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Discriminant functions to determine sex in modern human bone remains from the province of Mendoza (Argentina) ☆

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Abstract

Introduction: Human bone remains from forensic contexts can present different degrees of complexity due to the action of postmortem processes that can alter the state of the corpse. In these cases, osteometric methods to determine sex are very useful. This work aims to adjust 8 discriminant functions previously developed by Mansegosa et al. (2018) to determine sex in long bones with applicability in modern populations of central-western Argentina.

Materials and methods: Eight discriminant functions for long bones were adjusted by surveying 8 variables in the clavicle, humerus, ulna, radius, femur, and tibia in 103 adult individuals (42 females and 61 males) belonging to the "Osteoteca de Mendoza para la investigación científica y forense" (Mendoza, Argentina). A cross-validation test was carried out and then the formulas were applied to a sample of 12 individuals with known sex corresponding to real forensic cases worked on by the Anthropology Laboratory of the "Cuerpo Médico y Criminalístico de Mendoza".

Results: Of the 8 discriminant functions, 3 reached acceptable values (>80%) in both sexes, which correspond to the humerus, radius, and clavicle. Cross-validation yielded overall percentages ranging from 72.3 to 87.5%. The sample from forensic contexts could be completely sexed with an efficiency of 91.7%. The generated model constitutes a first step in the generation of methodology to strengthen forensic anthropological research in Argentina.

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PALABRAS CLAVE

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Perfil Biológico;
Cadáveres no
identificados

Funciones discriminantes para determinar el sexo en restos óseos humanos modernos de la provincia de Mendoza (Argentina)**Resumen**

Introducción: Los restos óseos humanos procedentes de contextos forenses pueden presentar distinto grado de complejidad debido a la acción de procesos postmortem que pueden alterar el estado del cadáver. En estos casos los métodos osteométricos para determinar el sexo resultan de gran utilidad. Este trabajo tiene como objetivo el ajuste de 8 funciones discriminantes previamente desarrolladas por Mansegosa et al. 2018, para determinar el sexo en huesos largos con aplicabilidad en poblaciones modernas del centro-oeste de Argentina.

Materiales y métodos: Se ajustaron 8 funciones discriminantes para huesos largos mediante el relevamiento de 8 variables en clavícula, húmero, cúbito, radio, fémur y tibia en 103 individuos adultos (42 femeninos y 61 masculinos) pertenecientes a la «Osteoteca de Mendoza para la investigación científica y forense» (Mendoza, Argentina). Se realizó una prueba de validación cruzada y luego se aplicaron las fórmulas a una muestra de 12 individuos con sexo conocidos correspondientes a casos forenses reales trabajados por el Laboratorio de Antropología del Cuerpo Médico y Criminalístico de Mendoza.

Resultados: De las 8 funciones discriminantes, tres alcanzaron valores aceptables (>80%) en ambos sexos, las cuales corresponden al húmero, radio y clavícula. La validación cruzada arrojó porcentajes generales que oscilan entre 72,3 a 87,5%. La muestra procedente de contextos forenses pudo sexarse en su completitud con una eficacia del 91,7%. El modelo generado constituye un primer paso en la generación de metodología para el fortalecimiento de la investigación antropológica forense de Argentina.

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Introduction

When a criminal investigation involving human skeletal remains commences, the forensic anthropologist must determine the sex as one of the first steps in the process of reconstructing the biological profile of the deceased. Bone remains may originate from very different contexts (e.g., single, multiple, or scattered burials), with varying degrees of entirety (complete, partially complete, selection of anatomical parts, a single bone element, or bone fragments), and preservation (skeletonised, partially skeletonised, mummified, burnt, scavenged, among others). As a result, determining the sex of the deceased is often a complex task. Methods by which to determine sex include both osteological and genetic techniques, although whether they can be applied or not will depend on the state of conservation, the condition of the material, as well as the human and technical resources available.

Classification of sex at the osteological level is primarily made by means of the pelvis and the skull.¹ But when these bones are not available or when mixed collections are involved, it is crucial that the postcranium be studied.² On an international level, the analysis of postcranial dimorphism has focused largely on differences in size and has yielded extremely accurate results. For the Hispanic population, it is worth mentioning that discriminant functions (DFs) have been developed on the basis of long bones, sacrum, and scapula,³ metacarpals and metatarsals,⁴ and cervical vertebrae.⁵ The evolution of osteological

methodology for sex estimation in modern populations is relatively scanty, especially in Argentina, albeit interesting contributions have been made in the last few years.^{6–8} Along these lines, the present research will focus on the use of the osteometric method, with the intention of developing FDs for sex diagnosis further. It is valuable given that it is fast, inexpensive, replicable, and can be used on incomplete, mixed, and burnt skeletons, i.e., where the field of genetics cannot provide an answer.

Inasmuch as the osteometric methods available to determine sex are population-specific, one must be devised for the local population under study.⁹ A previous work has demonstrated that the FDs created for the historical population of Mendoza that lived during the 17th–19th centuries are not suitable for use in forensic cases, with the exception of the one established to evaluate the clavicle.¹⁰ A decrease in body size was recorded for the variables under study over time in both sexes, i.e., a negative secular variation. Consequently, this paper pursues a dual objective: on the one hand, to update the FDs developed by Mansegosa et al. (2018)¹¹ for their use in modern populations in Mendoza and, on the other hand, to appraise their performance in 12 local forensic cases already identified.

Materials and methods

The human remains analysed in this paper are part of the Human Osteoteca for Scientific and Forensic Research housed in the Faculty of Philosophy and Letters of the

National University of Cuyo.¹² The collection comprises skeletons of the contemporary local population from municipal cemeteries, whose graves had expired and were unclaimed. The skeletons are from individuals whose dates of death are between 1951 and 1992, and all have documented sex, age, and provenance. The collection has been endorsed by the Ethics Committee of the CCT Mendoza-CONICET.

Six postcranial long bones (clavicle, humerus, ulna, radius, femur, and tibia) were measured to generate a model that can be used in cases involving different skeletal representation. A total of 103 adult individuals were included, of which 42 were female aged 18–83 years (average 53 years) and 61 males aged 22–84 years (average 51 years). Left-lateral elements were prioritised, and when not available or in suitable condition, they were replaced by right-lateral elements. Only well-preserved, pathology-free and trauma-free elements were included. In light of the fact that this work seeks to refine the FDs developed by Mansegosa et al. 2018,¹¹ the same bone elements and variables were used (Table 1 and Fig. 1). The measurements used for the calculations were taken by a single observer using an Insize digital slide calliper (accuracy=0.00 mm), tape measure, and osteometric table. Intra- and inter-observer error was previously assessed and found to be non-significant.⁴

None of the data were simulated; when the element was missing or the variable could not be measured, it was recorded as a missing datum. The proportion of missing data was low; the highest percentage noted for clavicles was 15%. The normal distribution of the variables was confirmed using the Shapiro–Wilk statistic ($p < 0.05$) and means and standard deviations were calculated for each variable. The presence or absence of significant differences between the sexes was also assessed using an independent means test. To evaluate the sexual dimorphism index (SDI) in the sample studied, the formula developed by Garn et al. (1968)¹³ was used, SDI: $(M-F)/F \times 100$, in which M and F are the averages of the measurements in the group of male and female individuals, respectively. We then proceeded to carry out a discriminant analysis and to apply their formula. This analysis was conducted for each of the variables individually, and in the case of the humerus and femur, it was also performed with both variables together. The results yielded the values of the coefficient and the constant from which the FD was constructed.¹⁴ When the formula is used, the result obtained is categorised as male if it is greater than zero, whereas if it is less than zero, it is classified as female.

Table 1 Bone elements selected.^a

Element	Variable (code)
<i>Clavicle</i>	Mid-shaft antero-posterior diameter (36CDA)
<i>Humerus</i>	Vertical head diameter (42HDVC)
<i>Ulna</i>	Minimum mid-diaphyseal diameter (44HDM_M)
<i>Radius</i>	Minimum circumference (52UCM)
<i>Femur</i>	Mid-shaft antero-posterior diameter (46RDAP)
<i>Tibia</i>	Physiological length (61FLB)

^a Metric variables collected following the methodology by Mansegosa et al. (2018).¹¹

The cross-validation method was used to establish the reliability and predictive ability of the generated FDs. For a method to be considered effective, the total correct classifications, i.e., including both sexes, must exceed 80% effectiveness.¹⁵ The statistical package SPSS Statistics v.19 was used in all analyses.

Finally, to evaluate the effectiveness of the FDs in actual forensic cases, sex was determined in a sample of 12 adult individuals with documented sex and identification, and the remains of whom had undergone different kinds of postmortem alteration (thermal modification, natural skeletonisation, mummification, and scavenging). The sample was taken from cases worked by the Forensic Anthropology Laboratory of the Forensic and Criminalistic Medical and Forensic Corps of the Public Prosecutor's Office of Mendoza.

Results

Descriptive statistics and IDS zx for each variable are given in Table 2. All the measurements displayed significant differences between the sexes ($p < .05$), i.e., they exhibit sexual dimorphism. On average, all the variables indicate that male individuals are larger than female individuals; that being said, as expected for the human skeletal system, there is an overlap between the maximum and minimum values. Based on the IDS obtained, the variables are ranked in order from highest to lowest: CDA36, RDAP46, HDM_M44, HDVC42, TCF74, FCM68, UCM52, and FLB61.

Table 3 contains the results of the discriminant analysis, statistics, and functions built for each element. Eight DFs were generated; both the humerus and femur have 2 DFs each (considering a single variable and the combination of the 2 variables); all other elements have only 1 DF. All the models developed were significant ($p < .00$). The Wilks' lambda value is between 0 and 1; the closer the value is to 0 and the higher the F value, the greater the discriminatory capacity the variable has. All F -values were high, especially the clavicle, radius, and humerus. For the most part, the Wilks' lambda values are intermediate to high, which is indicative of moderate discriminative ability. The clavicle presents the greatest discriminatory ability in comparison to the other elements ($\lambda = 0.476$), followed by the radius ($\lambda = 0.541$), and the humerus ($\lambda = 0.549$ and $\lambda = 0.599$), while the femur, tibia, and ulna exhibit poor fit. The last column of Table 3 illustrates the DF for each anatomical element.

Table 4 presents the results of the cross-validation analysis. On the whole, the model displayed correct classifications in the range of 72.3%–87.5% for both sexes. The humerus with FD3 was correctly classified achieved the highest number of correct classifications, specifically 87.5%, followed by the radius and clavicle with 86.6% and 86.4%, respectively, high percentages recorded for both sexes. The remaining functions exhibited a classification power of less than 80%, and the lowest power was seen in the case of the ulna at 72.3%, mainly in females at 52.6%.

On the basis of the FDs generated, 12 individuals were classified that corresponded to forensic cases whose sex was known through medical-forensic identification (Table 5). Despite the scant availability of long bones in most cases as a result of major postmortem alterations, the sex was able to be identified in all individuals. Almost 92% (91.7%) of the

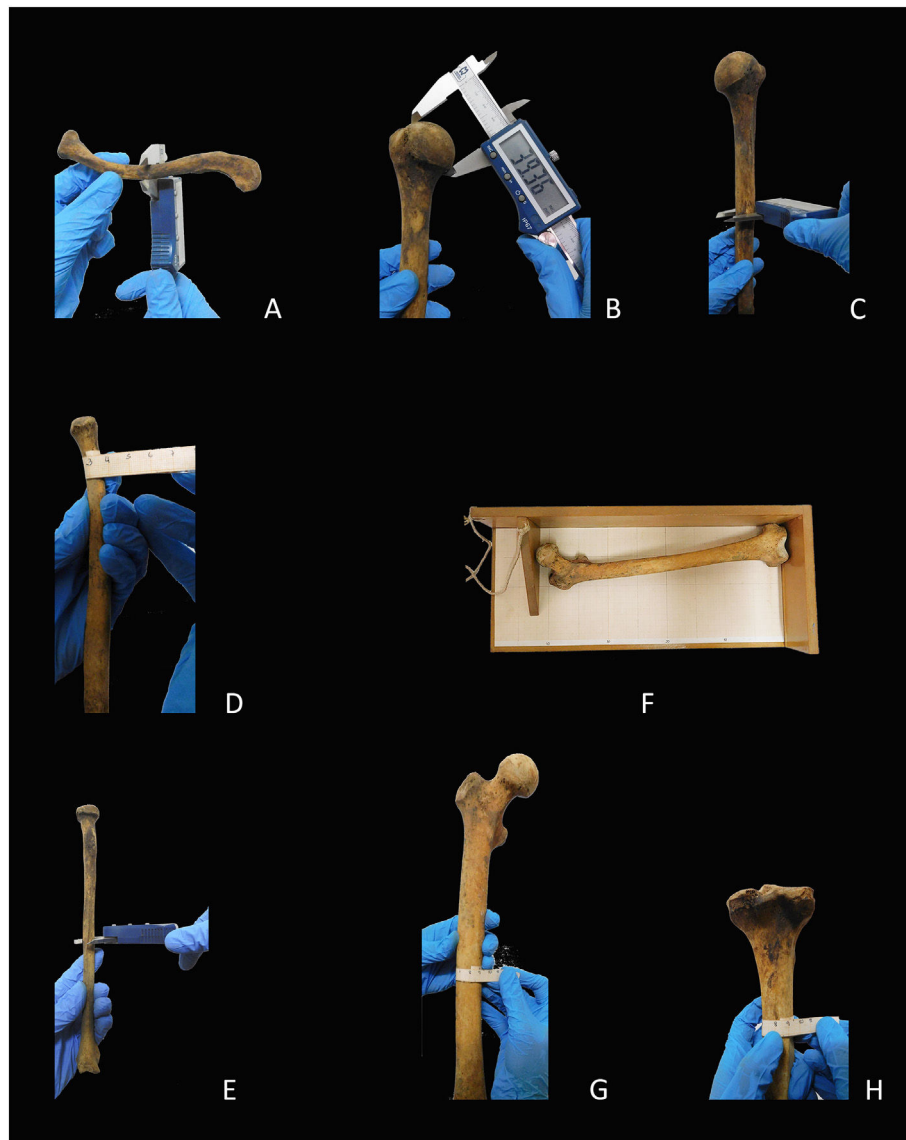


Fig. 1 The 8 measurements performed in line with the methodology put forth by Mansegosa et al. (2018).¹¹ (A) 36CDA; (B) 42HDVC; (C) 44HDM_M; (D) 52UCM; (E) 46RDAP; (F) 61FLB; (G) 68FCM; (H) 74TCF.

individuals were correctly categorised in terms of sex (11/12); all the males were classified to their corresponding sex (9/9, 100%). In contrast, one of the females was classified as males (2/3, 66.7%).

Discussion and conclusion

This project has been carried out to update the historical FDs proposed by Mansegosa et al. (2018)¹¹ that have been

Table 2 Descriptive statistics of the variables considered by sex. Results of the *T* test and sexual dimorphism.

	Female					Male					<i>T</i>	<i>p</i>	IDS zx
	<i>n</i>	Mean	Max.	Min.	SD	<i>n</i>	MeAN	Max.	Min.	SD			
<i>CDA36</i>	36	10.63	13.55	7.61	1.23	52	13.06	15.20	10.00	1.10	−9.727	.00	22.87
<i>HDVC42</i>	37	40.03	48.31	35.82	2.59	59	44.72	50.66	39.68	2.52	−8.779	.00	11.70
<i>HDM_M44</i>	38	15.54	18.90	13.05	1.65	59	17.99	20.77	14.82	1.46	−7.674	.00	15.78
<i>RDAP46</i>	40	10.37	12.72	8.98	0.87	57	12.12	14.12	8.90	1.00	−8.98	.00	16.90
<i>UCM52</i>	38	33.45	43.00	28.00	2.94	56	36.46	44.00	29.00	3.19	−4.643	.00	9.01
<i>FLB61</i>	42	40.40	45.70	36.50	1.77	60	43.17	47.80	36.50	2.27	−6.918	.00	6.85
<i>FCM68</i>	41	8.14	9.40	7.20	0.57	60	8.89	13.00	7.30	0.82	−5.028	.00	9.10
<i>TCF74</i>	38	83.71	100.00	73.00	5.99	58	91.86	107.00	70.00	7.55	−5.601	.00	9.73

Table 3 Discriminant analysis of each anatomical element and derived function.

DF N°	Element	Variable	Coefficient	Constant	Wilks' lambda	F	Discriminant function fitted to modern
FD1	Clavicle	CDA36	0.868	-10.466	0.476	94.621	(CDA36*0.868)-10.466
FD2	Humerus	HDVC42	0.26	-16.638	0.549	77.065	(HDVC42*0.260) + (HDM_M44*0.322)-16.638
		HDM_M44	0.322		0.599	63.024	
FD3	Humerus	HDVC42	0.393	-16.863	0.549	77.065	(HDVC42*0.393)-16.863
FD4	Humerus	HDM_M44	0.651	-11.084	0.617	58.897	(HDM_M44*0.651)-11.084
FD5	Radius	RDAP46	1.056	-12.043	0.541	80.634	(RDAP46*1056)-12.043
FD6	Ulna	UCM52	0.323	-11.4	0.811	21.558	(UCM52*0.323)-11.40
FD7	Femur	FLB61	0.368	-20.107	0.821	18.732	(FLB61*0.368) + (FCM68*0.541)-20.107
		FCM68	0.541		0.821	4.307	
FD8	Femur	FLB61	0.481	-20.23	0.695	43.865	(FLB61*0.481)-20.23
FD9	Femur	FCM68	1.375	-11.802	0.797	25.285	(FCM68*1375)-11.802
FD10	Tibia	TCF74	0.143	-12.711	0.750	31.374	(TCF74*0.143)-12.711

developed on the basis of a colonial population from the same region for use in the modern population of the same region in local forensic cases. Hence, the same variables corresponding to 6 long bones were collected and new FDs were generated. Their efficacy was tested by cross-validation and then applied to a sample of 12 individuals corresponding to local medical-forensic cases.

The 8 FDs developed in this work yielded reliability percentages that varied between 72.3% and 87.5%, surpassing the effectiveness of the historical FDs, which ranged from 53.2% to 82.95%.¹⁰ Another improvement is that the accuracy rates are more equal between both sexes (females between 52.6% and 83.8%; males between 78.3% and 89.9%) than those attained with the historical FDs (females between 86.5% and 94.7%; males between 25% and 75%). This is due to the fact that the degree of dimorphism has displayed variations over time in the population of Mendoza, principally with regard to the size of males, which revealed a negative secular trend.

With this new model, the functions that surpassed the 80% threshold required for suitability are: FD3 for the humerus, FD5 for the radius, and FD1 for the clavicle, with the rest falling below this percentage and whose use in

forensic cases is consequently discouraged. Other research on modern samples have also found the clavicle and humerus to be among the most dimorphic elements.^{3,16-18} The low percentages achieved in general and notably for the femur, an element that is of great use in many studies on dimorphism, are attributable to the fact that measurements of the midshaft were mainly used, which are subject to greater environmental influence and, as such, are less dimorphic than the joints that typically serve as better predictors.^{19,20} Nonetheless, the FDs that have been produced will be very useful in forensic cases in the province, inasmuch as the recovery of skeletal remains in highly variable and the epiphyses are not usually present or they are altered by common taphonomic factors, such as the scavenging of corpses.^{21,22} Along these lines, the FDs developed in the present study demonstrated a high degree of confidence when used on a sample of 12 actual forensic cases, yielding an accuracy rate of 91.7% of the individuals. The FDs generated by other researchers for the Hispanic/Latin American population based on variables and postcranial elements³⁻⁵ not addressed in this paper should be evaluated in the local population to determine their potential validity and consider their adaptation.

Table 4 Results of the cross-validation and percentages of correct classifications obtained with the discriminant functions created in this work.

Element	FD no.	Females		Males		Total	
		c/n	Correct %	c/n	Correct %	c/n	Correct %
Clavicle	FD1	30/36	83.3	46/52	88.5	76/88	86.4
Humerus com	FD2	30/37	81.1	52/59	88.1	82/96	85.4
Humerus 42	FD3	31/37	83.8	53/59	89.8	84/96	87.5
Humerus 44	FD4	26/38	68.4	50/59	84.9	76/97	78.4
Radius	FD5	33/40	82.5	51/57	89.5	84/97	86.6
Ulna	FD6	20/38	52.6	48/56	85.7	68/94	72.3
Femur com	FD7	30/41	73.2	49/60	81.7	79/101	78.2
Femur 61	FD8	33/42	78.6	47/60	78.3	80/102	78.4
Femur 68	FD9	26/41	63.4	50/60	83.3	76/101	75.2
Tibia	FD10	26/38	68.4	48/58	82.8	74/96	78.1
Total		285/388	73.5	494/580	85.2	779/968	80.5

c/n: correct/number of cases observed.

Table 5 Estimation of sex of individuals corresponding to forensic cases in the province of Mendoza.

INDIV	Sex, documented	Postmortem alteration	FD1	FD2	FD3	FD4	FD5	FD6	FD7	FD8	FD9	FD10	Sex determined	Coincidence
1	F	Thermoaltered	F	–	F	–	–	–	–	–	–	F	F	Yes
2	M	Skeletonised	–	M	M	M	–	M	–	–	–	M	M	Yes
		Scavenging												
3	F	Skeletonised	M ^a	–	–	–	M ^a	F	–	–	–	–	M	No
4	M	Skeletonised	–	–	M	–	–	–	–	–	–	M	M	Yes
5	M	Partially skeletonised	M	–	–	–	M	–	–	–	–	M	M	Yes
		Scavenging												
6	M	Thermoaltered	–	–	M	–	–	–	–	–	–	–	M	Yes
		Scavenging												
7	M	Mummified	M	–	–	–	–	–	–	–	–	M	M	Yes
8	M	Thermoaltered	–	–	M	–	–	–	–	–	–	–	M	Yes
9	M	Mummified	M	M	M	M	–	–	–	–	M	M	M	Yes
10	M	Skeletonised	–	M	M	M	–	–	M	M	M	–	M	Yes
11	F	Skeletonised	–	F	F	F	F	F	F	F	F	F	F	Yes
12	M	Skeletonised	M	M	M	M	M	F	M	M	M	M	M	Yes

F: female; M: male.

^a Incorrect sex estimation.

In conclusion, this work provides adjusted and validated FDs in order to establish the sex of individuals from forensic cases from central-western Argentina, that are especially useful when dealing with corpses the integrity of which have been damaged. Future studies should incorporate more measurements, with a particular focus on long bone epiphyses, so as to increase diagnostic effectiveness, in addition to other statistical methods, such as logistic regression or probabilistic analyses.

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Declaration of competing interest

The authors have no conflict of interests to declare.

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