Size-Related and Demographic Effects on the Morphology of the Lateral Meniscal Notch of the Proximal Tibia

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The Meniscal Notch and Hominin Bipedalism

The lateral meniscal notch of the proximal tibia is often utilized to interpret locomotor behavior and determine the taxonomic assignment of fossil hominin postcrania. A major difference between the human and ape knee is in the morphology and number of attachments of the lateral meniscus. While apes have a ring-shaped lateral meniscus with a single attachment, humans have a crescent-shaped lateral meniscus with two insertions into the tibial plateau.[6,8] The presence of the second insertion of the lateral meniscus has been assumed to be invariable and necessary for loading the knee in full extension,[8] and this feature is considered an important derived trait of the genus *Homo*.[7]

Fig. 1. Proximal view of the right tibia showing the three morphologies of the lateral meniscus in primates. **A:** Primitive mammalian condition with crescent shape and single insertion, **B:** Condition found in cercopithecoids and apes with ring shape and single insertion, **C:** Derived human condition with cresent shape and double insertion. After Tardieu.[6]

Variable Presence of the Meniscal Notch in Modern Humans

However, the meniscal notch is not visible in a significant minority of human tibiae.[2,4] Though Dugan and Holliday[2] discuss variability in this feature, previous work does not address the ways in which the posterior attachment of the lateral meniscus is influenced by body size and demography.

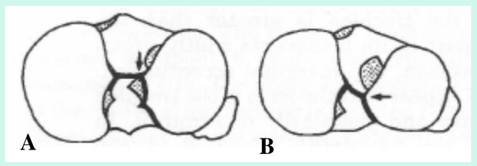

Fig. 2. Shape and tibial insertions of the two menisci in human (**A**) and chimpanzee (**B**) (right tibia). The arrow indicates the summit of he lateral tibial spine. Note the different morphology of the posterior border of the lateral condyle. After Tardieu.[7]

How Do Body Size and Demography Affect the Size and Presence of the Meniscal Notch?

Hypothesis 1 – Notch size will vary with overall tibia size.
Larger individuals will have larger notches and vice-versa.

Hypothesis 2 – Age will have no effect on notch presence.
The posterior attachment of the lateral meniscus is formed *in utero* and should not develop or degrade with age.

Hypothesis 3 – Differences in notch presence/size between males and females are explainable by body size alone.
Observed differences in rotary capability between males and females[1] are likely due to intraspecific allometry.

Hypothesis 4 – Individuals from Asian populations are more likely to lack a meniscal notch.
Discoid meniscus, a condition where the lateral meniscus has only one insertion into the tibial plateau, has been reported at higher incidences in Asian populations.[3,5]

Acknowledgments.
Terry Harrison and Susan Antón, New York University; Gisselle Garcia, American Museum of Natural History.

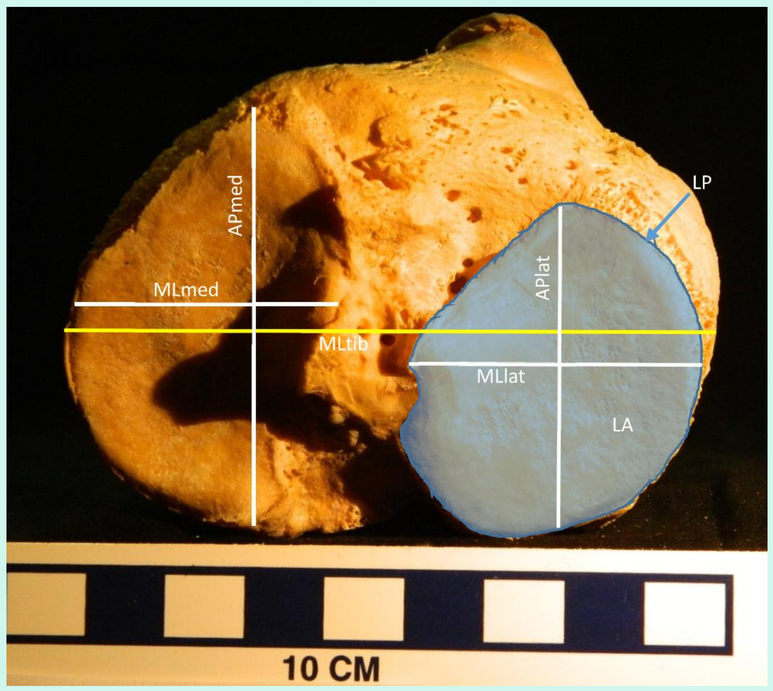

Fig. 3. Digital photograph of a human tibia, oriented with proximal end perpendicular to the camera for measurement in ImageJ. Measurements depicted: mediolateral tibial breadth (MLtib), mediolateral breadth of medial condyle (MLmed) and lateral condyle (MLlat), anteroposterior height of medial condyle (APmed) and lateral condyle (APlat), lateral condyle area (LA), and lateral condyle perimeter (LP).

A Quantitative Method for Assessing Meniscal Notch Size

Previous studies have found that qualitative assessment of the presence or absence of this feature is steeped in ambiguity.[2] In this study, I introduce quantitative methods for assessing the size and dimensions of the lateral meniscal notch relative to the tibial plateau in a large sample of modern humans (*n*=350) spanning the range of human body size.

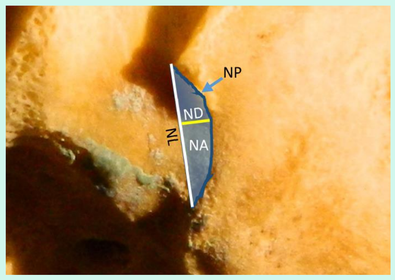

Fig. 4. Quantitative measurements of meniscal notch size: meniscal notch length (NL), meniscal notch depth (ND), meniscal notch perimeter (NP), and meniscal notch area (NA).

A Wide Range of Variation in Meniscal Notch Size

Of 350 tibiae measured, eight individuals (2.286%) lacked a notch (NA=0). An additional 18/350 (5.143%) had small notches (NA<3 mm^2). In those individuals with a meniscal notch, notch area ranged from 0.862-33.029 mm^2.

Fig. 5. Photographs showing variation in the size and morphology of the tibial plateau. Individual A is one of the smallest individuals and lacks a meniscal notch (MLtib=60.123), individual B is notched and near the mean of body size (MLtib=70.701), and individual C is the largest individual observed (MLtib=87.229).

Humans Who Lack or Have a Small Meniscal Notch Area (<3 mm^2) Are Significantly Smaller in Body Size than Those with Larger Notches.

Those with an absent or small meniscal notch were significantly smaller in absolute MLtib size (p=0.001) than those with a larger notch. They also had significantly smaller notch indices (NA/MLtib*100) than those with larger notches (p<0.001).

Females Are More Likely to Lack or Have a Small Meniscal Notch, Independent of Body Size.

Females have a significantly smaller absolute notch area (NA) than males (p<0.001) and significantly smaller notches relative to mediolateral tibial breadth (p<0.001). Individuals that lack or have a small notch are significantly more likely to be female (p=0.01). Females who lack or have a small notch have significantly smaller MLtib than those with a larger notch (p=0.008), while males do not show this relationship. There appears to be a difference between the way that size affects the meniscal notch in males and females that is not explainable by differences in body size alone.

Fig. 6. Photographs showing representative female and male proximal tibiae. Individual A: female (MLtib=70.121, NA=7.963). Individual B: male (MLtib=75.137, NA=10.410).

Implications for the Functional Interpretation of the Meniscal Notch in Fossil Hominins

Because small-bodied *Homo sapiens* females are significantly more likely to lack or have a small meniscal notch, care should be taken in the interpretation of early small-bodied female hominins. Lack of the meniscal notch in a small-bodied female does not, on its own, indicate that an individual did not engage in human-like terrestrial bipedality. The absence of a posterior lateral meniscal notch should also not be used to interpret an individual as incapable of loading the knee in full extension. Wider hips with shorter femora could contribute to greater inequality of forces acting on the medial and lateral menisci, and future study may demonstrate an important functional relationship between these features and the morphology of the meniscal notch.

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