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Sex Determination from Metacarpals and the First Proximal Phalanx

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ABSTRACT: Sex determination using metacarpals and the first proximal phalanx was carried out on a sample ($n = 60$) of documented sex. Six measurements were taken on each of metacarpals 1 to 5 and the first proximal phalanx. Regression equations were calculated for determining sex from the bones. The equations were then applied to a second sample ($n = 20$) also of documented sex to establish the degree of accuracy they produced in assigning sex. The equations for metacarpal 1 produced the highest degree of correct sex determination and overall the degree of accuracy ranged from 74% to 94%.

KEYWORDS: physical anthropology, sex determination, metacarpals, proximal phalanx

In both the forensic and archaeological analysis of human skeletal remains the determination of sex is the first and arguably the most important step. If this assessment is correct, then further investigations are likely to be more accurate as separate male and female standards may then be used for estimation of both age and stature. In addition, it allows the forensic pathologist attempting to identify an individual, to remove all members of the opposite sex from further consideration and the archaeologist to construct a more accurate demographic profile of the population under investigation.

Confidence in the accuracy of sex prediction depends both on the completeness of the remains and on the degree of sexual dimorphism exhibited by the skeleton. Krogman and Iscan [*1*] claim that approaching 100% accuracy may be achieved if the complete adult skeleton is available. However, remains are often incomplete or damaged, and, if neither the skull nor pelvis is available, then sex prediction must be attempted from other parts of the skeleton. It has long been accepted that most other elements show some degree of sexual dimorphism albeit to a lesser degree than the pelvis or skull [*2–6*]. Levels vary between different bones of the same individual and there is some evidence to suggest that non-weight bearing bones, such as the humerus, show higher levels of dimorphism than weight bearing bones such as the femur [*7*]. Differences have also been reported within the same bone. For instance, Black [*6*] found that the widths of long bones are more sexually dimorphic than their lengths.

The shafts of long bones often survive inhumation but their epiphyses, having a thin layer of compact bone over the more fragile cancellous bone are very prone to damage [*8*]. The smaller long bones of the hands and feet often remain complete.

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For a sexing method to be useful it should yield an accuracy of at least 80% and be as free as possible from subjective assessment. It is an additional advantage if the method can be used by a relatively inexperienced observer with simple apparatus. The purpose of this study was to assess the degree of sexual dimorphism present in human metacarpals and the first proximal phalanx using sliding calipers and applying a simple formula.

Material

All hand bones were of recent origin and derived from dissecting room cadavers from medical schools in the United Kingdom. The subjects were white and of British ancestry. Only bones of known sex, showing no evidence of pathology were included in the samples. Measurements from the first sample of 60 hands were used to calculate the regression equations. The second sample of twenty hands were used to test the accuracy of correct sex determination. The range of ages at death, dates of birth, dates of death and sex ratios are shown in Table 1.

Methods

Preparation of the Bones

All five metacarpals and the first proximal phalanx were disarticulated from the rest of the hand of each subject and as much soft tissue as possible was removed. They were then encased in muslin bags and boiled in 0.05 M solution of sodium hydroxide until the joint cartilages became detached. This took approximately two hours. Any remaining soft tissue was then dissected away.

Measurements

The measurements were completed without prior knowledge of the documented sex. They were taken to the nearest 0.05 mm with sliding calipers.

The following six measurements were taken

1) interarticular length;
2) mediolateral width of the base;
3) anteroposterior width of the base;
4) mediolateral width of the head;
5) anteroposterior width of the head;
6) maximum midshaft diameter.

Morphometric results are often difficult to replicate by other authors due to ambiguities in the description of the measurements taken. These points are therefore described in some detail and as precisely as possible in order to prevent this problem.

TABLE 1—*Details of samples.*

	Sample 1	Sample 2
Age at death	19–86	67–98
Dates of birth	1844–1930	1890–1921
Dates of death	1926–1988	1987–1988
Sex - male	$n = 33$	$n = 10$
female	$n = 27$	$n = 10$
	$n = 60$	$n = 20$

Lengths

These were the same as those used by Musgrave and Harneja [*9*].

Metacarpal 1—The interarticular length was measured from the center of the proximal articular surface to the apex of the head.

Metacarpal 2—The center of the proximal articular surface has a notch for articulation with the trapezoid consisting of a narrow anterior part and a wider posterior part, both running in a distal/proximal direction diagonally from the respective anterior and posterior surfaces of the bone. The measurement of length is taken from where these two parts meet to form a slight ridge, to the most distal point of the apex of the head.

Metacarpal 3—The center of the proximal articular surface of this bone may be defined as a point lying as near as possible to the longitudinal axis on the ridge that runs in an anteroposterior direction across the base and separates the articular facet for the capitate from that for metacarpal 2.

Metacarpal 4—The proximal articular surface of this bone is very variable and the length was measured from a point as close as possible to a hypothetical center of the base to the apex of the head along the longitudinal axis of the bone.

Metacarpal 5—The articular facet for the hamate is usually convex in the anteroposterior plane, and concave in the mediolateral plane and the length was measured from the most distal point in the concavity in the mediolateral plane to the apex of the head.

Proximal phalanx 1—The calipers were placed on the posterior surface of the bone and the length was taken from the middle of the posterior rim of the proximal articular surface to the concavity between the two condyles on the distal end. An exception to the rule of measuring from the center of the middle of the articular surface was made in the case of this bone. The base of the bone is basin shaped and it is not possible to measure the articular length without specially constructed calipers.

It has long been recognized that articular surfaces are more sexually dimorphic than other parts of a bone [*2,10–12*]. Therefore the maximum diameters of the articular areas of the heads and the bases of the bones rather than merely the maximum diameters were measured.

Bases

Mediolateral—The bases of metacarpals are very variable [*13*] especially in the case of metacarpal 4, but whatever the morphology of the articular surface, a measurement was taken from the most medial to the most lateral point. The calipers were always kept in the mediolateral plane. Where the articular surface of the metacarpals continued distally medially or laterally the most medial or lateral point respectively was used. Occasionally on metacarpal 4 the articular surface of the base was in two parts and the measurement was then taken from the most medial border of the medial articular surface to the most lateral border of the lateral articular surface.

Anteroposterior—This was measured at right angles to the previous measurement. In the case of the proximal phalanx, when the anterior rim of the articular surface had two anterior points, a measurement was taken from an imaginary line joining these two points to the most posterior point of the articular surface.

Heads

Mediolateral—The maximum mediolateral width of the articular surface of the heads was always that between the anterior tubercles. For proximal phalanx 1 the head was defined as the part of the bone to which the anterior collateral ligaments are attached.

Anteroposterior—This was a measurement of the maximum width of the articular surface of the head in the anteroposterior plane at right angles to the previous measurement. If either of the anterior tubercles at the head projected further anteriorly than the other, this measurement was taken from the apex of the larger tubercle. For proximal phalanx 1 a measurement of the maximum distance between the most posterior point on the articular surface and the most anterior points on the medial and lateral condyles was taken.

Mid-Shaft

A maximum diameter was recorded at the midpoint between the most proximal and distal points already defined. It was found by rotating the shaft of the bone to find the maximum dimension whilst being firmly clasped by the calipers.

Statistical Analysis

1. The means, standard deviations and pooled standard deviations were calculated.
2. The index of separation (d/s) between males and females was calculated using the formula

$$d/s = \frac{\text{male mean} - \text{female mean}}{\text{pooled standard deviation}}$$

where the pooled standard deviation is the weighted combination of the two separate standard deviations for males and females (for method see Chinn [*14*]). Once these figures were known it was apparent which bones and measurements showed the most sexual dimorphism. The larger the d/s value the greater the dimorphism. The probability of correct sex determination p{C.S.D.} was also calculated using the formula

$$1 - S \times 100$$

where S = the probability of incorrect sex determination (normal distribution probability tables).

3. In order to increase the degree of separation as much as possible some of the variables were combined together by multiple regression. This was done, both by using all the measurements on any one individual bone and by using a single measurement on all the different bones.

Sex (Y), where $Y = 1$ for males and $Y = 2$ for females, was regressed on the bone measurements (X) to produce equations with the generalized formula

$$Y = k_1 + k_2X_1 + k_3X_2 + k_4X_3 + k_5X_4 \ldots \text{ where } k \text{ is a}$$

constant so that, for prediction purposes,

if $Y > 1.5$ the bone is female and $Y < 1.5$ the bone is male

4. The index of separation was also calculated on the predicted value from each equation. The equations producing a high index of separation and probability of correct sex determination above 74% were then tested on the second sample of 20 hands.

Results

A major aim of this investigation was to develop equations based on measurements with acceptable levels of reproducibility. There was no significant intra- or interobserver error in a test of six individuals. The measurements with the lowest percentage error were the interarticular lengths and the midshaft diameters whilst the greatest errors were found in both the mediolateral and anteroposterior widths of the bases.

Table 2 shows the means and standard deviations for the measurements on each bone. Although the male mean values were larger than the female means for every measurement there was considerable overlap of the ranges.

Table 3 summarizes the indices of separation for each variable. These are the largest in the midshaft measurements except for metacarpals 2 and 5.

Multiple Regression Equations

Metacarpal 2

$$Y\,(\text{Sex}) = 3.61 + (0.0143 \times a) - (0.167 \times b) + (0.0124 \times c) - (0.0152 \times d) + (0.0910 \times e) - (0.166 \times f)$$

Metacarpal 1

$$Y\,(\text{Sex}) = 4.58 - (0.0092 \times a) - (0.0240 \times b) - (0.0619 \times c) - (0.0118 \times d) + (0.0108 \times e) - (0.132 \times f)$$

Metacarpal 3

$$Y\,(\text{Sex}) = 4.33 + (0.0099 \times a) - (0.107 \times b) - (0.0870 \times c) - (0.0245 \times d) + (0.0770 \times e) - (0.155 \times f)$$

Proximal phalanx 1

$$Y\,(\text{Sex}) = 4.15 - (0.0173 \times a) + (0.0139 \times b) - (0.119 \times c) - (0.0511 \times d) + (0.0895 \times e) - (0.1320 \times f)$$

Metacarpal 5

$$Y\,(\text{Sex}) = 4.56 - (0.0011 \times a) - (0.0669 \times b) + (0.0617 \times c) + (0.0413 \times d) - (0.0235 \times e) - (0.0795 \times f)$$

Metacarpal 4

$$Y\,(\text{Sex}) = 3.72 + (0.0198 \times a) + (0.0085 \times b) - (0.0102 \times c) - (0.0185 \times d) - (0.1370 \times e) - (0.1780 \times f)$$

where

a = Length	d = Head M/L
b = Base M/L	e = Head A/P
c = Base A/P	f = Midshaft

TABLE 2—*Means and standard deviations of measurements on each bone.*

	Metacarpal 1			Prox. phal. 1			Metacarpal 2		
	Sex	*n*	Mean S.D.	Sex	*n*	Mean S.D.	Sex	*n*	Mean S.D.
Length	M	33	44.12 ± 3.72	M	32	30.38 ± 2.43	M	32	65.24 ± 4.99
	F	26	41.65 ± 3.46	F	27	28.31 ± 2.79	F	27	62.79 ± 5.02
Base M/L	M	32	15.45 ± 1.32	M	32	14.72 ± 1.32	M	32	17.59 ± 1.41
	F	24	13.91 ± 1.34	F	27	13.71 ± 1.13	F	27	15.51 ± 1.54
Base A/P	M	32	13.65 ± 1.22	M	32	11.22 ± 0.96	M	33	16.45 ± 2.30
	F	24	12.56 ± 1.29	F	27	10.19 ± 0.96	F	27	15.44 ± 1.42
Head M/L	M	33	14.97 ± 1.12	M	32	13.15 ± 1.21	M	32	14.93 ± 1.42
	F	26	13.72 ± 1.26	F	27	12.18 ± 0.95	F	27	13.77 ± 1.22
Head A/P	M	33	14.16 ± 1.21	M	32	9.18 ± 1.04	M	32	14.97 ± 1.31
	F	26	13.17 ± 1.37	F	27	8.61 ± 0.95	F	27	13.99 ± 1.26
Midshaft	M	33	12.48 ± 1.12	M	32	9.93 ± 1.07	M	33	9.95 ± 0.90
	F	26	10.98 ± 1.21	F	27	8.82 ± 0.90	F	27	8.94 ± 0.95
	Metacarpal 3			Metacarpal 4			Metacarpal 5		
	Sex	*n*	Mean S.D.	Sex	*n*	Mean S.D.	Sex	*n*	Mean S.D.
Length	M	33	63.29 ± 3.76	M	33	56.97 ± 3.54	M	33	52.95 ± 2.75
	F	27	60.17 ± 4.94	F	26	54.90 ± 4.59	F	27	50.62 ± 3.90
Base M/L	M	33	14.45 ± 1.21	M	33	12.51 ± 1.52	M	33	11.62 ± 1.49
	F	27	13.16 ± 1.38	F	25	11.76 ± 1.30	F	27	10.51 ± 1.13
Base A/P	M	33	15.88 ± 1.62	M	33	11.64 ± 1.26	M	33	11.33 ± 1.14
	F	27	14.33 ± 1.39	F	25	10.72 ± 1.40	F	27	10.60 ± 1.22
Head M/L	M	33	14.60 ± 1.30	M	33	12.47 ± 0.84	M	33	12.08 ± 0.78
	F	27	13.52 ± 1.24	F	27	11.63 ± 1.06	F	27	11.29 ± 1.09
Head A/P	M	33	15.25 ± 1.41	M	33	13.62 ± 1.06	M	33	12.49 ± 0.89
	F	27	14.10 ± 1.40	F	27	12.49 ± 1.07	F	27	11.49 ± 0.93
Midshaft	M	33	9.99 ± 0.83	M	33	7.99 ± 0.79	M	33	8.28 ± 0.93
	F	27	9.05 ± 0.95	F	27	7.15 ± 0.70	F	27	7.72 ± 0.90

NOTE: *n* varies slightly depending on whether there was damage or pathology at relevant sites.

TABLE 3—*Summary of the indices of separation for each variable.*

	Met 1	Prox. ph. 1	Met 2	Met 3	Met 4	Met 5
Length	0.67	0.80	0.49	0.72	0.51	0.70
Base M/L	1.16	0.81	1.41	1.00	0.52	0.83
Base A/P	0.87	1.07	0.52	1.02	0.70	0.62
Head M/L	1.06	0.88	0.87	0.84	0.89	0.84
Head A/P	0.77	0.57	0.76	0.82	1.06	1.10
Midshaft	1.29	1.12	1.09	1.06	1.11	0.62

Midshafts

$$Y\,(\text{Sex}) = 3.82 - (0.177 \times A) - (0.102 \times B) + (0.0476 \times C) + (0.0905 \times D) - (0.175 \times E) + (0.0858 \times F)$$

where

A = metacarpal 1
B = proximal phalanx 1
C = metacarpal 2
D = metacarpal 3
E = metacarpal 4
F = metacarpal 5

Table 4 shows that the standard deviations of predicted values for males and females were similar, and therefore the index of separation, shown in Table 5, was a valid comparison of the different equations.

TABLE 4—*Means and standard deviations of predicted values from regression equations.*

	Males			Females		
Equation	n	Mean	SD	n	Mean	SD
Metacarpal 2	31	1.28	0.23	27	1.69	0.26
Metacarpal 1	32	1.29	0.23	24	1.62	0.25
Metacarpal 3	33	1.29	0.24	27	1.62	0.23
Prox. phal. 1	32	1.33	0.23	27	1.62	0.23
Metacarpal 5	33	1.33	0.24	27	1.61	0.22
Metacarpal 4	33	1.32	0.23	25	1.60	0.22
Midshafts	32	1.29	0.25	26	1.64	0.23

TABLE 5—*Summary of indices of separation and probability of correct sex determination produced by regression equations.*

	d/s	p{C.S.D.}
Metacarpal 2	1.62	79%
Midshaft	1.44	76%
Metacarpal 1	1.41	76%
Metacarpal 3	1.37	75%
Proximal phalanx 1	1.26	74%
Metacarpal 5	1.23	73%
Metacarpal 4	1.20	73%

TABLE 6—*Percentage correct sex determination on test sample.*

Regression equation	Probability of correct sex	Actual correct sex
Metacarpal 2	79%	78%
Midshaft	76%	80%
Metacarpal 1	76%	94%
Metacarpal 3	75%	74%
Prox. phalanx 1	74%	78%

Table 6 shows the results of sex determination of the best five equations on the test sample of twenty bones. Although the probability of correct sex determination was highest in metacarpal 2 the best figure for actual correct determination in the test sample was with metacarpal 1.

Discussion

There is little literature on sex differences in hand bones per se. Plato et al. [*15*] found that the second metacarpal was longer in both adult Guamanian and American white males than in females. Himes and Malina [*16*], in a study of Mexican children, showed that the sexual dimorphism in metacarpal diaphyseal diameter is related to differences in body size, but, at a constant body size and age, boys have significantly larger diaphyseal diameters than girls. It would therefore appear that this difference was present from a juvenile stage of development.

It is now standard to use the second metacarpal as an index of body size or bone mass [*17–20*]. All these authors give separate values for males and females thus indicating that there is general acceptance that metacarpals show some degree of sexual dimorphism. There are also methods in the literature for the estimation of adult stature from hand and foot bones [*9,21,22*]. Where this is the method of choice, it is necessary to sex the metacarpals as again, *all* these authors give separate regression equations for males and females.

Krogman [*23*] stated that close to 100% accuracy of sex prediction could be achieved from an intact skeleton but this falls to 80% if only the long bones are available and it is certainly better to use the larger long bones for sex determination. Black [*6*] pointed out that measurement errors as small as 0.5 mm can account for 5 to 6% of the total width in hand and foot bones so that larger bones are preferred for this reason alone. However, in poorly preserved remains metacarpals are often found undamaged following inhumation when larger bones are either broken or missing. Complete metacarpals are sometimes preferred to long bone fragments. For example, Meadows and Jantz [*21*] stated that stature estimation equations from metacarpals possess lower standard errors of estimate than those from long bone fragments. There are also occasions in an archaeological [*24*] or a paleontological [*25,26*] context when handbones form either the majority, or the only postcranial bones.

The relatively low indices of separation were augmented somewhat by using multiple regression equations but it was nevertheless surprising to find that, using metacarpals only, an accuracy of up to 94% was found. The probability of correct sex determination and the actual percentage obtained did not match when tested on the relatively small sample of 20 hands and there was a higher than expected accuracy using both the bones of the thumb and the midshaft measurements. The results undoubtedly reflect the larger body size and power grip of the male hand.

There is always a need for further techniques of sex determination that will work with both poorly preserved remains and with single finds. Work on a larger documented sample and on other populations would test the usefulness of these equations.

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