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Sex Estimation from the Metatarsals

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ABSTRACT: Discriminant-function analysis of osteometric data from the metatarsals of 200 individuals in the Terry Collection provides a reliable method for estimating sex. Functions derived from individual metatarsals and from complete sets of metatarsals are tested on the sample used to generate the functions and on two independent samples: one comprising 25 additional individuals from the Terry Collection and the other comprising 12 cadavers donated to the University of Missouri. Functions based on race-specific samples (blacks and whites) and on the pooled-race sample correctly classify 83 to 100% of each sample (including a jackknifed study sample), with a few exceptions. These results are similar to sex-estimation methods from other regions of the appendicular skeleton.

KEYWORDS: forensic science, physical anthropology, metatarsals, sex estimation, osteometry, discriminant analysis, sexual dimorphism

When presented with a sample of skeletons, bioarchaeologists and forensic anthropologists usually attempt to estimate the sex of each individual represented. Accurate estimation of sex allows more precise conclusions about demographic structure and mortuary customs from archaeological samples and enhances the probability of identification in forensic cases. Properly trained osteologists can estimate sex from an adult skeleton with near 100% confidence when no elements are missing (1), but skeletal remains are often incomplete or fragmentary. In such cases, estimating sex can be problematic; if the skull and pelvis are absent, sex estimation can be especially difficult. Methods that employ nonpelvic postcranial bones to estimate sex are useful in such cases.

Many bones of the appendicular skeleton have been investigated for their capacity to aid the osteologist in sex estimation. Sex differences have been found in bones from the upper (2–5) and lower (2,6,7) limbs, including bones of the hand (8–10) and foot (11,12). Classification methods derived from these elements are approximately 84–96% accurate. Below, we present a sex-estimation method based on osteometric data from the metatarsals. The motivation for this study was twofold. First, the metatarsals frequently are well preserved in forensic situations because they often are recovered from inside the stocking and shoe, which afford protection from weathering and scavengers and are easily recovered if remains are scattered. Second, the short, stout nature of the metatarsals makes them useful in bioarchaeological contexts because they often survive unbroken.

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Materials and Methods

A study sample of 200 individuals of known sex was chosen at random from the Terry Collection, housed at the National Museum of Natural History of the Smithsonian Institution. The sample comprised complete sets of metatarsals from 48 white males, 48 white females, 52 black males, and 52 black females. Each metatarsal in the sample was inspected; if a bone exhibited evidence of disease, if it was fractured, or if it showed signs of taphonomic degeneration, the entire set from which it came was replaced by a set from a normal individual of the same race and age group. Age at death of individuals in the study sample ranged from 21 to 85 and was equally distributed among five-year intervals.

Two test samples were also assembled. The first comprised complete sets of metatarsals from 12 cadavers from the University of Missouri's Department of Anatomy, and the second sample comprised 25 randomly selected individuals (6 white males, 6 black males, 7 white females, and 6 black females) from the Terry Collection. None of the individuals from the Terry Collection test sample was used in the study sample. Each metatarsal (MT) was measured to the nearest tenth of a millimeter with sliding calipers as described in Table 1 and illustrated in Fig. 1.

Most of the measurements described in Table 1 are novel. Martin and Saller (13) described: (a) length measurements and two midshaft diameter (superoinferior and mediolateral) measurements for all five metatarsals, and (b) two head (capitulum) and two base measurements for the first metatarsal. The SIB and MLB measurements for the first metatarsal described here are equivalent to those described in Martin and Saller. Additionally, our MT5 length corresponds to the morphological length of MT5 described by Byers et al. (14). The rest of the measurements used here are novel; we measured maximum lengths instead of Martin and Saller's functional lengths, and head, base, and midshaft measurements were taken from points where the stationary jaw of the caliper could be stabilized either along a flat surface or across two protrusions of bone (for example, see SIH and MLH of MT1).

The metatarsals from 110 individuals in the study sample were measured by both authors. Additionally, one of us (A.G.R.) measured 45 individuals from the study sample a second time after a period of 3 months. From these repeated measures, interobserver and intraobserver error were calculated as outlined by Droessler (15) (Table 2). As one would expect, measurements with low values tend to produce relatively high error. However, MSD error rates for MT2 and MT3 appear disproportionately high. It is likely that the rapid and fluid distal tapering of MT2 and MT3 shafts is responsible for their greater errors; diameters measured a few millimeters distal or proximal to midshaft may affect the result substantially.

TABLE 1—*Description of measurements taken on metatarsals.*

Measurement	Bone(s)	Description
Length* (L)	MT1-4	From the most distal point on head to the most proximal point on lateral edge of proximal articular surface
	MT5†	From the most distal point on head to the most proximal point on proximal tuberosity
Superoinferior Head Height (SIH)	MT1	Maximum height of head perpendicular to line between the most plantar points on crests of medial trochlear surface
	MT2-4	Maximum height of head perpendicular to superior margin of distal diaphysis
	MT5	Maximum height of head from medial plantar extension of head to superior surface
Mediolateral Head Width (MLH)	MT1	Maximum width of head perpendicular to line between tubercle for medial metatarsophalangeal ligament and medioplantar margin of head
	MT2-5	Width of distal articular surface perpendicular to medial margin
Superoinferior Base Height (SIB)	MT1‡	Superoinferior height of base on metaphyseal ridge
	MT2 & 3	Height of entire base perpendicular to flat superior surface
	MT4	Height of proximal articular facet perpendicular to flat superior edge
	MT5	Height of articular facet for cuboid
Mediolateral Base Width (MLB)	MT1§	Width of base at metaphysis perpendicular to lateral side
	MT2	Width of base perpendicular to medial edge of proximal articular facet
	MT3	Width of proximal articular facet perpendicular to entire lateral edge
	MT4	Width of proximal articular facet perpendicular to facet for MT5
	MT5	Width of base perpendicular to medial surface of diaphysis
Midshaft Diameter‖ (MSD)	MT1	Diameter at midshaft perpendicular to flat lateral side
	MT2	Diameter at midshaft perpendicular to flat superomedial surface
	MT3	Diameter at midshaft perpendicular to flat superomedial surface
	MT4	Diameter at midshaft perpendicular to flat superolateral surface
	MT5	Diameter at midshaft perpendicular to flat superior surface

*Lengths were taken parallel to the superior surface of the diaphysis on MT1–4. Metatarsals 2–4 exhibit longitudinal torsion; the superior surface of the diaphysis near the base and that near the head usually are not in the same plane. The superior surface of the diaphysis is arbitrarily defined in reference to the head, not the base. Additionally, the diaphyses of MT2-4 often exhibit marked curvature in the superoinferior plane. In such cases, the superior surface is defined as the line from the superior surface of the proximal shaft to the superior surface of the distal shaft (cf. 14). The length of MT5 was taken parallel to the medial surface of the diaphysis.

†Same as morphological length described in (14) and used in (12).

‡Same as "Höhe der Basis des Os metatarsale 1" described in (13) and used in (12).

§Same as "Breite der Basis des Os metatarsale 1" described in (13) and used in (12).

‖Midshaft diameter is defined as the midpoint of the Length (L). Variations in midshaft geometry, especially of MT2 and MT3, necessitate careful consideration in identifying the surface from which midshaft measurements are taken.

The mean and standard deviation were calculated for each measurement from the Terry Collection study sample (Table 3). Side asymmetry (16,17) was checked on the first 50 individuals with Student's t-test for paired variates. Statistically insignificant ($p > .05$) differences were found between antimeres for every variable. Data from the right foot were used arbitrarily for calculating each function (see below).

The measurements then were processed using BMDP, in which stepwise discriminant functions were generated. An overview of discriminant analysis is provided by Giles (18). BMDP produces a classification function for each group to be discriminated (in this case, two groups). Tables 4–7 give a male function and a female function for each bone and for complete sets of metatarsals. An individual of unknown sex is assigned to a group by calculating his or her "male" score (using the male function) and "female" score (using the female function). The greater of the two scores indicates the probable sex of the individual [see (19) for discussion].

For example, to estimate sex from a first metatarsal with MLH = 20.7 mm, SIB = 28.0 mm, and MLB = 19.1 mm, the functions from Table 6 should be used as follows:

Male Function	Female Function
20.7 × 4.57723 = 94.74866	20.7 × 4.01449 = 83.09994
28.0 × 9.97772 = 279.37616	28.0 × 9.23746 = 258.64888
19.1 × 2.58050 = 49.28755	19.1 × 1.76753 = 33.75982
Constant = −241.21741	Constant = −189.65654
sum = 182.19496	sum = 185.85210

The female score (185.85210) is greater than the male score (182.19496), which suggests that the metatarsal originated from a female.

The predictive power of each function from Tables 4–7 was tested on the study sample used to generate each function, on the same sample using the "jackknife" procedure, and on two independent samples (Tables 8–10). The jackknife procedure is an operation available in BMDP that withholds one case (individual) from the data set, calculates a function based on the remaining cases, then tests the function on the withheld case. This operation is repeated until each case has been withheld and tested. The jackknife procedure can be used to perform a less-biased test of the study sample.

Results

Tables 8–10 indicate the percentage of individuals correctly classified by each function. Because Student's t-test indicated significant ($p < .05$) racial differences for at least one of the six measurements from each metatarsal, race-specific functions were generated. Pooled-race functions also were generated for cases presenting unknown race.

The functions based on data from blacks (Table 4) correctly classified 85 to 100% of the blacks from the 3 samples tested, with one exception. When applied to the Terry Collection test sample, the MT4 functions classified all of the females and half of the males as females, resulting in 75% combined accuracy.

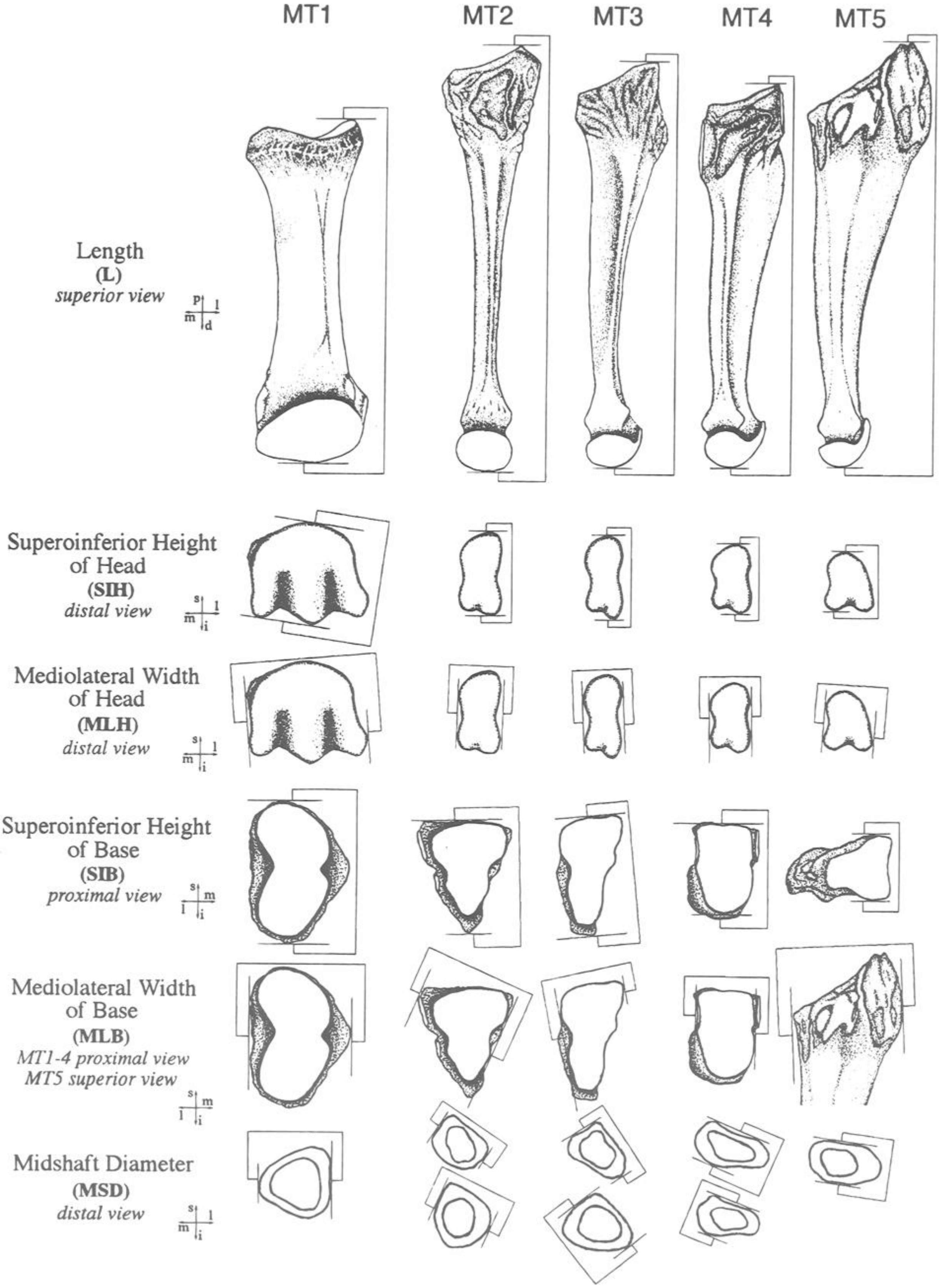

FIG. 1—*Measurements taken on metatarsals (left side depicted). Note two examples of midshaft diameter are given for MT2-4, illustrating some of the variation in geometry.*

TABLE 2—*Measurement replicability expressed in percent difference in observations between and within observers (interobserver error ♦ intraobserver error).**

	MT1	MT2	MT3	MT4	MT5
L	0.99 ♦ 0.71	0.17 ♦ 0.22	0.25 ♦ 0.16	0.27 ♦ 0.09	0.98 ♦ 0.61
SIH	2.90 ♦ 1.95	2.00 ♦ 1.47	2.10 ♦ 1.12	2.20 ♦ 1.08	2.80 ♦ 1.64
MLH	1.67 ♦ 1.00	1.39 ♦ 1.45	1.20 ♦ 0.88	2.20 ♦ 0.96	3.40 ♦ 2.94
SIB	0.55 ♦ 0.50	1.44 ♦ 1.10	2.70 ♦ 2.14	2.60 ♦ 1.43	2.70 ♦ 2.29
MLB	1.37 ♦ 1.02	2.40 ♦ 2.10	3.00 ♦ 2.04	2.70 ♦ 1.12	2.60 ♦ 2.04
MSD	1.66 ♦ 0.98	6.50 ♦ 4.29	6.70 ♦ 4.26	3.10 ♦ 2.54	2.92 ♦ 2.03

*Error calculated according to Droessler (15). Interobserver error, $n = 110$. Intraobserver error, $n = 45$.

TABLE 3—*Summary statistics for Terry Collection study sample by sex and race.**

				MT1		MT2		MT3		MT4		MT5	
	Race	Sex	n	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
L	Black	♂	52	67.7	4.1	81.6	4.5	76.4	4.4	74.7	4.3	74.7	4.6
	Black	♀	52	62.4	2.6	74.9	3.7	70.2	3.7	68.7	3.8	69.1	3.8
	White	♂	48	65.3	2.6	78.3	3.7	73.1	3.7	72.1	3.5	72.9	4.5
	White	♀	48	60.9	3.2	72.6	3.8	67.7	3.7	66.4	3.9	67.4	3.2
	Pooled	♂	100	66.5	3.6	80.0	4.4	74.8	4.4	73.4	4.1	73.8	4.6
	Pooled	♀	100	61.7	3.0	73.8	3.9	69.0	3.9	67.6	4.0	68.3	3.6
SIH	Black	♂	52	21.9	1.6	17.0	1.3	16.3	1.2	15.5	1.0	13.9	1.3
	Black	♀	52	19.4	1.3	14.7	1.1	14.0	1.1	13.2	1.0	11.8	1.0
	White	♂	48	22.0	1.4	16.5	1.0	16.0	1.0	15.3	1.0	14.0	1.1
	White	♀	48	20.0	1.4	14.8	0.9	14.3	1.0	13.4	0.9	12.0	0.9
	Pooled	♂	100	22.0	1.5	16.8	1.2	16.2	1.1	15.4	1.0	14.0	1.8
	Pooled	♀	100	19.7	1.3	14.7	1.0	14.1	1.1	13.3	0.9	11.9	0.9
MLH	Black	♂	52	23.7	1.5	11.8	1.1	10.3	0.9	10.4	1.0	10.4	1.1
	Black	♀	52	20.8	1.5	9.9	0.9	8.7	0.8	8.7	0.8	8.5	0.8
	White	♂	48	23.7	1.4	11.5	0.8	10.0	0.8	10.2	0.7	10.4	1.0
	White	♀	48	20.8	1.5	10.1	0.8	8.7	0.7	8.7	0.7	8.6	0.6
	Pooled	♂	100	23.7	1.4	11.6	1.0	10.1	0.9	10.3	0.9	10.4	1.0
	Pooled	♀	100	20.8	1.5	10.0	0.8	8.7	0.7	8.7	0.7	8.6	0.7
SIB	Black	♂	52	31.7	1.8	22.3	1.3	21.5	1.2	18.4	1.4	15.0	1.1
	Black	♀	52	28.1	1.4	19.7	1.1	18.9	1.2	16.3	1.3	13.0	1.0
	White	♂	48	31.3	1.4	21.9	1.4	21.1	1.6	17.6	1.3	14.6	0.9
	White	♀	48	28.4	1.5	19.9	1.1	19.1	1.4	15.8	1.2	13.0	1.0
	Pooled	♂	100	31.5	1.7	22.1	1.4	21.3	1.4	18.0	1.4	14.8	1.0
	Pooled	♀	100	28.3	1.5	19.8	1.1	19.0	1.3	16.0	1.3	13.0	1.0
MLB	Black	♂	52	22.6	1.9	16.5	1.4	14.9	1.2	12.3	1.3	21.6	1.6
	Black	♀	52	19.2	1.2	14.4	0.8	13.2	1.0	11.2	1.1	19.1	1.9
	White	♂	48	22.3	1.5	16.2	1.0	14.6	1.0	11.9	1.0	21.4	1.6
	White	♀	48	19.2	1.4	14.7	0.9	13.0	0.9	10.8	1.1	19.4	1.4
	Pooled	♂	100	22.5	1.7	16.4	1.2	14.8	1.1	12.1	1.2	21.5	1.6
	Pooled	♀	100	19.2	1.3	14.5	0.8	13.1	0.9	11.0	1.1	19.2	1.7
MSD	Black	♂	52	14.8	1.3	9.0	1.0	7.6	0.8	7.6	0.6	8.4	0.7
	Black	♀	52	12.8	1.1	8.3	1.2	6.5	0.8	6.7	0.7	7.3	0.8
	White	♂	48	13.8	1.0	8.0	1.0	7.4	0.6	7.2	0.6	7.8	0.8
	White	♀	48	11.6	1.0	7.4	0.9	6.3	0.6	6.2	0.6	6.7	0.7
	Pooled	♂	100	14.3	1.3	8.5	1.1	7.5	0.7	7.4	0.6	8.1	0.8
	Pooled	♀	100	12.2	1.2	7.9	1.1	6.4	0.7	6.5	0.7	7.0	0.8

*In mm.

TABLE 4—*Unstandardized discriminant function coefficients for predicting sex among blacks from individual metatarsals.*

	MT1		MT2		MT3		MT4		MT5	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
L									3.37081	3.22121
SIH			5.71442	4.75939	5.89153	4.81365	15.26762	13.04759		
MLH									1.97320	0.75412
SIB	9.93944	9.06656	10.08331	8.92964	12.32833	11.03531			9.74316	8.63504
MLB	3.66956	2.75696	9.15931	7.82254						
MSD			−3.42433	−2.59612						
C*	−199.59677	−154.44756	−221.73183	−168.96947	−181.34100	−138.86569	−119.52359	−87.47839	−210.21968	−172.33972

*Constant.

TABLE 5—*Unstandardized discriminant function coefficients for predicting sex among whites from individual metatarsals.*

	MT1		MT2		MT3		MT4		MT5	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
L			3.87728	3.66721			4.48579	4.22551	4.24308	3.97923
SIH					10.94776	9.81968			6.52864	5.69413
MLH	4.98750	4.28271	13.10122	11.30344			13.04877	10.45442	10.33844	8.15091
SIB	12.27349	11.46297	9.11098	8.25422						
MLB	3.08226	2.22756			10.12447	9.08245				
MSD					10.63846	8.64002				
C*	−286.46973	−228.89355	−327.51807	−274.19263	−201.93700	−156.80528	−229.93523	−187.12314	−254.93704	−204.68250

*Constant.

TABLE 6—*Unstandardized discriminant function coefficients for predicting sex from individual metatarsals (pooled races).*

	MT1		MT2		MT3		MT4		MT5	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
L			3.28773	3.10506			3.35604	3.20366	3.29237	3.12374
SIH					8.31315	7.18076	7.13759	5.73050	5.04082	4.43919
MLH	4.57723	4.01449	6.06473	4.67840			3.91495	2.59507	2.30303	0.98867
SIB	9.97772	9.23746	7.60927	6.78513	7.53330	6.83613			7.56608	6.86066
MLB	2.58050	1.76753	7.60690	6.66508			−0.06599	0.40054		
MSD			−5.94030	−5.09253	7.54703	6.25996				
C*	−241.21741	−189.65654	−288.78955	−234.74025	−176.66724	−136.46791	−199.32747	−161.05417	−225.64131	−183.51707

*Constant.

TABLE 7—*Race-specific and pooled-race discriminant function coefficients (unstandardized) for predicting sex from complete sets of metatarsals.*

		Male					Female				
		MT1	MT2	MT3	MT4	MT5	MT1	MT2	MT3	MT4	MT5
Blacks	L										
	SIH				8.59325					6.63297	
	MLH	7.73169					6.61505				
	SIB			8.73060					7.78623		
	MLB		9.51166		−3.20450			8.10752		−2.07992	
	MSD		−3.83892					−2.95107			
	C*		−294.56470					−221.61043			
Whites	L	6.39253					6.10699				
	SIH										
	MLH	6.66576				8.25152	5.75833				6.30978
	SIB										
	MLB										
	MSD			10.43521					8.54769		
	C*		−370.24927					−300.66895			
Pooled races	L										
	SIH	−0.46200			5.75366		0.10429			4.39494	
	MLH	6.34102					5.36922				
	SIB		7.73119					7.14406			
	MLB	1.43380	8.66320		0.03416		0.75288	7.57346		0.66728	
	MSD		−3.1283	5.54141				−2.41173	4.50938		
	C*		−295.67187					−228.91483			

*Constant.

Observer error (Table 2) is low for the variable used in the MT4 functions and therefore does not explain the relatively greater misclassification in this case.

Functions based on data from whites (Table 5) correctly classified 83 to 100% of the whites from the 4 samples tested, with two exceptions: functions based on MT5 correctly classified 50% of the males and 86% of the females (69% combined) from the Terry Collection test sample, and those based on MT3 correctly classified 100% of the males but only 40% of the females (75% combined) from the MU cadaver sample. Observer error (Table 2) was relatively low among all 3 variables used in the MT5 functions, but one variable (MSD) from the MT3 functions exhibited relatively greater error. However, it is unlikely that the greater observer-error rate associated with MSD from MT3 is responsible for the poor performance of the MT3 functions when tested on the MU cadaver sample, because: (a) the same functions, i.e., the same variables, correctly classified approximately 90% of the individuals from the other 3 samples, and (b) MSD is used in the pooled-race functions for MT3, and results from all four pooled-race samples ranged from 88 to 92% in accuracy.

The observed misclassification in these three cases is difficult to resolve. A more extensive test of the functions on a large,

TABLE 8—*Percent of blacks correctly classified using black functions.*

	Terry Collection Study Sample			Terry Collection Jackknifed Study Sample			Terry Collection Test Sample			MU Cadaver Sample		
	♂ (n = 52)	♀ (n = 52)	Combined (n = 104)	♂ (n = 52)	♀ (n = 52)	Combined (n = 104)	♂ (n = 6)	♀ (n = 6)	Combined (n = 12)	♂ (n = 0)	♀ (n = 0)	Combined (n = 0)
MT1	88.5	90.4	89.5	88.5	90.4	89.4	100	100	100	*	*	*
MT2	80.8	98.1	89.5	80.8	98.1	89.4	100	83.3	91.7	*	*	*
MT3	84.6	88.5	86.6	82.7	88.5	85.6	100	83.3	91.7	*	*	*
MT4	90.4	90.4	90.4	90.4	90.4	90.4	50.0	100	75.0	*	*	*
MT5	84.6	86.5	85.5	84.6	84.6	84.6	100	100	100	*	*	*
All	90.4	96.2	93.3	86.5	96.2	91.3	100	100	100	*	*	*

*Material not available.

TABLE 9—*Percent of whites correctly classified using white functions.*

	Terry Collection Study Sample			Terry Collection Jackknifed Study Sample			Terry Collection Test Sample			MU Cadaver Sample		
	♂ (n = 48)	♀ (n = 48)	Combined (n = 96)	♂ (n = 48)	♀ (n = 48)	Combined (n = 96)	♂ (n = 6)	♀ (n = 7)	Combined (n = 13)	♂ (n = 7)	♀ (n = 5)	Combined (n = 12)
MT1	93.8	91.7	92.8	91.7	89.6	90.6	100	100	100	100	80.0	91.7
MT2	89.6	85.4	87.5	89.6	83.3	86.5	83.3	85.7	84.6	100	80.0	91.7
MT3	93.8	87.5	90.7	89.6	87.5	88.5	83.3	100	92.3	100	40.0	75.0
MT4	89.6	87.5	88.6	87.5	83.3	85.4	83.3	85.7	84.6	100	80.0	91.7
MT5	89.6	93.8	91.7	89.6	93.8	91.7	50.0	85.7	69.2	85.7	80.0	83.3
All	97.9	95.8	96.9	91.7	93.8	92.7	66.7	100	84.6	100	60.0	83.3

TABLE 10—*Percent correctly classified using pooled-race functions.*

	Terry Collection Study Sample			Terry Collection Jackknifed Study Sample			Terry Collection Test Sample			MU Cadaver Sample		
	♂ (n = 100)	♀ (n = 100)	Combined (n = 200)	♂ (n = 100)	♀ (n = 100)	Combined (n = 200)	♂ (n = 12)	♀ (n = 13)	Combined (n = 25)	♂ (n = 7)	♀ (n = 5)	Combined (n = 12)
MT1	91.0	92.0	91.5	91.0	92.0	91.5	100	100	100	100	80.0	91.7
MT2	89.0	90.0	89.5	89.0	90.0	89.5	100	76.9	88.0	100	80.0	91.7
MT3	88.0	88.0	88.0	87.0	88.0	87.5	91.6	92.3	92.0	100	80.0	91.7
MT4	90.0	90.0	90.0	90.0	89.0	89.5	91.6	92.3	92.0	100	80.0	91.7
MT5	90.0	91.0	90.5	90.0	91.0	90.5	83.3	100	92.0	85.7	100	91.7
All	95.0	95.0	95.0	93.0	94.0	93.5	100	92.3	96.0	100	80.0	91.7

independent sample would better substantiate any problems in the method.

Functions derived from the pooled-race sample produced 88 to 100% correct classification in each sample (Table 10). As would be expected, functions based on complete sets of metatarsals were the most accurate, achieving 92 to 96% accuracy in the four samples tested, followed by MT1, MT5, MT4, MT3, and MT2 in order of decreasing accuracy.

In many cases, the pooled-race functions achieved greater classification success than one or both of the race-specific functions (Tables 8–10). This can be attributed to: (a) the larger sample used to calculate the pooled-race functions and the greater statistical power associated therewith, and (b) the observation that the metatarsals of blacks and whites are not different enough from each other to make race-specific functions as effective as pooled-race functions.

The second point deserves some attention. Two lines of evidence indicate that in general, differences in the metatarsals between blacks and whites, though they exist for some variables, are not great (20). First, we calculated race-estimation functions from the same measurements of the study sample described above. The functions predicted race little better than the chance expectation of 50%, giving correct predictions 50 to 70% of the time (cf. 12). Second, each sex-estimation function generated from the sample of blacks was tested on the white samples, and vice versa. A high rate of success resulted, ranging from 81 to 100% accuracy with only three exceptions (Tables 11 and 12).

Discussion

The role of the metatarsals in human identification had previously been confined to stature estimation (14), though sex differences in the metatarsals have been reported elsewhere. Riesenfeld (21) studied the metatarsals of 36 primate genera and found those

TABLE 11—*Percent of blacks correctly classified using white functions.*

	Terry Collection Study Sample			Terry Collection Test Sample			MU Cadaver Sample		
	♂ (n = 52)	♀ (n = 52)	Combined (n = 104)	♂ (n = 6)	♀ (n = 6)	Combined (n = 12)	♂ (n = 0)	♀ (n = 0)	Combined (n = 0)
MT1	92.3	92.3	92.3	100	100	100	*	*	*
MT2	88.5	82.7	85.6	100	83.3	91.7	*	*	*
MT3	90.4	76.9	83.7	100	83.3	91.7	*	*	*
MT4	92.3	84.6	88.5	100	83.3	91.7	*	*	*
MT5	86.5	82.7	84.6	100	83.3	91.7	*	*	*
All	94.2	84.6	89.4	100	66.7	83.3	*	*	*

*Material not available.

TABLE 12—*Percent of whites correctly classified using black functions.*

	Terry Collection Study Sample			Terry Collection Test Sample			MU Cadaver Sample		
	♂ (n = 48)	♀ (n = 48)	Combined (n = 96)	♂ (n = 6)	♀ (n = 7)	Combined (n = 13)	♂ (n = 7)	♀ (n = 5)	Combined (n = 12)
MT1	87.5	91.7	89.6	100	100	100	100	80.0	91.7
MT2	87.5	75.0	81.3	100	57.1	76.9	100	80.0	91.7
MT3	75.0	77.1	76.0	83.3	100	92.3	85.7	80.0	83.3
MT4	87.5	89.6	88.6	83.3	100	92.3	100	80.0	91.7
MT5	85.4	95.8	90.6	50.0	100	76.9	85.7	100	91.7
All	97.9	87.5	92.7	100	85.7	92.3	100	80.0	91.7

of humans to be the most sexually dimorphic. Cwikla et al. (20) analyzed 8 measurements from the first metatarsal and found significant differences ($p < .05$) between sexes for each measurement. We found significant differences between sexes in the remaining four metatarsals and in additional measurements of the first metatarsal.

While this manuscript was in preparation, we became aware of a forthcoming paper that addresses the estimation of sex and ancestry from the metatarsals and pedal phalanges (12). Although most of the metatarsal measurements used in Smith's study (12) are different from those outlined here (see Table 1), her results regarding sex estimation are quite similar to ours.

The results of this study are also similar in accuracy to those from studies based on other areas of the appendicular skeleton. Berrizbeitia (5) was able to correctly classify 94 to 96% of the radii by sex from her sample. Holman and Bennett (4) were 80 to 95% successful in estimating sex from the long bones of the arm and forearm. Black's (6) assessment of sex from the femur was consistent with 85% of his sample. İşcan and Miller-Shaivitz (7) correctly predicted sex in 85 to 95% of the tibiae they analyzed.

Several authors have investigated sex differences in the human hand. Scheuer and Elkington (8) correctly predicted sex from the metacarpals and first proximal phalanx in 74 to 94% of their sample, though Lazenby (17) reported little success in classifying females using their equations. Falsetti (9) and Smith (10) also used hand bone dimensions to calculate sex-estimation functions. Falsetti achieved better results (84 to 92% accuracy) from his study sample than he did from two independent test samples (58 to 85% accuracy). Smith's results from her study sample and jackknifed study sample were approximately equal (90 to 94% and 89 to 94% accuracy, respectively).

Studies of sex differences in the foot approximate those of the hand in accuracy. Steele (11) was 79 to 89% successful in assigning individuals to sex based on the talus and calcaneus. From the metatarsals and pedal phalanges, Smith (12) correctly predicted sex in 86 to 94% and 84 to 91% of the individuals from her study sample and jackknifed study sample, respectively. The functions we present here correctly classified 86 to 95% of the study sample, 85 to 94% of the jackknifed study sample, 69 to 100% of the Terry Collection test sample, and 75 to 92% of the MU cadaver sample.

Lazenby (17) recently addressed the problem of side asymmetry in the second metacarpal (16) and its effect on sex estimation (8). Because right-sided metacarpals are usually larger than those from the left side, comparison of bones from the left hand of males with those from the right hand of females produces confounding results. Side asymmetry was investigated for the metatarsals; Student's *t*-test for paired variates revealed no significant differences between sides. Unlike the metacarpals, the metatarsals exhibit no indications of side dominance, or "handedness," of the feet (cf. 22).

Conclusions

The most reliable way to estimate sex from the skeleton of an unknown individual is to examine the pelvis and skull. If they are absent or badly damaged, sex must be estimated using other bones of the postcranial skeleton. Sex can be estimated from the metatarsals with 88 to 100% accuracy using pooled-race functions presented here. Race-specific functions resulted in a greater range of successful classification (69 to 100% correct), often not producing results as successful as those produced by the pooled-race functions. Given the similarity in the metatarsals of blacks and whites and the performance of the pooled-race functions, we recommend the pooled-race functions for estimating sex from individuals known to be either black or white.

As with other discriminant functions, those presented here are population specific and may require adjustments if applied to other populations (23). For example, Munsee Indian first metatarsals are significantly shorter than those from Terry Collection whites, even after correction for leg length (22). Moreover, several authors (24,25) have elucidated recent secular trends in the length and proportion of long bones among Americans. Forensic methods (e.g., stature estimation) based on femur and tibia metrics derived from individuals as recent as those in the Terry Collection may be inappropriate for application to more modern body proportions and size. Presently, secular change among the metatarsals has not been investigated and consequently, remains unclear. The metatarsals offer useful information about the sex of the individual represented if such limitations are taken into account.

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