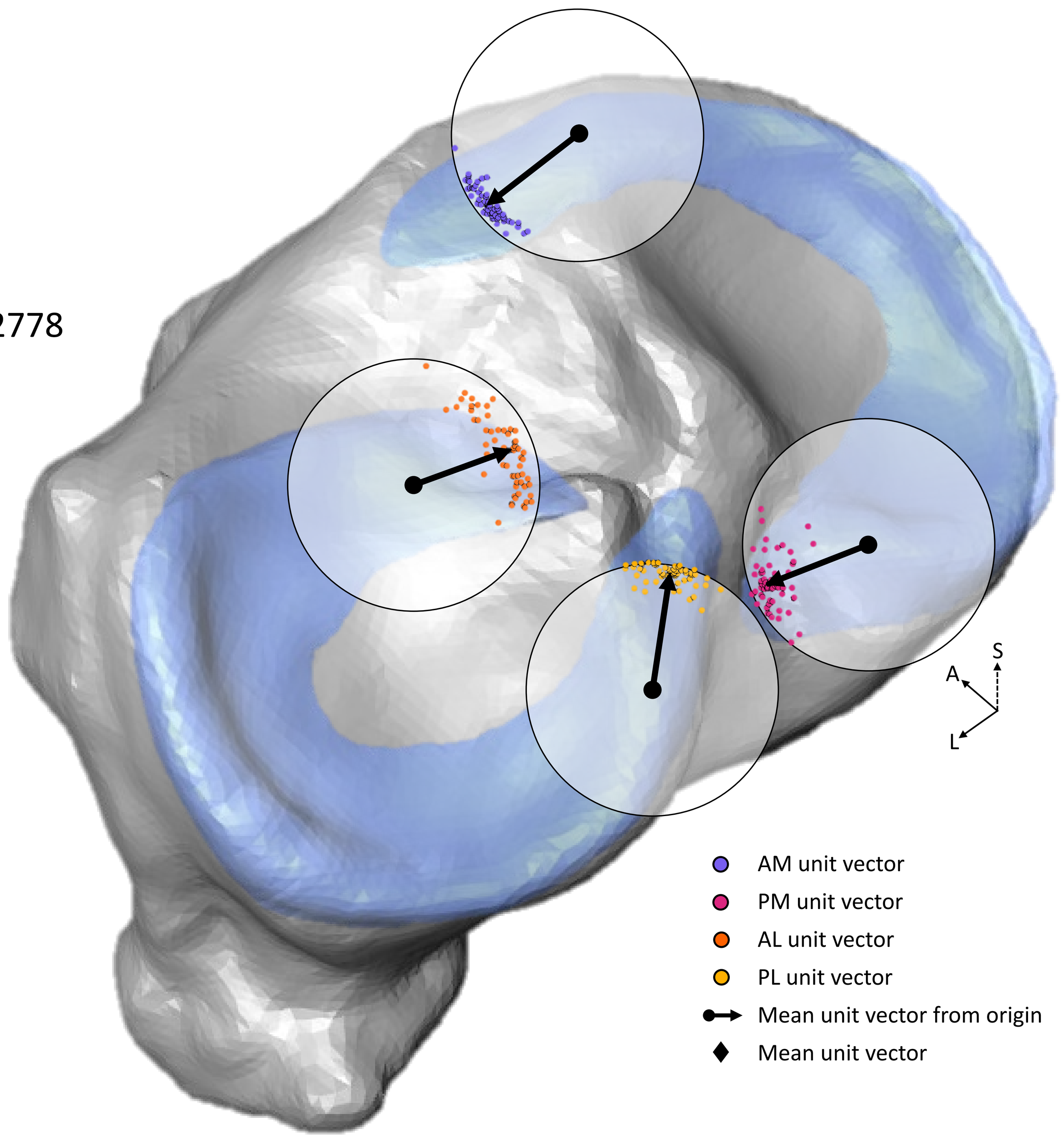


Mean Orientation:
-0.2743782, 0.7488474, -0.6032778
Concentration (Kent):
30.5561157
Ovalness (Kent):
12.1050224

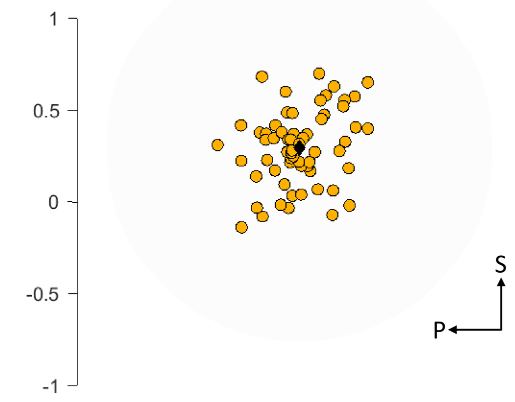
Anteromedial (AM) Root



Mean Orientation:
0.5528232, -0.7121625, 0.4326790
Concentration (Kent):
84.0746088
Ovalness (Kent):
27.5022535

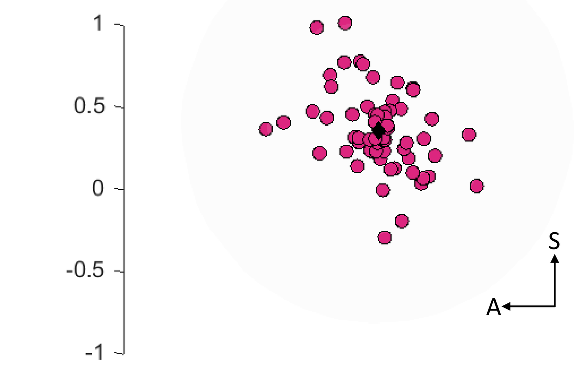


Posterolateral (PL) Root



Mean Orientation:
-0.9311277, 0.1398087, -0.3368305
Concentration (vMF):
29.72968
Ovalness (Kent):
4.9358151

Posteromedial (PM) Root



Mean Orientation:
0.3044522,-0.7888488,0.5338786
Concentration (vMF):
23.94952
Ovalness (Kent):
5.7960236

Conclusions

These results indicate that there is three-dimensional variation in the orientation of the meniscal roots and that the degree of meniscal orientation variation differs for each root. These findings have implications for the prevention and treatment of knee injury as training and surgical methodologies develop to incorporate a more thorough understanding of individual variation in human knee anatomy.

Acknowledgements

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References

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