TECHNICAL NOTE

Francesco Introna Jr,[1] *M.D.; Giancarlo Di Vella,*[1] *Ph.D., M.D.; Carlo Pietro Campobasso,*[1] *Ph.D. candidate, M.D.; and Michele Dragone,*[1] *M.D.*

Sex Determination by Discriminant Analysis of *Calcanei* Measurements

REFERENCE: Introna Jr F, Di Vella G, Campobasso CP, Dragone M. Sex determination by discriminant analysis of *calcanei* measurements. J Forensic Sci 1997;42(4):725–728.

ABSTRACT: Eight measurements taken on the right *calcaneus* (maximum length, load arm width, minimum width, height of *calcaneus,* body height, breadth of the *facies articularis talaris posterior,* breadth and height of the *facies articularis cuboidea)* of a known contemporary Southern Italian skeletal population (40 males and 40 females) were used to determine sex by multivariate discriminant analysis. Three functions revealed a correct sex-determination of 85%. These functions were obtained by the association of the following parameters: maximum length, load arm width and breadth of the *facies art. talaris post.* (function no. 1); maximum length and breadth of the *facies art. talaris post.* (function no. 2); maximum length and height of the *facies art. cuboidea* and breadth of the *facies art. cuboidea* (function no. 3). These results may aid the forensic anthropologist when no other remains, useful for skeletal sex determination, are available.

KEYWORDS: forensic science, forensic anthropology, physical anthropology, human identification, calcanei measurements, discriminant functions, sex determination, Italy

Sex determination is one of the major challenges for the forensic anthropologist within a medicolegal context; it is considered an early step in personal identification from skeletal remains and it is indispensable for applying procedures to define race and age at the time of death. Skeletal sex may be determined by studying morphological parameters or performing quantitative analysis of selected skeletal measurements (1–3).

Morphological analysis is usually applied to unfragmented skeletal remains. It can yield accurate results only if used by experienced examiners. Quantitative analysis is more objective, repeatable and requires less technical experience. Furthermore quantitative analysis can be performed even on fragmentary skeletal remains and therefore it can be useful in mass-disasters, natural calamities, charred bodies and criminal cases in which scattered, mixed or incomplete remains are recovered (4,5).

In such cases, it is decidedly helpful for the forensic anthropologist, to have some prior knowledge of the race or nationality of the individual(s) to be sexed (6). In both cases the investigations could concern victims of various ethnic group; misclassification errors can occur if sex discriminant functions, obtained from a well-known population or from old skeletal collections, are applied to skeletal remains belonging to a different population or on a recent sample. Bone structure and size differences between populations and within the same population over time can be so wide as to induce, if not correctly considered, gross misclassification errors. Furthermore the wide interchange among populations, the increased mobility, and the new waves of immigration, make it more and more important to have sex discriminant functions for each bone, obtained from different contemporary skeletal populations.

This study is part of a research program to determine sex and stature from a well-known skeletal sample, carried out at the Forensic Medicine Institute, School of Medicine of the University of Bari, Italy (7–16). The final purpose is to supply forensic anthropologists with formulae obtained from an Italian skeletal population that can be used world-wide on remains belonging (or supposed to belong) to Italians.

In this research we applied multivariate analysis on *calcanei* measurements taken from a skeletal collection concerning the contemporary Southern Italian population with sex, age, and time of death known. The purpose of this paper is to consider the reliability of determining sex from measurements of the calcaneus, the largest and most durable bone of the foot.

There are very few studies regarding sex determination from *calcanei* measurements (17). In 1976 Steele, studying the Terry Collection (Smithsonian Institution in Washington, D.C. USA) focused on the sexual dimorphism of the calcaneus and talus (18). He considered five *calcanei* and five *tali* parameters obtaining discriminant functions that allowed a correct sex-determination in 79–89% of the examined sample.

Materials and Methods

Eighty unfractured and nonpathological right *calcanei* samples (40 male, 40 female) from skeletons in the collection at the Institute of Legal Medicine of the University of Bari and belonging to the contemporary Southern Italian population with time of death around 1970 and ages ranging from 25 to 80 years were analyzed. Eight measurements were taken by two examiners, separately and

[1]Institute of Legal Medicine, University of Bari, Italy.
Received 18 Dec. 1995; and in revised form 4 March 1996, 21 May 1996, 2 Aug. 1996 and 15 Oct. 1996; accepted 16 Oct. 1996.

at different times using sliding calipers graduated to 0.5 mm. The measurements considered were the following:

-maximum length	[1]
-load arm width	[2]
-minimum width	[3]
-height of *calcaneus*	[4]
-body height	
-breadth of the *facies art. talaris posterior*	[10]
-breadth of the *facies articularis cuboidea*	[12]
-height of the *facies articularis cuboidea*	[13]

Except for body height, all measurements follow Martin's numeration reported in brackets (19). *Body height* is defined as the greatest projected height of calcaneus measured from the highest point of the facies *articularis talaris posterior* to the lowest point of tuber *calcanei.* This measurement has been described and considered by Steele and by Krogman and Iscan (20).

As in our previous research, for descriptive, statistical and discriminant analysis, we used a modified translation of Davies programs n.1 and 29 implemented in MS-BASIC on a microcomputer with an "INTEL 80386" microprocessor (21). Statistical analysis of each parameter including mean, standard deviation, standard error, variance and coefficient of variability was then carried out (22). The overlap between male and female samples (d/s) was also determined from the ratio of the mean difference and the mean standard deviation. The formula used was the following:

$$d/s = (Xm - Xf)/ \sqrt{(nM\, s^2M + nF\, s^2F) / (nM + nF)}$$

(Xm − Xf = means; nM, nF = examined samples; s^2M, s^2F = variance in two samples)

Univariate discriminant analysis was initially performed to indicate the efficiency of each measurement for sex discrimination [Z = ax; Z = output value of sex discrimination, a = bone measurement considered]. Multivariate discriminant analysis was then performed applying the Fisher formula: [$Z = a_1x_1 + a_2x_2 + \ldots\ldots a_nx_n$; Z = output value of sex determination; a_{1-n} = bone measurements; x_{1-n} = discriminant coefficients]. All possible combinations between the considered parameters were then automatically performed and the discriminant functions were listed for the highest sex-discriminant degree. The Davies program n.29 considered nonsignificant the functions with the determinant of covariance matrix <0.0001 and they were excluded automatically; anyway, in our sample, no functions were dropped either in univariate or in multivariate analysis.

Results and Discussion

The results of descriptive statistical analysis with mean, variance, standard deviation (SD) and distance between sex means (d/s) are reported in Table 1. The larger female variance for maximum length (0.28) is related to a slight increase in this measurement observed in the young females (ages ranging from 25 to 45 years) of the present sample. The statistical analysis reveals that height of calcaneus is the measurement with the greatest sex difference (d/s) followed by the maximum length, the body height and the load arm width.

The efficiency for sex determination of each parameter was tested using univariate discriminant analysis. The results are reported in Table 2. The maximum length was the parameter with the highest autonomous percentage of correct classification (83.75%), followed by the load arm width (77.50%), the height of calcaneus (76.25%), the body height and breadth fac. art. tal. post. (71.25%). The statistical and the univariate discriminant analysis indicated that the maximum length, the load arm width and the height of calcaneus are the most sex-differentiated parameters.

The association of the more sex-differentiated measurements does not always provide the best multivariate functions. In our results the best multivariate discriminant function was not obtained by the association of the best three parameters from univariate analysis. The best multivariate discriminant functions for sex determination are reported in Table 3.

Function no. 1 was obtained using three measurements (maximum length, load arm width and breadth of the *facies art. talaris post.*); function no. 2 uses only two parameters (maximum length and breadth of the *facies art. talaris post.*); function no. 3 associates three parameters (maximum length, breadth and height of the *facies art. cuboidea*). These three functions show the highest percentage of correct sex determination (85%). Functions no. 4 and no. 5 show a lower percentage of correct classification (83.75%). The remaining functions have too high a percentage of misclassification to be considered.

We have compared our results with those obtained from *calcanei* measurements by Steele in 1976. Steele obtained his results from studying a 70-year-old skeletal collection (Terry Collection) and he was conscious that the functions obtained could not have similar accuracy if applied to a present day American population. His study was based on a population smaller in foot-bone size than those of today and tends to misclassify larger females. Therefore Steele suggests that new studies should be carried out on recent bone collections.

Furthermore, when analyzing his results, Steele considered the discriminant functions obtained from the calcaneus to be less accurate than those obtained from talus or from the both *tali* and *calcanei* measurements. He reported only one sex discriminant function using calcanei parameters. This function, obtained from the association of *calcanei* body height and the load arm width, allowed a 79% of accuracy in sex determination. Nevertheless in forensic cases and in mass disasters, the opportunity to determine the skeletal sex on isolated and fragmented calcaneus can occur. Furthermore the wide interchange between populations stresses the opportunity to use sex discriminant functions obtained from the population to which the person belongs.

Our results, from the analysis of a representative Southern Italian skeletal collection, confirm and build on the results obtained by Steele. First of all, we present eight univariate discriminant functions (Table 2) and eight multivariate discriminant functions (Table 3) obtained from *calcanei* measurements alone that allow sex determination even on fractured or fragmented *calcanei.* In addition we present six discriminant functions with a better percentage of accuracy (ranging from 85 to 80) than the one indicated by Steele (79%).

The applicability of the Steele function to the recent Southern Italian population is allowed but it does not supply the best correct sex determination. Indeed (Table 3) function no. 7 (set up with the same calcanei parameters indicated by Steele) gives a percentage of accuracy of 77.5 if calculated on Italian measurements versus the 79 obtained by Steele using the Terry collection measurements.

Finally, our results can be considered free from the influence of the social-economic improved conditions noted by Steele in

TABLE 1—*Descriptive statistical analysis and distance of the population for each parameter.*

	Male			Female			
	Mean	Variance	SD	Mean	Variance	SD	D/S
Maximum Length	7.91	0.14	0.37	7.25	0.28	0.53	1.43
Load Arm Width	4.19	0.13	0.36	3.75	0.08	0.29	1.38
Minimum Width	2.84	0.09	0.30	2.53	0.07	0.26	1.09
Height of Calcaneus	4.52	0.11	0.33	4.00	0.10	0.32	1.59
Body Height	4.68	0.12	0.34	4.19	0.12	0.35	1.41
Breadth *Facies art. talaris pos*	2.60	0.05	0.22	2.32	0.05	0.23	1.23
Breadth *facies art. cuboidea*	2.17	0.07	0.26	1.94	0.07	0.26	0.85
Height *facies art. cuboidea*	2.45	0.06	0.24	2.24	0.06	0.24	0.88

TABLE 2—*Univariate discriminant analysis.*

Maximum Length	3.14							
Load Arm Width	—	4.27						
Minimum Width	—	—	3.89					
Height of calcaneus	—	—	—	4.88				
Body Height	—	—	—	—	4.10			
Breadth *facies art. talaris post.*	—	—	—	—	—	5.49		
Breadth *facies art. cuboidea*	—	—	—	—	—	—	3.23	
Height *facies art. cuboidea*	—	—	—	—	—	—	—	3.67
Section Point	23.80	16.97	10.43	20.81	18.20	13.56	6.63	8.60
Percent Accuracy	83.75	77.50	68.75	76.25	71.25	71.25	66.25	68.75

TABLE 3—*Multivariate discriminant analysis.*

Function n.	1	2	3	4	5	6	7	8
Parameters used	3	2	3	3	3	2	2	2
Maximum Length	1.96	2.54	2.62	2.49	2.38	1.96	—	—
Load Arm Width	2.39	—	—	—	—	—	3.03	—
Minimum Width	—	—	—	—	—	—	—	1.14
Height of Calcaneus	—	—	—	—	—	—	—	4.35
Body Height	—	—	—	—	—	2.42	2.99	—
Breadth *facies art. talaris post.*	3.03	3.85	—	3.65	3.66	—	—	—
Breadth *facies art. cuboidea*	—	—	1.39	0.42	—	—	—	—
Height *facies art. cuboidea*	—	—	1.25	—	0.91	—	—	—
T2	63.82	54.51	45.96	54.71	55.31	49.28	56.02	52.04
F value	20.72	26.91	14.93	17.76	17.96	24.32	27.65	25.68
Degree of freedom	3-76	2-77	3-76	3-76	3-76	2-77	2-77	2-77
Centroid Male	33.48	30.11	26.87	30.15	30.62	26.88	26.70	22.91
Centroid Female	30.29	27.38	24.57	27.41	27.86	24.42	23.90	20.31
Section Point	31.89	28.75	25.72	28.78	29.24	25.65	25.30	21.61
Percent Accuracy	85	85	85	83.75	83.75	80	77.50	76.25

his results (obtained from a 70-year-old skeletal population). Our regression formula have been obtained from a recent skeletal collection containing people exposed to the same socio-economic conditions as today. Thus our percentage of classification can be related exclusively to the sex induced bone dimorphism.

In conclusion, we suggest that our discriminant functions should be tested on recent skeletal collections of different populations to compare the differences and compile a list of sex discriminant functions applicable worldwide.

References

1. Krogman WM, Iscan MY. The human skeleton in forensic medicine. Springfield: Charles C Thomas, 1986:189–267.
2. Iscan MY, Kennedy KAR, editors. Reconstruction of life from the skeleton. New York: Alan R. Liss, Inc., 1989.
3. Ubelaker DH, Scammell H. Bones: A forensic detective's casebook. New York: Edward Burlingame Books, 1992.
4. Stewart TD, editor. Personal identification in mass disasters. Washington D.C.: Smithsonian Institution Press, 1970.
5. Stewart TD. Essentials of forensic anthropology: Especially as developed in the United States. Springfield: Charles C Thomas, 1979.
6. Giles E. Discriminant function sexing of the human skeleton in personal identification in mass disasters. In: Stewart TD, editor. Personal identification in mass disasters. Washington, D.C.: Smithsonian Institution Press, 1970:99–107.
7. Introna Jr. F, Scattarella V, De Lucia E, Tomasicchio M, Pesce Delfino V, Colonna M. Determinazione del sesso, a mezzo di analisi discriminante multivariata, di misure craniche in un campione pugliese contemporaneo. Riv It Med Leg 1983;5:673–88.
8. Introna Jr F, Dattoli V, Colonna M. Sex identification by means multivariate discriminant analysis of some occipital measurements. Zacchia 1985;3(3–4):382–92.

9. Introna Jr. F, Dattoli V, Colonna M. Sexual diagnosis by tibial measurements on a contemporary Southern Italian population. Zacchia 1987;5(1–2):93–104.
10. Introna Jr. F, Dattoli V. Determinazione del sesso scheletrico mediante analisi discriminante multivariata di parametri femorali. In: Vimercati F, Colonna M, Vinci F, editors. Proceeding of 30th National Congress of Italian Society of Legal Medicine; 1989 Sept. 27–30; Bari (Italy). Bari: Graphiservice, 1989:1307–12.
11. Introna Jr. F, Dragone M, Colonna M. Sex determination from skeletal remains by radial measurements. Zacchia 1993; 11(1–2):159–72.
12. Introna Jr. F, Dragone M, Frassanito P, Colonna M. Sexual identification by ulnar measurements on a Southern Italian population. J Biol Res 1993;69(9):517–23.
13. Di Vella G, Campobasso CP, Dragone M, Introna Jr F. Skeletal sex determination by scapular measurements. J Biol Res 1994; 70(12):299–305.
14. Introna Jr F, Dragone M, Vitale L. Determinazione del sesso scheletrico mediante funzioni discriminanti applicate all'omero. Riv It Med Leg 1994;16:673–83.
15. Introna Jr F, Di Vella G, Dragone M, Campobasso CP. Sex determination by discriminant analysis of clavicular measurements. In: Bergamini PR, editor. Proceeding of the 4th International Meeting on Forensic Medicine, Alpe-Adria-Pannonia, 1994 May 12–14; Grado (Italy). Gorizia: Tipografia USL/2 Goriziana, 1994;113–9.
16. Di Vella G, Campobasso CP, Dragone M, Introna Jr F. Sex determination by sternal measurements on a contemporary Southern Italian population. Bergamini PR, editor. Proceeding of the 4th International Meeting on Forensic Medicine, Alpe-Adria-Pannonia, 1994 May 12–14; Grado (Italy). Gorizia:Tipografia USL/2 Goriziana, 1994:127–33.
17. Olivier G, Pineau H. Détermination du sexe par les poids des os. Bull et Mém de la Soc d'Anthropol de Paris 1957;10(9):328–39.
18. Steele DG. The estimation of sex on the basis of the talus and calcaneus. Am J Phys Anthropol 1976;45:581–8.
19. Martin R, Saller K. Lehrbuch der Anthropologie. Stuttgart: Gustav Fischer Verlag, 1957.
20. Krogman WM, Iscan MY. The human skeleton in forensic medicine. Springfield: Charles C Thomas, 1986:529.
21. Davies RG. Computer programming in quantitative biology. New York: Academic Press, 1971.
22. Snedecor GW, Cochran WG. Statistical methods. Iowa State, Ames: University Press, 1967.

Additional information and reprint requests:
Francesco Introna Jr, Associate Professor
Istituto di Medicina Legale
Università degli Studi
P.zza G. Cesare—70100—Bari
Italy