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Sex assessment using the calcaneus and talus

Ana Maria Silva
Departamento de Antropologia
Universidade de Coimbra
3006 Coimbra Codex - Portugal

Abstract. Calcaneus and talus of 165 skeletons (80 males and 85 females) of the Identified Skeletal Collection (n = 505) of the Museum of Anthropology of Coimbra University were measured for the purpose of sex determination in complete and fragmentary calcaneus and/or talus. After testing Steele's (1976) formulae for sex diagnosis, which were able to correctly assign sex for 77-89% of the portuguese sample, this was analysed by means of stepwise discriminant analysis, using several possible sets of combinations of the measurements taken. The functions were elaborated and selected on the basis of their reliability in predicting sex and on their applicability on fragmentary talus and/or calcaneus. Twenty-one functions were formulated, which correctly predicted the sex of the sample with 82-93% accuracy. From these, five discriminant functions were selected, as well as discriminant functions number 1, 2 and 5 of Steele's method (1976), which were tested in a control group of 50 pairs of left talus/calcaneus, also drawn from the Identified Skeleton Collection, that was correctly classified with, respectively, 82-94% and 80--84% accuracy. Therefore, even incomplete talus and/or calcaneus may be useful in sexual identification in poorly preserved or intermixed Skeletal remains.

Key-words: calcaneus; talus; sex diagnosis; discriminant functions.

Resumo. O calcâneo e talus de 165 esqueletos (80 indivíduos masculinos e 85 femininos) da Colecção de Esqueletos Identificados (n = 505) do Museu Antropológico da Universidade de Coimbra, foram medidos com o fim de desenvolver um método para a diagnose sexual que possa, nomeadamente, ser utilizado em ossos incompletos. Após se terem testado as fórmulas propostas por Steele (1976) na série portuguesa, as quais classificaram correctamente o sexo de 77 - 89% da amostra, esta foi submetida a análise discriminante. As fórmulas foram elaboradas e seleccionadas

com base na percentagem de classificação correcta assim como na sua aplicabilidade em talus e calcâneos incompletos. Foram assim construídas vinte e uma funções discriminantes que permitiram classificar correctamente o sexo de 82 a 93% da amostra. Uma amostra control, constituída por 50 pares de talus e calcâneos esquerdos, igualmente seleccionada da Colecção de Esqueletos Identificados, foi utilizada para testar cinco das novas funções discriminantes assim como as discriminantes nº 1, 2 e 5 de Steele (1976), permitindo classificar correctamente o sexo de, respectivamente, 82 - 94% e 80 - 84%, da amostra. Pode-se então concluir que o talus e o calcâneo podem ser de considerável utilidade na determinação do sexo de material ósseo mal preservado ou encontrado misturado.

Palavras-chaves: calcâneo; talus; diagnose sexual; funções discriminantes.

Introduction

Various criteria for sex diagnosis of human skeletal remains can be used only on well preserved bones from relatively complete skeletons. In many cases, particularly those involving intact cranium and pelvis, qualitative morphological observations are sufficient for accurate sex attribution. In other cases, involving only fragmentary or incomplete remains, sex can de determined through quantitative metric analyses, although with somewhat lower accuracy. Discriminant function analysis, based on measurements of several skeletal bones as cranium (Giles and Elliot 1963; Cunha and Van Vark, 1991), humerus (Dittrick and Suchey, 1986), humerus, radius and ulna (Holman and Bennett; 1991), tibia (Iscan and Miller-Shaivitz, 1984a,b), femur (DiBennardo and Taylor, 1979) femur and innominate (DiBennardo and Taylor, 1983), talus and calcaneus (Steele, 1976), among others, has been the most used statistical technique.

Accuracies for sex prediction vary from method to method, but most generally fall within the middle to upper 80th to low 90th percentile range (Holman and Bennett, 1991). However, many of these methods need complete or almost complete bones. In response, some authors have presented techniques to perform in cases where intact bones are not available and in minor skeletal elements (Black, 1978; Holland, 1986; Holland, 1991).

Sexing can also be a problem when the bones are found in mixed lots, such as ossuaries or collective burials. Therefore, there is a definite need for techniques of sexual determination to deal with poorly preserved remains and with individual bones, namely those that are more durable. The talus and calcaneus are two foot bones that are frequently well preserved, representing a great potential for sex determination.

Results proving sexual variation in foot bones were published in 1964 by Bunning. He used the number and arrangement of the superior articular facets of the calcaneus. His study, based on 183 adult males, 63 adult females and 64

fetuses, from Nigeria, demonstrated that calcaneus with two superior facets occured in 57,7% of males and 80,2% of females. However, this does not prove to be of particularly practical aid, due to the high incidence of calcaneus with double anterior facets in individuals of both sexes.

The value of the calcaneus and talus in assessing sex was also demonstrated by Steele in 1976. Based on a sample of 120 individuals (thirty each of white males, white females, American black males and American black females) of the Terry Skeletal Collection of the Smithsonian Institution of Washington D.C., he developed five discriminant function. However, with the exception of the discriminant function number 1, this technique lacks of applicability to fragmentary remains, since it requires intact bones. Unfortunately, both archaeological and forensic specimens are commonly recovered without intact or even repairable bones.

The same problem can be reported to the method proposed by Gunn and McWilliams (1980), which estimates sex from the volume of the patella, talus and calcaneus. They conclude that body mass can be best measured by means of volume rather than by linear measurements. This method was based on a sample consisting of 100 European and 100 American negro skeletons (50 adult males and 50 adult females of each racial group) of the Todd Collection, stored at the Cleveland Museum of Natural History in Cleveland, Ohio.

Besides the reasons already mentioned that justify the selection of the calcaneus and talus for sex determination (existence of sexual dimorphism and relatively good preservation of this two bones) we can add, as pointed out by Holland (1995), that measurements taken in these two bones are relatively easy to obtain and replicate.

Therefore, the present study is an attempt to develop a new technique for sex determination, mainly in incomplete calcaneus and talus, beyond in complete bones.

Material and Methods

The sample under study was chosen from the large Identified Skeleton Collection of the Museum of Anthropology, stored at the Department of Anthropology (University of Coimbra), consisting of 505 Identified Portuguese skeletons, who were born between 1826 and 1922 and died between 1910 and 1936.

Several criteria had to be filled in order to select a specimen. Since the obituary records contained information on the individual age at death, sex and birth place, it was selected those individuals who were born in the council of Coimbra. Additionally, the selected bones had to be free of broken and/or

extensive arthritic growths around the articular surfaces or any other obvious or suspected pathology that might have adversely affect the results.

On the basis of these criteria, the author selected 165 pairs of calcaneus and talus. The elements represented 80 males and 85 females, ranged in age at death from 21 to 89 years.

For the analysis both talus and calcaneus of each individual were measured using sliding calipers, taking six measurements for the talus and nine for the calcaneus. All measurements, which were repeated after two months, were done according to Martin (1928) methodology, with exception of two defined by Steele (1976) (see appendix). The measurements used for the talus are: maximum length (TM1), talus width (TM2), body height (TM3), maximum body height (TM3a), maximum length of the trochlea (TM4) and maximum width of the trochlea (TM5).

The following measurements for the calcaneus were taken: maximum length (CM1), length (CM1a), load arm width (CM2), load arm length (CSlal, according to Steele, 1976), height (CM4), maximum height (CSmh, according to Steele, 1976), body length (CM5), *tuber calcanei* heigth (CM7) and *tuber calcanei* width (CM8).

The obtained data were submitted to statistical treatment, for which a database file was created, including for each individual, a numerical code for sex and laterality, as well as the results of the 15 measurements. For each one the mean, standard deviation, standard error, maximum and minimum value were calculated. Students' t-test was computed to test equality of the means on the left and right side measurements.

After testing the sex assessment method proposed by Steele (1976) the portuguese sample was submitted to discriminant analysis, performed by SPSS X, using several combinations of measurements of the talus alone, the calcaneus alone and of both bones.

To check the accuracy of some of the new discriminant functions in classifying material not included in the original computation, a second sample, also drawn from the Identified Skeleton Collection, was randomly chosen as test group. This sample consisted of 50 left pairs of talus and calcaneus (25 males and 25 females) belonging to individuals who were born outside the council of Coimbra.

The control sample was used to test Steele's discriminant functions number 1, 2 and 5 as well as the three new discriminant functions, that use the same measurements of Steele's method, number 13, 4 and 18.

In addition, to evaluate this new technique in fragmentary remains from a different sample, it was investigated the discriminant power of measurements that can be taken in incomplete bones. For this purpose, it was selected discriminant function number 5 for the talus, which uses measurements of the trochlea, and

for the calcaneus, discriminant function number 12, which works with the *tuber calcanei*.

Results

Tables 1 and 2 (respectively for the talus and calcaneus) contain the descriptive statistics for the reference sample, in which female means for all measurements were significantly smaller than males' values at $p < 0{,}001$. These means are lower than the ones from the reference sample of Steele's study, with the exception of the body height of the talus and the load arm width for the calcaneus. However, they are in the magnitude of other portuguese series, including some of other historic periods, such as neolithic/chalcolithic ones (Silva, 1993).

Table 1. Sample statistics - Talus.

Means S.D.	TM1 (mm)	TM2 (mm)	TM3 (mm)	TM3a (mm)	TM4 (mm)	TM5 (mm)
Males	53.35 2.88	41.32 2.20	30.67 1.90	32.06 1.98	32.78 1.99	27.91 1.84
Females	48.12 2.33	37.31 2.21	27.68 1.55	29.06 1.63	29.79 1.83	24.84 1.66

Table 2. Sample statistics - Calcaneus.

Means S.D.	CM1 (mm)	CM1a (mm)	CM2 (mm)	CM4 (mm)	CM5 (mm)	CM7 (mm)	CM8 (mm)	CSlal (mm)	CSmh (mm)
Males	79.05 4.48	74.07 4.27	41.83 2.32	43.30 3.37	56.30 3.54	46.34 3.75	31.19 2.09	47.09 2.96	49.67 3.18
Females	72.10 3.95	67.24 3.74	37.74 2.26	38.34 2.43	51.64 3.30	40.93 2.96	27.78 1.74	42.67 2.47	44.01 2.46

Students' t-test revelead that there are no statistical differences on the measurements due to laterality.

Table 3 lists the accuracy with which the reference sample was sexed according to Steele's method. Discriminant function number 1, 2 and 5 gave accuracy levels very similar to Steele's results. However, the other two functions,

show a widely different misclassification: 8 to 10 percent lower. Such distortion, in both cases, seems to arise from the large misclassification of the male sample: 42% for function 3 and 40% for function 4. This, on the other hand, is probably related not only with the lower sizes of portuguese bones, but also with different proportions of the envolved zones of the bones. Perhaps a new average sectioning point could attenuate the problem.

Table 3. Classification results and the percentage of correctly predicted individuals Steele's method (1976).

Steele's discriminant functions	Steele's sample Correct classification	Coimbra's sample Males - Correct classification	Coimbra's sample Females - Correct classification	Coimbra's sample Total -Correct classification
Discr. function 1	79%	93,3%	58.8%	77.0%
Discr. function 2	83%	65.0%	98,9%	82.4%
Discr. function 3	86%	57.5%	97.6%	78.2%
Discr. function 4	88%	60.0%	96.5%	78.8%
Discr. Function 5	89%	83.8%	95.3%	89.7%

Table 4. Unstandardized discriminant function coefficients for predicting sex of the talus *.

Measurements	Discr. function 1	Discr. function 2	Discr. function 3	Discr. function 4	Discr. function 5	Discr. function 6	Discr. function 7	Discr. function 8
Max. length (TM1)	.1645311	.2466274	.2329563	.2573032				
Width (TM2)	.1211462	.1859568	.1823157	.1910786		.1850264	.2909815	.4529338
Body height (TM3)	.07303904		.05569264				.3482996	
Max. body height (TM3a)	- .1115300	.02577688					-.07974359	
Trochlea length (TM4)	.1609030				.2861175	.2317023		
Trochlea width (TM5)	.1709546				.3896566	.2332657		
Constant	- 21.34242	- 20.57918	- 20.57951	- 20.53448	- 19.19835	- 20.64312	- 19.13427	- 17.77834
Male mean	1.15	1.09	1.09	1.09	1.06	1.11	1.02	0.94
Female mean	- .109	- 1.02	- 1.03	- 1.02	- 1.0	- 1.04	- 0.96	- 0.88
Accuracy	87.9%	86.7%	86.1%	86.1%	85.2%	84.9%	83.9%	82.1%
Correct male	86.3%	83.8%	82.5%	83.8%	81.9%	83.1%	82.5%	81.3%
Correct female	89.4%	89.4%	89.4%	88.2%	88.2%	86.5%	85.3%	82.9%

* Total discriminant scores less than 0 classify as female.

The unstandardized discriminant functions' coefficients are given in tables 4 to 6. To use the tables, the value of the required measurements (in mm) is multiplied by the appropriate coefficient located opposite the measurement designation. The score equals the sum of the products minus the appropriate constant. Discriminant scores less than 0 are considered female. The next table row lists the accuracy of each equation in predicting the sex of the total sample, followed by the correct classification of the male and female samples, separately.

Table 4 summarizes the results of the stepwise discriminant function analysis based on measurements of the talus alone. On the first step of the analysis, maximum length was found to be the most discriminant variable, which is in agreement with Steele's results. Therefore, if specimens with a maximum

Table 5. Unstandardized discriminant function coefficients for predicting sex of the calcaneus *.

Measurements	Discr. function 9	Discr. function 10	Discr. function 11	Discr. function 12	Discr. function 13	Discr. function 24	Discr. function 15	Discr. function 16
Max. length (CM1a)	-.03411009							-.03359872
Length (CM1a)	.2002685							.1560853
Load arm width (CM2)	.1156055				.1896672			.2736903
Load arm length (CSlal)	.08346965	.1285608					.1984063	
Heigth (CM4)	-1.010864	-.09781314	-.09381036				.2082229	
Maximum heigth (CSmh)	.2482596	.2951148	.3152456		.2405645			
Body heigth (CM5)	- .2649114	-0.1034794	-.05889149			.02735570		
Tuber calcanei heigth (CM7)	0.02170931	.02906974	.03484959	.1264744		.1162338		
Tuber calcanei width (CM8)	.2199708	.2702412	.3050561	.3682293		.3489627		
Constant	- 20.46868	- 19.17730	- 18.20949	- 16.33190	- 18.78170	- 16.79188	-17.36899	- 19.34883
Male mean	1.36	1.27	1.23	1.05	1.10	1.05	0.99	1.00
Female mean	-1.22	- 1.14	- 1.10	- .94	- 1.04	- 0.94	- 0.92	- 0.95
Accuracy	92.6%	90.0%	87.4%	86.1%	86.1%	85.8%	83.8%	82.1%
Correct male (%)	89.7%	87.0%	84.9%	80.1%	83.1%	81.5%	81.0%	78.1%
Correct female (%)	95.1%	92.6%	89.6%	91.4%	88.8%	89.6%	86.5%	85.9%

* Total discriminant scores less than 0 classify as female.

length less than 52mm are considered to be females, while those with a length greater or equal to 52mm were considered males, then 84% of the portuguese sample can be correctly sexed, against 81% of Steele's sample.

As it can be seen from table 4, the success in assigning sex based on the eight selected discriminant function varied from 82.1 to 87.9%. In addition, the success rates for identifying females are more consistant overall than those for males.

Table 6. Unstandardized discriminant function coefficients for predicting sex of the talus and the calcaneus *.

Measurements	Discr. function 17	Discr. function 18	Discr. function 19	Discr. function 20	Discr. function 21
Max. length talus (TM1)	.06468497	.1500827	.1983795	.2257151	.3261971
Width talus (TM2)	.03140227	.1314950	.1490612	.1579532	
Body height talus (TM3)	.2142021				
Max. body height talus (TM3a)	- .2422189				
Trochlea length (TM4)	.2173294				
Trochlea width (TM5)	.1460842				
Max. length calc. (CM1)	-.003904331			-.003798989	.04486827
Length calc.(CM1a)	.2084700		.3108891		
Load arm width (CM2)	.005633177				
Load arm length (CSlal)	- .003440326				
Height calc. (CM4)	- .03398512		.06137030	.07201593	
Max. height calc. (CSmh)	.1878201	.1639110			
Body length calc. (CM5)	- .3377099				
Tuber calcanei height (CM7)	-.001195908				
Tuber calcanei width (CM8)	.1652865				
Constant	- 22.42024	- 20.42779	- 20.58581	- 20.27305	- 19.91041
Male mean	1.51	1.16	1.14	1.11	1.04
Female mean	- 1.35	- 1.09	- 1.04	- 1.03	- 0.98
Accuracy	92.9%	87.0%	86.9%	86.3%	84.2%
Correct male	90.4%	83.1%	82.3%	82.9%	81.3%
Correct female	95.1%	90.6%	91.2%	89.4%	87.1%

* Total discriminant scores less than 0 classify as female.

The eight discriminant function based on measurements of the calcaneus alone (table 5) show an accuracy in sex determination from 82.1 to 92.6%. Again, females were better predicted than males.

The maximum length of the calcaneus is the most discriminant variable and can also be used alone to predict sex. Therefore, if specimens with a maximum length greater or equal to 75.5mm are considered males, while those with length less than this value are females, then 81% of the reference sample can be correctly sexed.

The use of discriminant analyses with multiple sets of variables from both bones, does not appreciably improve the accuracy of sex prediction over the use of discriminant function using measurements of the calcaneus alone. Nevertheless, in what the discriminant function using measurements of the talus alone is concerned, there is an improvement of 5%. The discriminant functions listed in table 6, show 84.2 to 92.9% in correctly sex determination, based on measurements of the talus and calcaneus. The males are again worst predicted than the females.

Table 7 indicates the results of the application of the eight selected discriminant functions on the control sample, which was performed to test the usefulness of the new method in other samples. Our discriminant function number 13, 4 and 18, that are homologous to, respectively, Steele's discriminant functions number 1, 2 and 5, present a higher percentage of accuracies in both samples (reference and control) than Steele's equations.

Table 7. Percent of accurate prediction for two samples using Steele's and Silva's discriminant functions.

Discriminant functions	Reference sample - Correct classification	Control sample - Correct classification
Discr. function 1 (Steele)	77.0%	80.0%
Discr. function 13 (Silva)	86.1%	82.0%
Discr. function 2 (Steele)	82.4%	82.0%
Discr. function 4 (Silva)	86.1%	94.0%
Discr. function 5 (Steele)	89.7%	84.0%
Discr. function 18 (Silva)	87.0%	90.0%
Discr. function 5 (Silva)	85.0%	86.0%
Discr. function 12 (Silva)	86.0%	86.0%

Concerning discriminant functions number 5 and 12, which were selected because of their great potential use in incomplete bones, 86 percent of the control sample could be accurately sexed, which represent the same degree of accuracy in relation to the reference sample.

Summary and conclusions

As tables 4 to 6 illustrate, the talus and calcaneus are useful for sex determination. Prediction rates for the reference sample range from 82.1 to 92.9 percent. The control group was sexed with 80-94 percent accuracy. Therefore, the technique presented here is more accurate than Steele's (1976). In addition, several equations can be applied in poorly preserved bones, sustaining a high level of accuracy.

The measurements of the talus and calcaneus that have some pratical value by their own, in sex determination, for both cases, the maximum length, predicted sex correctly, respectively, 84 and 81 percent, of the studied sample.

From a practical standpoint, since these two bones are solid relatively compact elements, the results of this study can be applied in situations where the talus and calcaneus are in fragmentary conditions or when other sexual diagnosis elements are missing, a situation that commonly occurs in archaeological sites. Another advantage of this method is that it will work with intermixed remains in multiple interments, such as ossuaries and collective burials.

Nevertheless, the usual limitations in using a statistical (discriminant function) technique in determining sex subsist. The most important of these is the representativeness of the sample for those individuals outside the region of the study sample (Kajanoja, 1969), and/or from different historic periods. The author plan to apply the results of the study to other samples.

Despite these limitations, it appears that these two foot bones can be useful tools in sex determination, especially when the remains are incomplete. For skeletal remains in good condition, they can serve as reliable corroboration of sexual assessments done by other means.

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Appendix

Talus measurements

Maximum length (M1):

From the M. flexor hallucis longus groove to the most anterior point on the head measured parallel to the sagittal axis of the trochlea.

Width of the talus (M2):

Maximum projected line laterally/medially perpendicular to the sagittal plane. The lateral point is the most lateral point on the articular surface for the lateral maleolus and the line generally bisects the articular surface for the tibia slightly forward of the midpoint.

Body height (M3):

Height of the body along the sagittal plane, taking above the articular surface for the tibia. The measurement is taken by placing the talus on a flat surface .

Maximum body height (M3a):

Maximum height of the body in an inferior/medially perpendicular to the sagittal plane. The measurement is taken by placing the talus on a flat surface and then determining the most superior point of the articular surface for the tibia. The superior point is generally along the medial rim of the facet.

Trochlear length (M4):

Maximum length of the trochlear articular surface on the midline measured parallel to the sagittal axis of the trochlea.

Trochlear width (M5):

From the mid-lateral edge of the trochlea to its mid-medial edge measured perpendicular to the sagittal plane of the trochlea.

Calcaneus measurements

Maximum length (M1):

Projected line from the most posterior point of the tuberosity of the calcaneus to the most anterior/superior point of the cuboidal facet.

Length (M1a)

Projected line from the most posterior point of the tuberosity of the calcaneus to the mid-point of the cuboidal facet.

Load arm width (M2):

Transverse projected line perpendicular to the long axis from the most lateral point of the posterior articular surface, to the most medial point of the sustentaculum tali.

Load arm length (Slal, according to Steele, 1976):

Projected line from the most posterior point of the posterior articular surface for the talus, to the most anterior/superior point of the cuboidal facet.

Height (M4):

Projected height from the most inferior point of the tuberosity of the calcaneus to the most inferior point of the body of the calcaneus.

Maximum height (Smh, according to Steele, 1976):

Greatest projected height of the calcaneus, and measured from the most inferior point of the tuberosity of the calcaneus to the most superior point of the posterior facet of the calcaneus.

Body length (M5):

Projected line from the most superior point of the tuber calcanei to the most distally point of the posterior facet of the calcaneus, measured parallel to the sagittal axis of the bone.

Tuber calcanei length (M7):

Greatest projected height of the tuber calcanei, measured from the most superior point of the tuber calcanei to the most inferior point of the *Processus medialis tuberis calcanei.*

Tuber calcanei width (M8):

Projected line laterally/medially of the tuber calcanei, perpendicular to the sagittal plane.