JOURNAL OF FORENSIC SCIENCES

J Forensic Sci, January 2010, Vol. 55, No. 1
doi: 10.1111/j.1556-4029.2009.01222.x
Available online at: interscience.wiley.com

TECHNICAL NOTE

ANTHROPOLOGY

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Intercondylar Eminences and Their Effect on the Maximum Length Measure of the Tibia*

ABSTRACT: Maximum length measurement of the tibia has been found to be variable both in description and implementation. Historically, the literature often excludes the intercondylar eminences from the tibia in metric analysis. This paper explores the quantitative effects of inclusion or exclusion of the eminences on the maximum length measure across ancestral population, age and sex in five human adult populations of American Whites and Blacks, two Native American samples, and East Asians. A Tukey's *post hoc* comparison was employed to determine the overall effect of inclusion the intercondylar eminences has on metric assessment of the tibia. Results show no significant effect on comparative analysis of the tibia by age or sex. However, the difference between sample means by ancestry is significant ($p < 0.0001$). These results pose interesting questions concerning the morphological differences between ancestral groups. This investigation prompts further study of population variation of the human knee.

KEYWORDS: forensic science, forensic anthropology, metric analysis, tibia, population variation, intercondylar eminences

Techniques of metric analysis for postcranial human remains have long been used in physical anthropology to quantify morphological change and variation. As the science has developed, many of these methods have been modified and reformulated to suit the changing direction of morphological analysis and sophistication of measuring equipment. Changes and confusion have also arisen when the original definitions have been misinterpreted. Case in point is the human tibia where numerous authors have reworded specific methods of the maximum tibia measure (see Table 1) and have discovered variation in how a specific technique is applied in the literature (1–4).

The tibia has been a proverbial "bone of [metric] contention." In 1952, Trotter and Gleser took long bone measurements of tibiae from WWII war dead and a sample from the Terry Collection in order to develop living stature estimation formulae (5). These same authors later (6) re-evaluated their stature assessment by including a sample of Korean War casualties. This paper even alluded to discrepancies in the lengths of the tibia from the 1952 study to the 1958 study when they compared the means between the tibia and fibula (6). Re-examination of Trotter and Gleser's original sample data by Jantz et al. (1,2) discovered that contrary to Trotter's own definition, actual maximum length values for the tibia in the WWII and Terry Collection did not include the malleolus in the measurement. It instead reported the physiological length of the tibia. When using Trotter and Gleser regressions for stature, the physiological length would have to be employed to have correct stature outcomes, rather than the reported "maximum length."

For most appendicular long bones a "maximum length" measure exists defining the distance between the proximal- and distal-most points on the element (e.g., [7,8]). Few references (e.g., [9]) provide a true "maximum" definition for the tibia. The objective of this report is to investigate intercondylar eminence variation and its effect on the metric assessment of the tibia. In this analysis, age, sex, and ancestry will be evaluated for their effects on the differences in tibial measurement and variance of the intercondylar eminences.

Hypotheses

To assess the variation of the intercondylar eminences in the measurement of the tibia, following previous research, we investigate the null hypothesis that the intercondylar eminences do not have a significant effect on the maximum length measure of the tibia among individuals. In this case, it may have been historically considered an insignificant biological factor leading to its exclusion in metric analysis or that in an archeological context these rather fragile protuberances would be likely broken off or lost as a result of various postmortem taphonomic effects.

If the null hypothesis is rejected, four alternative hypotheses will be explored. Given age-related arthritic changes that frequently occur to the proximal tibia over time, age will be investigated as a contributing factor to intercondylar eminence variation. Many studies note variation in morphological factors due to sexual dimorphism. This idea highlighted in the clinical literature (e.g., [10,11]) suggests that differences between male and female construction of the knee, in both bone and soft tissue, could account for variation in the proximal tibia. Similarly, forensic and clinical research alike

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*This work was presented in part at the 58th Annual Meeting of the American Academy of Forensic Sciences, February 20–25, 2006, in Seattle, WA.

Received 13 Sept. 2008; and in revised form 5 Jan. 2009; accepted 11 Jan. 2009.

TABLE 1—*Referenced definitions of the maximum length measurement of the tibia.*

Reference	Definition
Stewart (7:170)	This is secured by placing the spine within the orifice of the vertical part of the board, applying the most prominent point on the condyles (generally the external) to the vertical, while holding the block applied to the malleolus, until the maximum length is determined
Trotter & Gleser (5:473)	End of the malleolus against vertical wall of the osteometric board, bone resting on its dorsal surface with its long axis parallel with the long axis of the board, block applied to the most prominent part of the lateral half of lateral condyle
Martin (8:930)	The distance from the superior face of the lateral condyle to the point of the medial malleolus
McHenry (9:330)	The maximum distance between the most proximal and most distal points on the tibia measured parallel to the shaft
Montagu (23:72)	The bone resting on its dorsal surface with the medial malleolus resting against the fixed upright. The movable upright is brought into contact with the antero-superior surface of the lateral condyle
Bass (24:233)	Place the end of the malleolus against the vertical (fixed) wall of the osteometric board, with the bone resting on its dorsal surface with its long axis parallel to the long axis of the board. Apply the block to the most prominent part of the lateral half of the lateral condyle
Buikstra & Ubelaker (21:83)	Distance from the superior articular surface of the lateral condyle to the tip of the medial malleolus
Jantz et al. (1:70)	The distance from the superior articular surface of the lateral condyle of the tibia to the tip of the medial malleolus

has explored human knee variation due to ancestral origin (e.g., [12,13]). Lastly, the possibility will be explored that none of these three variables alone but in combination best account for intercondylar eminence variation.

Theoretical and Methodological Assumptions (Modeled After Ref. [14])

Population studies based upon archaeological human remains are subject to a series of theoretical and methodological assumptions.

Our analysis is predicated upon the following assumptions:

- The sex and age of each individual included in this analysis was estimated without error. On the samples excluding the Whites and Blacks of the Terry Collection, this assumption is supported through an intra-observer analysis which resulted in no significant variation between the first and subsequent age and sex assessment of each individual. Inter-observer tests were also conducted and found nonsignificant variation to museum catalog records and sex and age assessments made by independent anthropological investigators. Accuracy of the sex and age assessment by the first author was assessed by comparing estimated age and sex of the Terry sample to the known documentation for each of these individuals.
- These skeletal series represent five comparable samples which would be representative of that population from a specific temporal and geographic period. These samples are from American White and Black populations, two Native North American groups from different subsistence and environmental habitats, and one East Asian population.
- To explore intercondylar eminence metric variation of the tibia, age, sex, ancestry, and the interaction between these factors are the best variables through which to test the theoretical and methodological assumptions.

Materials and Methods

The samples chosen for our analysis consist of varied and diverse ancestral and contemporary adult populations having both male and female components as well as a broad age spectrum. In the initial evaluation only four populations were utilized since they met all the age and sex criteria, American Blacks and Whites from the Terry Anatomical collection (15), South Dakota Arikara from late pre- to post contact historic sites (16), and Native Alaskan populations (17,18). Subsequent evaluation also included a fifth population of northern Chinese (19) to broaden the scope of the investigation; however, this small sample consists of males only. All individuals analyzed in this investigation were housed at the National Museum of Natural History, Smithsonian Institution, Washington, DC.

To investigate possible age-related changes to the knee joint having a significant effect on intercondylar eminence length, age ranges were employed in this investigation. Because of the archaeological nature of the South Dakota Arikara, Native Alaskan, and Chinese materials, ranges were grouped into two broad categories: "younger" (17–35 years of age) and "older" (35+ years of age) adults (Table 2). The Terry samples were also divided into these two categories. If age was found to be a significant factor in analysis of the tibia at this level, age categories would be broken down to further analyze the source of variation. Estimated age ranges for the archaeological samples were assessed using the Suchey-Brooks pubic symphysis aging system (20). In the few cases where the os pubis was absent, other age-related morphological criteria such as cranial suture closure, changes to the joint surfaces, enthesophytic and cortical bone texture, and dental attrition were used to estimate age (21).

Two measurements were made on the left tibia of each individual (the right side was used if the left side was absent or fragmented; this substitution was made in 46 cases, 8% of the total sample). The measurements are contrasted in Fig. 1 and defined as:

"*Maximum length*" (MaxL) = the total length of the tibia, from the proximal-most point to the distal-most point of the element.

Condylo-malleolar length (CondMal) = "distance from the superior articular surface of the lateral condyle to the tip of the medial malleolus" (21:83).

All measurements were taken by the first author and analyzed by all in an attempt to determine the length of the most prominent

TABLE 2—*Sample distribution.*

	Terry White	Terry Black	S.D. Arikara	Native Alaskan	Chinese	Total
Young male	20	20	31	33	15	119
Young female	14	20	25	43	—	102
Older male	30	30	46	68	36	210
Older female	30	30	18	57	—	135
Total	94	100	120	201	51	566

FIG. 1—*"Maximum length" vs. "Condylo-malleolar length."*

intercondylar eminence. This was predominantly the medial eminence.

In evaluation of whether the intercondylar eminences vary significantly by age, sex, ancestry or any combination of these variables a Tukey's *post hoc* comparison was employed to determine the overall effect their inclusion has on metric assessment of the tibia (22). To control for size bias we calculated the percent difference of intercondylar eminence inclusion, [(MaxL-CondMal)/MaxL]×100. This analysis identifies the effect this feature has on overall length of the tibia to interpret whether inclusion of the intercondylar eminences affects metric assessment (22).

Results

Table 3 represents the results of Tukey's analysis of the percent difference in total length through the inclusion of the intercondylar eminences by age, sex, ancestry, and interaction between these variables. Results of this analysis illustrate that only ancestry has a significant effect on the overall length of the tibia; all other variables are found not to be significant at the 0.05 level. In this first analysis, the Chinese were not included since the sample consists of only male individuals. The initial investigation, analyzed by sex, displayed comparable results to those seen in Table 3. Since age and sex were found to have no significant effect in this analysis, the Chinese were reintroduced and the sexes pooled to determine how this population compared to those previously investigated.

Tables 4 and 5 provide the descriptive statistics of the data by ancestry for both the raw differences between the MaxL and CondMal measurements as well as the percent difference in maximum tibia length when the intercondylar eminences are included in metric assessment. Terry Whites were found to have the largest difference in maximum length by the inclusion of the intercondylar eminences, followed by Terry Black, South Dakota Arikara, Native Alaskans, and the Chinese sample.

Tukey's analysis further highlights how these groups compare by ancestry. Table 6 displays the *p*-values obtained from the Tukey's *post hoc* comparison of the means between populations. The sample of Terry Whites is found to be significantly different from all other populations compared. Terry Blacks are significantly distinct from Terry Whites and the Chinese sample, but not from the two Native North American samples. The South Dakota Arikara are significantly different from Terry Whites and the Chinese sample could not be separated from Terry Blacks and Native Alaskans. Native Alaskan populations analyzed are found to be indistinguishable from Terry Black, South Dakota Arikara, and the Chinese. Finally, the Chinese were significantly different from all groups except the Native Alaskan sample.

TABLE 3—*Tukey's procedure: analysis of age, sex, ancestry, and interactions.*

Variable	DF	*F*-Value	*p*-Value
Ancestry	4	16.80	<0.0001
Sex	1	0.03	0.8635
Age	1	0.26	0.6085
Anc*Sex	3	1.55	0.1997
Anc*Age	4	1.37	0.2433
Sex*Age	1	0.37	0.5426

TABLE 4—*Descriptive statistics—raw mean difference between MaxL and CondMal measurements.*

Ancestry	Mean	Minimum	Maximum	Standard Deviation
Terry White	3.277	0	8	1.762
Terry Black	2.460	0	9	1.893
S.D. Arikara	2.050	0	7	1.644
Native Alaskan	1.701	0	7	1.432
Chinese	1.216	0	6	1.447

TABLE 5—*Descriptive statistics—percent difference in maximum tibia length when intercondylar eminences are included.*

Ancestry	Mean (%)	Minimum (%)	Maximum (%)	Standard Deviation (%)
Terry White	0.89	0.00	2.05	0.47
Terry Black	0.64	0.00	2.46	0.49
S.D. Arikara	0.55	0.00	1.69	0.43
Native Alaskan	0.51	0.00	2.09	0.43
Chinese	0.34	0.00	1.64	0.41

TABLE 6—*Significance between populations of percent difference in maximum tibia length when intercondylar eminences are included.*

	Terry White	Terry Black	S.D. Arikara	Native Alaskan
Terry Black	0.0011			
S.D. Arikara	<0.0001	0.5155		
Native Alaskan	<0.0001	0.1323	0.9681	
Chinese	<0.0001	0.0009	0.0452	0.0956

Discussion

The results of this study readdress the varying definitions for metric assessment of the tibia, investigate whether the addition of the intercondylar eminences influences comparative analysis, as well as raise an important observation concerning the morphological variation in the proximal portion of this element. While it still remains uncertain as to why previous researchers excluded the intercondylar eminences from previous definitions of maximum tibial measure, the present analysis has shown that these eminences display significant variances between some human populations. The differences and/or similarities between population ancestries found in this study have some interesting patterns. Following ancestral lines, it would be expected that the two Native American populations (Arikara of South Dakota and Native Alaskan groups) would have nonsignificant differences in the intercondylar eminence effect on the overall length of the tibia as seen in Table 6. It is also not surprising to find no significant differences present between the Native Alaskan and Chinese populations. However, at the 95% confidence interval, the South Dakota Arikara are found to be significantly different from the Chinese, but only by a small margin when this result is compared to the *p*-value of the Terry White and Black groups. The association found between the Terry Black and South Dakota Arikara is unusual and certainly cannot be accounted for by strict evolutionary relatedness. The similarity in morphology may be an artifact of an additional morphological component of the knee joint, the functional complex of the knee, the samples themselves, similar soft tissue association, or related to variation in body proportions.

While this study represents a strictly univariate analysis of a single feature, this investigation opens the door to further inquiry concerning population variation in the morphology of the human knee (4). Further analysis is in progress to enlarge the sample size, include additional ancestral groups to this research as well as adding a series of measurements of the tibial plateau and the associated distal femur to see if there are true distinctions between ancestral groups or if the differences are an artifact of size, shape, or functional variation among human populations (4). This investigation does not intend to add a new definition of maximum length of the tibia to the already long list left by previous researchers. However, we hope to contribute to the ongoing discussion of modern human variation and the accuracy and consistency of metric techniques.

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