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TECHNICAL NOTE

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Testing the Validity of Metacarpal Use in Sex Assessment of Human Skeletal Remains*

ABSTRACT: To assess the potential of employing metacarpals in assessing sex of human skeletal remains, previous investigators have generated regression equations (Scheuer & Elkington, 1995) and linear discriminant functions (Falsetti, 1995; Stojanowski, 1999) based upon measurements from metacarpals. Results have varied in overall accuracy and which metacarpal produces the greatest accuracy. Using a contemporary sample, this study seeks to evaluate the validity of using metacarpals to assign sex by testing methodologies of previous studies. Measurements defined by previous authors were repeated on metacarpals from 23 adult cadavers and data were subjected to regression equations and linear discriminant analysis according to previous methodologies. Accuracy in sex determination from methods of Scheuer & Elkington (1993) and Falsetti (1995) were lower than originally reported while accuracy from methods of Stojanowski (1999) were higher than previously reported. These results suggest that the use of metacarpals in sex determination may be limited and should be applied cautiously.

KEYWORDS: forensic science, forensic anthropology, metacarpal, sex assessment

Determination of sex is one of the most important steps during forensic and archeological analyses of human skeletal remains. Presence of both the skull and pelvis may provide the most accurate sex determination potential (2). However, both of these components may not be present in every instance or in pristine condition, necessitating the use of other skeletal elements. Three previous studies in particular (1,3,4) have addressed the issue of using metacarpals in determining the sex of adult human skeletal remains. Scheuer and Elkington (3) generated multiple regression equations for determining the sex of skeletal remains by employing six measurements for each metacarpal. Using a contemporary, adult white British sample, they reported sexing accuracy from 74–94%, with metacarpal 1 providing the greatest accuracy.

Falsetti (1) generated linear discriminant functions using five measurements for each metacarpal. Using samples from the Terry collection at the Smithsonian Institution (consisting of both black and white individuals of non-contemporary origins), cadavers from the Royal Free Medical School in London (whites of British ancestry), and the University of New Mexico collection (consisting of both black and white individuals born after 1900), accuracy from 84.37–92.0% was reported with metacarpal 2 providing greatest accuracy. However, only metacarpals 2, 4, and 5 were used due to significant race differences being found in metacarpals 1 and 3.

Finally, Stojanowski (4) generated linear discriminant functions using the six measurements of Scheuer & Elkington (3) for each metacarpal. In this case, the six measurements per metacarpal were arranged so that there were seven functions for each bone (35 separate functions altogether). These functions were generated based upon likely preservation scenarios, which included fragmentary remains. Using samples from the University of New Mexico collection, accuracy ranged from 75–90% with metacarpal 4 providing the most consistently accurate estimates.

These previous studies all conflict in terms of range of accuracy in predicting sex as well as which metacarpal yielded the most accurate results. This study seeks to test each of these methodologies using a contemporary white, adult population in order to determine which methodology yields the most accurate sex determination and which metacarpal provides the most accurate information.

Methods

Metacarpals from 23 adult human cadavers that were used in gross anatomy courses at Slippery Rock University School of Physical Therapy were harvested and cleaned of all soft tissue. All cadavers were white and of known sex (11 females; 12 males). Age at death ranged from 64–93 years. Only metacarpals that showed no pathology (such as healed fractures, osteoarthritis) were used in this study. Seven metacarpals were thus excluded from measurements due to excessive lipping at the articular ends, indicating possible osteoarthritis. Measurements were taken without knowledge of the sex of the cadaver from which the bone was harvested. All measurements were taken with digital sliding calipers to the nearest 0.01mm.

In order to evaluate the multiple regression equations of Scheuer and Elkington (3), the six measurements defined in their study were

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repeated (Fig. 1):

- Interarticular length;
- Mediolateral breadth of the base;
- Mediolateral breadth of the head;
- Anteroposterior breadth of the base;
- Anteroposterior breadth of the head; and
- Mediolateral breadth of the midshaft.

All data were then subjected to the regression equations.

To test the methods of Falsetti (1), the five measurements used in that study were repeated here (Fig. 1), using only the left hands:

- Interarticular length;
- Mediolateral breadth of the head; and
- Mediolateral breadth of the base;
- Mediolateral breadth of the midshaft; and
- Anteroposterior breadth of the midshaft.

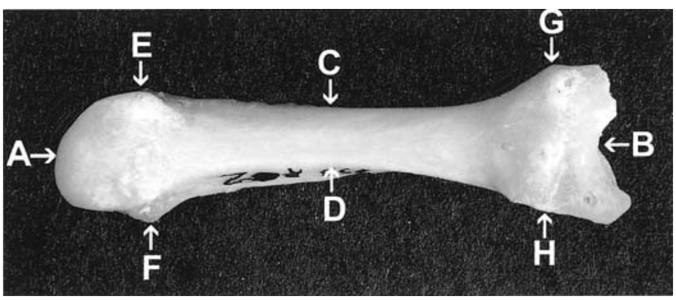

FIG. 1—*Dorsal view of right second metacarpal showing the landmarks and measurements used in the present study. Distance AB: interarticular length; EF: mediolateral breadth of the head; GH: mediolateral breadth of the base; CD: mediolateral breadth of the midshaft. Not shown are anteroposterior breadth of the head (taken at a right angle to EF); anteroposterior breadth of the base (taken at a right angle to GH); and anteroposterior breadth of the midshaft (taken at a right angle to CD).*

All data were then subjected to linear discriminant analysis accordingly. As Falsetti (1) employed only metacarpals 2, 4, and 5 due to significant racial differences being located in metacarpals 1 and 3, only these metacarpals were used in this study.

For evaluation of the methods of Stojanowski (4), the same six measurements used by Scheuer and Elkington (3) were again employed, using only the left hands. Stojanowski (4) defined seven linear discriminant functions per metacarpal, for a total of 35 functions. These were designed around multiple combinations of measurements in order to mimic various fragmentary preservation scenarios:

Function 1: anteroposterior breadth of base + mediolateral breadth of base
Function 2: anteroposterior breadth of head + mediolateral breadth of head
Function 3: measurements from functions 1 and 2 together
Function 4: all measurements except anteroposterior breadth of base
Function 5: all measurements except mediolateral breadth of base
Function 6: all measurements except anteroposterior breadth of head
Function 7: all measurements except mediolateral breadth of head

All data were subjected to linear discriminant analyses accordingly.

Results and Discussion

Means and standard deviations of measurements for each metacarpal are shown in Table 1. Results of the multiple regression equations from Scheuer and Elkington (3) are presented in Table 2.

TABLE 1—*Means and standard deviations (in mm) of measurements by metacarpal (includes both measurements used by Scheuer & Elkington, 1993, and Falsetti, 1995).*

	Metacarpal 1		*Metacarpal 2*		*Metacarpal 3*		*Metacarpal 4*		*Metacarpal 5*	
	Sex	$\bar{X}$ (±SD)	Sex	$\bar{X}$ (± SD)	Sex	$\bar{X}$ (± SD)	Sex	$\bar{X}$ (+ SD)	Sex	$\bar{X}$ (+ SD)
Length	M	46.31 (2.33)	M	68.02 (4.09)	M	66.62 (4.06)	M	59.35 (3.83)	M	55.49 (3.60)
	F	43.14 (3.24)	F	64.64 (3.89)	F	62.75 (4.01)	F	55.38 (3.83)	F	51.94 (3.30)
	P*	44.79 (3.20)	P	66.40 (4.31)	P	64.77 (4.44)	P	57.41 (4.28)	P	53.83 (3.86)
MLB†	M	17.18 (1.54)	M	19.62 (1.62)	M	12.19 (1.59)	M	11.43 (1.38)	M	14.09 (1.66)
	F	15.49 (1.32)	F	16.50 (1.27)	F	10.08 (1.35)	F	9.41 (1.09)	F	12.71 (1.30)
	P	16.37 (1.66)	P	18.09 (2.14)	P	11.18 (1.81)	P	10.47 (1.60)	P	13.43 (1.64)
APB‡	M	18.32 (2.07)	M	17.59 (2.10)	M	16.81 (2.39)	M	13.10 (1.46)	M	11.83 (1.16)
	F	15.41 (1.19)	F	15.65 (1.75)	F	15.61 (1.26)	F	11.62 (1.00)	F	10.20 (0.80)
	P	16.93 (2.24)	P	16.66 (2.16)	P	16.24 (2.00)	P	12.37 (1.45)	P	11.07 (1.29)
MLH§	M	15.49 (1.10)	M	13.53 (1.40)	M	13.90 (1.34)	M	12.31 (1.25)	M	11.56 (1.18)
	F	13.36 (1.22)	F	11.72 (2.17)	F	11.30 (1.31)	F	10.31 (1.20)	F	9.30 (1.54)
	P	14.47 (1.57)	P	12.66 (2.01)	P	12.65 (1.85)	P	11.35 (1.58)	P	10.78 (1.58)
APH‖	M	14.29 (1.19)	M	15.50 (1.01)	M	15.96 (1.43)	M	14.34 (1.92)	M	12.89 (1.10)
	F	12.45 (1.09)	F	14.08 (1.05)	F	13.87 (0.97)	F	12.53 (1.05)	F	11.54 (0.79)
	P	13.10 (1.46)	P	14.82 (1.25)	P	14.96 (1.61)	P	13.50 (1.81)	P	12.25 (1.17)
MidML¶	M	12.52 (1.28)	M	10.05 (0.85)	M	9.63 (0.61)	M	7.92 (0.81)	M	8.48 (0.91)
	F	11.18 (0.90)	F	8.47 (0.90)	F	8.36 (0.73)	F	6.73 (0.82)	F	7.65 (1.11)
	P	11.88 (1.29)	P	9.30 (1.18)	P	9.02 (0.92)	P	7.35 (1.01)	P	8.08 (1.08)
MidAP**	M	9.35 (0.78)	M	9.78 (0.97)	M	9.76 (0.82)	M	7.97 (0.87)	M	7.43 (0.62)
	F	8.00 (0.85)	F	8.69 (1.14)	F	8.57 (0.92)	F	6.50 (0.73)	F	6.26 (0.65)
	P	8.66 (1.06)	P	9.26 (1.18)	P	9.19 (1.04)	P	7.27 (1.09)	P	6.88 (0.86)

*P: pooled sexes; †MLB: mediolateral breadth of base; ‡APB: anteroposterior breadth of base; §MLH: mediolateral breadth of head; ‖APH: anteroposterior breadth of head; ¶MidML: mediolateral midshaft breadth; **MidAP: anteroposterior midshaft breadth

Those from the methods of Falsetti (1) are shown in Table 3 and those from the methods of Stojanowski (4) are shown in Table 4. Results from applying the methods of Scheuer & Elkington (3) to metacarpal 5 produced numbers in the female range for every metacarpal, yielding a very low accuracy for the fifth metacarpal. In examining their original regression equation for this metacarpal there appeared to be an error in the fifth element (3). When this element of their regression equation is changed by moving the decimal point from 0.0235 to 0.235, reasonable results were obtained in the present study. Thus, all displayed results in Table 2 reflect this change in their original formula as outlined above.

Overall, ranges of accuracy were lower than those reported by the original investigators except for the results obtained using Stojanowski's methods (4). The pooled accuracy (i.e., both sexes combined) range obtained using the present sample and the methods of Scheuer & Elkington (3) was 63.04–91.1% (see Table 2), as compared to their range of 74–94%. In their previous study, greatest accuracy was produced using metacarpal1 and least accuracy was found using metacarpal 3.

In the present study, metacarpal 3 produced the least accurate estimations, also, while metacarpal 2 produced the greatest accuracy. In separating the sexes, female accuracy was lowest with metacarpal 1 (10%) and greatest with metacarpal 3 (100%). Male accuracy was lowest with metacarpal 3 (25%), as in the pooled sexes, and greatest with metacarpals 1, 2, and 5 (all 100%). In all cases except metacarpal 3, the regression equations of Scheuer & Elkington (3) tended to overestimate the male sex.

In analyses of metacarpals 2, 4, and 5 using the methods of Falsetti (1), pooled accuracy ranged from 83.3–87.0% (see Table 3), as compared to his previous range of 84.37–92.00%. In the previous study, greatest accuracy was found with metacarpal 2 and least accuracy with metacarpal 5. Here, greatest accuracy was with metacarpal 2 as well but with least accuracy using metacarpal 4. In separate sex estimations female accuracy was greatest with metacarpal 2, also (90.9%), and lowest with metacarpal 5 (70%) while male accuracy was greatest with metacarpal 5 (100%) and lowest with metacarpal 2 (83.3%).

Using methods of Stojanowski (4), the present study revealed a pooled accuracy range from 65.2–95.7% (see Table 4), as compared to his previous range of 75–90%. The previous study found most consistent accuracy using functions derived from metacarpal 4 and least consistent accuracy using functions derived from metacarpal 2. The present study produced most consistent accuracy using functions derived from metacarpal 3 but metacarpal 2 produced almost as consistent accuracy. With metacarpal 2, those functions associated with five or more variables were seen to be most accurate but with metacarpal 3 there is no clear pattern (see Table 4). Least accuracy was noted for functions associated with metacarpal 5. Function 1 was unable to be calculated for metacarpals 4 and 5 as F-levels for intersex differences were insignificant.

In examining the sexes separately, female accuracies were consistently greatest using metacarpal 3 as in the pooled sexes while metacarpal 4 producing the lowest accuracies. For males, greatest consistent accuracies were also produced using metacarpal 2 with metacarpal 5 produced the lowest accuracies as in the pooled sexes.

This study tested methodology from three previous studies, which used various metacarpal dimensions and equations to determine sex of human skeletal remains (1,3,4). Accuracy in sex determination ranged broadly, depending upon which methodology was used. Overall, using pooled sexes the methods of Stojanowski (4) produced the highest accuracy (95.7%) but also produced the largest range, starting at 65.2%. Results using the methods of Scheuer & Elkington (3) produced the next highest accuracy (91.1%) with a similar range starting at 63.04%. Finally, the methods of Falsetti (1) produced a peak accuracy of 87.0% but with the smallest range starting at 83.3%.

TABLE 2—*Percent accurate sex determination for methods of Scheuer & Elkington (1993).*

Metacarpal	Percentage Accuracies: Pooled	Female	Male
Metacarpal 1	65.85%	10%	100%
Metacarpal 2	91.11%	81.8%	100%
Metacarpal 3	63.04%	100%	25%
Metacarpal 4	88.37%	90%	90.9%
Metacarpal 5	76.2%	50%	100%

TABLE 3—*Percent accurate sex determination for methods of Falsetti (1995)*.*

Metacarpal	Percentage accuracies: Pooled	Female	Male
Metacarpal 2	87.0%	90.9%	83.3%
Metacarpal 4	83.3%	81.8%	84.6%
Metacarpal 5	85.7%	70%	100%

*Note that since Falsetti (1995) only employed metacarpals 2, 4, and 5 these same metacarpals are solely analyzed in the present study.

TABLE 4—*Percentage accuracies for methods of Stojanowski (1999).*

	Metacarpal 1			Metacarpal 2			Metacarpal 3			Metacarpal 4			Metacarpal 5		
	Pooled	Female	Male	Pooled	Female	Male	Pooled	Female	Male	Pooled	Female	Male	Pooled	Female	Male
Function															
1	70.8%	72.7%	69.2%	73.9%	72.7%	75.0%	73.9%	72.7%	75.0%	. . .	. . .	. . .	. . .	. . .	. . .
2	83.3%	81.1%	84.6%	78.3%	81.8%	75.0%	91.3%	90.9%	91.7%	73.9%	81.8%	66.7%	69.6%	1.8%	58.3%
3	83.3%	81.1%	84.6%	73.9%	72.7%	75.0%	91.3%	90.9%	91.7%	78.3%	81.8%	75.0%	65.2%	1.8%	50.0%
4	83.3%	81.1%	84.6%	95.7%	90.9%	100.0%	91.3%	90.9%	91.7%	78.3%	72.7%	83.3%	78.3%	0.9%	66.7%
5	83.3%	81.1%	84.6%	82.6%	81.8%	83.3%	91.3%	90.9%	91.7%	78.3%	72.7%	83.3%	82.6%	2.7%	91.7%
6	83.3%	81.1%	84.6%	95.7%	90.9%	100.0%	82.6%	81.8%	83.3%	78.3%	72.7%	83.3%	87.0%	1.8%	91.7%
7	79.2%	81.1%	76.9%	95.7%	90.9%	100.0%	82.6%	81.8%	83.3%	77.3%	72.7%	81.8%	78.3%	0.9%	66.7%

When performing the analyses on female and male groups separately, results were quite mixed. Again, the methods of Stojanowski (4) produced the most consistently accurate results with accuracies approximately even between the sexes except for metacarpal 5 (female predictions more accurate than males). In fact, 100% accuracies were achieved for males when using metacarpal 2. The methods of Falsetti (1) also produced roughly even accuracies between the sexes with 100% accuracy achieved in male metacarpal 5. Using the methods of Scheuer & Elkington (3), however, produced widely varying results. Here, males are overestimated in every case except for metacarpal 3. Females were only classified accurately 10% of the time when using metacarpal 1 and males were only classified accurately 25% of the time using metacarpal 3. However, male accuracy reached 100% when using metacarpals 1, 2, and 5. Such mixed results may be due to the relatively small sample sizes (11 females and 12 males) or may be a result of greater populational differences (British vs. American) in male metacarpals than in females.

All three previous studies reported different metacarpals as producing the greatest accuracy. Scheuer & Elkington (3) reported greatest accuracy using metacarpal 1, while the present study found low accuracy using this bone (65.85%) with their methods. Here, greatest accuracy was achieved using metacarpal 2. Falsetti (1) reported greatest accuracy (92%) using metacarpal 2; the present study also found the greatest accuracy (87%) with this bone using his methods. Finally, Stojanowski (4) reported greatest consistent accuracy (82%–89%) using functions derived from metacarpal 4. The present study located greatest consistent accuracy (79.3%–91.3%) using functions derived from metacarpal 3, but greatest highlighted accuracy in metacarpal 2 (functions 4, 6, and 7 produced accuracies of 95.7%).

While the discriminant functions of Stojanowski (4) performed well here, there is conflict between results from the present study and results from the studies of Falsetti (1) and Scheuer & Elkington (3). A number of factors may explain this. The present study used metacarpals derived from American cadavers of individuals dead not more than three years prior to execution of this study. It is possible that using skeletal material from a British sample as done by Scheuer and Elkington (3) may produce regression equations that are inappropriate for skeletal material derived from other populations such as the United States. In general, the means obtained in the present study in all measures are greater than those reported by Scheuer and Elkington (3), despite the fact that contemporary populations were employed in both studies. The use of the Terry collection by Falsetti (1) to generate his calibration sample may similarly be inappropriate as this collection is not contemporary and there may be secular changes in metacarpal dimensions that have occurred.

Results of this study agreed most closely in percentage accuracy with the study by Stojanowski (4). While other independent tests of these methodologies are necessary for any conclusive remarks, his methodology may be most accurate as reflected in the present study due to the multiple functions that he generated. By isolating specific measurements for each function, it may be possible to pinpoint the most predictive regions of each metacarpal and pool percentage accuracies for all seven functions, thereby giving a more "average" picture of accuracies in each metacarpal. In addition, the relative recent acquisition of his sample may account for its greater accuracy relative to the population of the present study.

In general, results from this study suggest that the potential utility of metacarpals in determining sex of human skeletal remains may be limited, especially if used as a sole determinant. Further work on this subject with a larger, known sex sample is certainly warranted in order to understand these conflicting results and to make any definitive conclusions regarding the utility and validity of using metacarpals in the determination of sex for human skeletal remains. Considering the results of this study, it may be prudent to consider the potential nationality and relative age of the skeletal remains in question and to pair analysis of metacarpal remains, if possible, with other more definitive analyses such as the skull, pelvis, or femur.

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