Forensic Sciences Research, 2024, Vol. 9, Issue 2
https://doi.org/10.1093/fsr/owae015
Research Article

Metric analysis of the patella for sex estimation in a Portuguese sample

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Abstract

The biological profile estimation is the first step toward positive identification. However, it is not always possible to access a complete and well-preserved skeleton due to postmortem damage and taphonomic changes. As such, there is a need to develop new alternatives to analyze different bones of the human skeleton. The present study aims to analyze the patellar osteometry, with attention to its degree of sexual dimorphism, to establish a simple method for estimating sex in Portuguese adults. Six measurements were taken from 222 patella pairs, including 117 females and 105 males from the XXI Century Identified Skeleton Collection of the University of Coimbra. Subsequently, this method was validated in a different sample of 50 individuals equally representing both sexes. Maximum height stands out with a 77.0% of correct sex estimation, reaching 98.0% when applied to the new sample. The linear discriminant function analysis containing all the six variables showed the best results, with 80.2% of correct classification after cross-validation and 96.0% when applied to the independent sample.

Keywords: patella; sex estimation; discriminant function; Portuguese population; forensic anthropology

Introduction

Sex estimation is one of the major challenges in forensic anthropology. In majority of forensic cases, human skeleton remains are either incomplete or damaged. As such the skull, pelvis, and long bones, commonly used to estimate this parameter, are frequently fragmented or even absent. In this sense, it is important to establish methodologies that allow us to overcome this impasse, providing and complementing information to achieve a positive identification.

The sex estimation is the first step through a positive identification and an indispensable information for the accurate assessment of other parameters, such as age-at-death and stature. It is intimately linked to the notion of sexual dimorphism, which is the differences in size and form between male and female individuals of the same species. These differences begin to stand out in puberty through the action of the hormonal system, resulting in differences in size and shape between males and females [1–3]. In general, the sexual dimorphism in humans presupposes that male individuals are bigger and more robust than female and, consequently, the female sex will be smaller and more graceful [1, 4]. However, some regions of the skeleton may not display any differences: the sexual dimorphism is not linear, and besides having a physical and anatomical dimension, it also has a behavioral and environmental one [5]. There are intra- and inter-populational differences of size and robustness that we need to understand in order to avoid errors in data interpretation.

In this sense, to increase the capacity of forensic anthropology dealing with population diversity, it is important to develop specific techniques for population groups and invest in the study of different bones of the human skeleton [6]. After the pelvis, which sexual dimorphism is known to lack population specificity [5], nowadays the best sex indicators are the long bones and only after the skull [7].

This article presents the metric study of the patella in a Portuguese sample of adults, assessing the validity of this bone for the sex estimation in forensic anthropology.

The patella is a small and compact bone in the knee joint. It articulates posteriorly with the femoral sulcus and is supported anteriorly by the quadriceps tendon. This triad that provides stability and movement constitutes the knee joint [8, 9].

The value and utility of the osteometric analysis of the patella in sex estimation has been addressed in several studies across different population. There are differences in the volume of patellae between the sexes and ancestry should be considered for better results in sex estimation [10, 11]. As such, it highlights the importance of the existence of population studies for a better effectiveness of this method in anthropology.

Dayal and Bidmos [12] studied a sample of the South African black population obtaining 85% accuracy of classification, decreasing to 81.7% of correct classification after cross-validation; Bidmos et al. [13] analyzed white South Africans obtaining 85% accuracy in classification, decreasing to 83% after cross-validation. The Indian population already has two studies [14, 15], obtaining 80.5% and 89.1% accuracy of classification in the sample. Phoophalee et al. [16]

Received: August 1, 2023. **Accepted:** January 26, 2024

achieved 88.9% accuracy after cross-validation for the Thai population; Sakaue [17] achieved 85% accuracy in a sample of the Japanese population; Akhlaghi et al. [18] obtained 92.9% accuracy in a sample of the Iranian population; Peckmann and Fisher [19] assessed the African American population obtaining 85% accuracy, and 82% after cross-validation.

In Europe, Introna et al. [20] studied a sample of the Italian population obtaining a correct classification of 83.8%; Peckmann et al. [21] analyzed a sample of the Spanish population, obtaining a rating of 84.8% which after cross-validation decreased to 83.8%. Overall, the accuracy of classification through the patella exceeds 80% in different populations, proving to be an advantage for a positive identification.

The current work presents an osteometric analysis of the patella in a Portuguese adult skeletal sample and aims to assess the sexual dimorphism of this structure and its validity for the sex estimation in this populational context.

Material and methods

The sample consists of 222 individuals, 117 females and 105 males, from the XXI Century Identified Skeleton Collection of the University of Coimbra (CEI/XXI) with institutional approval. This study was approved by the Scientific Commission of the 21st Century Identified Skeletal Collection. It is a retrospective study where any new osteological material was recovered on purpose. Six measurements were taken using a caliper, similarly to previous studies [12, 13, 16, 17, 19, 21] (Figure 1; Table 1).

In an initial phase, the inter- and intra-observer error in data collection was assessed, taking into account the technical measurement error and the reliability coefficient [22–24].

The next step of data analysis was to evaluate bilateral asymmetry in order to assess whether it is possible to use this method regardless of the laterality: for this purpose, 127 pairs of patellae were analyzed from the original sample. The evaluation of asymmetry consisted of an evaluation of the mean deviation (MD), allowing to perceive the dispersion of the data and to quantify the distance between the two cumulative distribution functions, left patella and right patella, by calculating the Kolmogorov–Smirnov index (D). D index or statistic is a simple yet robust statistical tool to compare two distributions using the entire cumulative function instead of simple descriptive parameters such as the sample mean and standard deviation.

To analyze sexual dimorphism, the average deviation index was calculated. However, this does not consider the variability of the characteristics. Thus, dimorphism was assessed using a *t*-test for independent samples and, again, the D was used, quantifying the distance between male and female distribution functions. However, the D index should be chosen over the *t*-test since the *t*-test is dependent on the sample size [25].

Finally, sectioning points for each measurement and a discriminant function for the sex estimation through the patella were computed. The sectioning point or cutoff point was established by finding the supremum, that is the value that maximizes the difference between the cumulative distribution of each sex. Subsequently, this method was validated in a different sample of 50 identified skeletons from the Identified

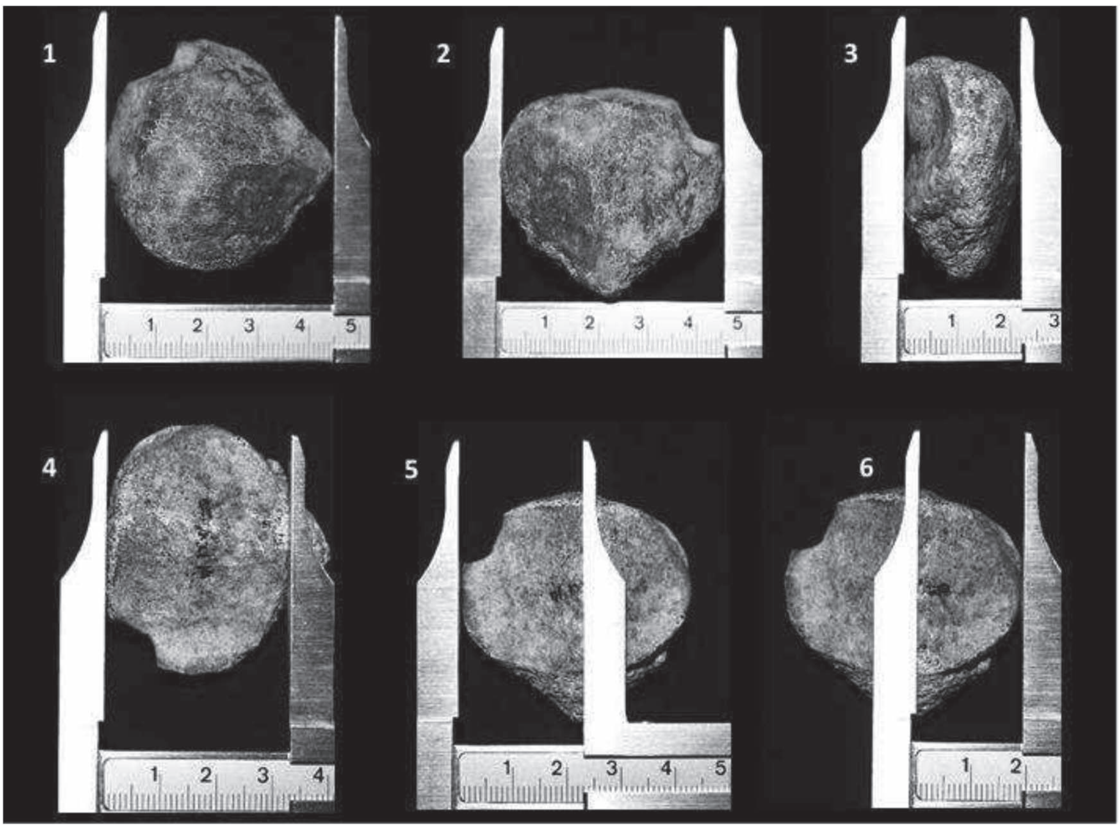

Figure 1 Patellar measurements demonstration. For detailed description of the six measurement see Table 1.

Table 1. Description of the measurements used in the study of the patella.

No.	Measurements		Description
1	**MAXH**	(maximum height)	Maximum distance between the base of the patella and the apex
2	**MAXB**	(maximum breath)	Maximum distance between the medial and lateral ends
3	**MAXT**	(maximum thickness)	Maximum thickness between anterior and posterior region
4	**HAF**	(maximum height of articulating facet)	Maximum height between the upper and lower edges of the articular surface of the patella
5	**MAFB**	(medial articular surface breath)	Maximum distance between the vertical crest and the medial end of the articular surface
6	**LAFB**	(lateral articular surface breath)	Maximum distance between the vertical crest and the lateral end of the articular surface

Skeleton Collection of the University of Coimbra (CEI) with institutional approval, equally representing both sexes.

All statistical analysis was carried out using the R-statistical environment [26].

Results and discussion

The first step in data analysis consisted in the evaluation of the inter- and intra-observer error, in order to assess the replicability of this method (Table 2). According to Ulijaszek and Kerr [24] the measurement error is acceptable whenever the reliability coefficient (R) is >0.95. In this sense, the variables with higher values of R are maximum height (MAXH) and maximum breadth (MAXB), being the measurements regarding the articular surface more variable. This may be related to morphological variations in the region, as well as to the subjectivity of the joint surface for the collection of measurements.

The analysis of bilateral symmetry (Table 3) was followed in order to ascertain whether there are significant differences between literalities: there are no significant differences for any of the measurements made between the left or right patella (P-value > 0.05). This fact is supported by observing the D index values close to 0. Once again, greater differences are observed in the measures related to the articular surface. In general, the variations in the values between the sides are within the precision of the measuring instrument (1 mm), a fact supported by the low values of MD showing a small dispersion of the data. Although Buikstra and Ubelaker [27] recommend that the collection of measures in anthropology be carried out on the left side, the preservation or availability of osteological material does not always allow it. In this sense, as there are no significant differences, it is possible to measure only one patella, regardless of laterality, for the application of this method.

The evaluation of the existence of differences between sexes is the last point to verify according to previous studies [16, 20, 21, 26]: differences in patella size between sexes are expected due to sexual dimorphism, associated with robustness and a larger dimension in males compared with females (Table 4).

Table 2. Intra- and inter-observer error evaluation (n = 100).

Variables	Error	TEM	rTEM (%)	R
MAXH	Intra-observer	0.604 152 3	1.509 437	0.971 048 8
	Inter-observer	0.659 545 3	1.647 422	0.964 678 2
MAXB	Intra-observer	0.608 276 3	1.455 903	0.971 553 0
	Inter-observer	0.663 325 0	1.587 282	0.965 812 6
MAXT	Intra-observer	0.591 608 0	2.977 393	0.909 618 2
	Inter-observer	0.744 983 2	3.765 394	0.857 995 1
HAF	Intra-observer	0.943 398 1	3.244 148	0.865 491 5
	Inter-observer	1.236 931 7	4.260 874	0.792 569 9
MAFB	Intra-observer	0.924 662 1	4.873 055	0.848 203 4
	Inter-observer	1.324 764 1	6.959 622	0.730 677 7
LAFB	Intra-observer	1.090 871 2	4.328 854	0.733 322 1
	Inter-observer	1.294 217 9	5.147 019	0.652 350 1

MAXH: maximum height; MAXB: maximum breadth; MAXT: maximum thickness; HAF: height of articular facet; MAFB: medial articular facet breadth; LAFB: lateral articular facet breadth; TEM: technical error of measurement; rTEM: relative technical error of measurement; R: reliability coefficient.

Table 3. Evaluation of the bilateral symmetry of the patella (n = 127).

Variables	MD	MAD	MedAD	MAPD	D	P-value
MAXH	−0.272	1.130	1	2.854	0.071	0.907
MAXB	0.039	1.157	1	2.790	0.031	1.000
MAXT	−0.008	0.559	0	2.765	0.031	1.000
HAF	0.465	1.283	1	4.497	0.118	0.338
MAFB	0.134	1.205	1	6.525	0.047	0.999
LAFB	0.409	1.134	1	4.576	0.126	0.266

MAXH: maximum height; MAXB: maximum breadth; MAXT: maximum thickness; HAF: height of articular facet; MAFB: medial articular facet breadth; LAFB: lateral articular facet breadth; MD: mean deviation; MAD: mean absolute deviation; MedAD: median absolute deviation; MAPD: mean absolute percentage deviation; D: Kolmogorov–Smirov index.

Table 4. Sexual dimorphism evaluation.

Variables	IDM (%)	t	D	P-value
MAXH	10.156	10.399	0.548	0
MAXB	9.142	9.291	0.486	0
MAXT	8.281	7.636	0.379	0
HAF	9.649	8.260	0.431	0
MAFB	11.182	8.156	0.424	0
LAFB	8.424	8.479	0.442	0

MAXH: maximum height; MAXB: maximum breadth; MAXT: maximum thickness; LAFB: lateral articular facet breadth; HAF: height of articular facet; MAFB: medial articular facet breadth; IDM: mean deviation index; t: t-test for independent samples; D: Kolmogorov–Smirov index.

In this sense, MAXH and MAXB stand out as the most dimorphic measures, with values in the D index closer to 1 and higher t-test statistics, which also translates into higher values in the standard deviation index. Thus, according to the results obtained, we can state that the measurements taken on the patella are between 8.281% and 11.182% higher in males compared with females, with the MAXH and MAXB values being more dimorphic and taking into account the intra-sexual variability.

To visually assess differences between sexes, conditioned density graphs were constructed using non-parametric probability estimators (Figure 2). There is a large overlap between variables, which reflects the large intra-sexual variability of the sample, indicating that the measurements alone will have little significance with a large area of intersection.

Finally, a discriminant function was created for the sex estimation through the patella (Table 5). The function with the highest discriminating power includes all variables, obtaining 80.2% correct classification after cross validation: Dayal and Bidmos [12], Bidmos et al. [13], Sakaue [17], Phoophalee et al. [16], Peckmann and Fisher [19], also highlight better results with the joint analysis of the six variables included in this study. When applied to the control sample CEI, the function achieves 96% of correct rating.

Despite the lower individual ability of the measurements for sex estimation, probably due to the high intra-sexual variability, it is possible to state that the discriminant function, which results from the combination of several measures to discriminate a characteristic, allows the estimation of sex in forensic anthropology in the Portuguese population, obtaining the highest classification accuracy, 80.2% after cross-validation, and, when applied to the independent sample, it reached 96% accuracy:

$$y = (0.162 \times MAXH) + (-0.040 \times MAXB) + (-0.011 \times MAXT) + (0.121 \times HAF) + (0.221 \times MAFB) + (0.127 \times LAFB) - 15.692$$

The patella metric analysis has shown to be a useful element for sex estimation, with accuracy exceeding 80% in different studies ([12–21]. However, the patella and its characteristics are specific to each population, so it is important to take specific population studies for a better applicability of the method. Authors such as Bidmos et al. [13], Sakaue [17], Peckmann et al. [21] tested their best discriminant functions in other populations and there was a decrease in classification accuracy.

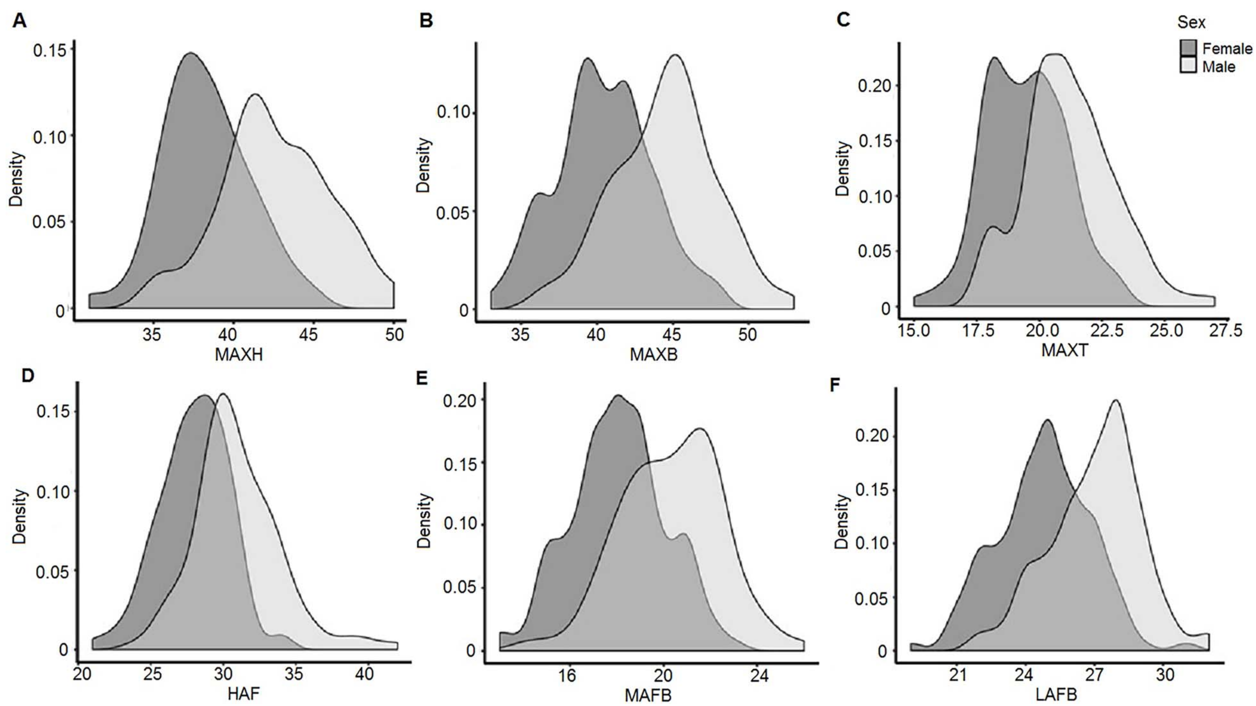

Figure 2 Graphic representation of the sexual differences in the patellar measurements. (A) Maximum height (MAXH). (B) Maximum breath (MAXB). (C) Maximum thickness (MAXT). (D) Maximum height of articulating facet (HAF). (E) Medial articular facet breath (MAFB). (F) Lateral articular surface breath (LAFB).

Table 5. Discriminant functions and respectively accuracy for sex estimation through the patella in Portuguese adult population.

Functions	Variables	Standardized coefficient	Unstandardized coefficient	Group centroids		Sectioning point	Accuracy (%)		
				Male	Female		O	CV	V
1	MAXH	0.496	0.162	0.882	−0.791	0.417	81.1	80.2	96
	MAXB	−0.129	−0.040						
	MAXT	−0.018	−0.011						
	HAF	0.321	0.121						
	MAFB	0.457	0.221						
	LAFB	0.253	0.127						
	Constant	-	−15.692						
2	MAXH	0.460	0.150	0.879	−0.789	0.416	80.18	80.1	98
	HAF	0.308	0.116						
	MAFB	0.411	0.199						
	LAFB	0.193	0.096						
	Constant	-	−15.764						
3	MAXH	0.549	0.179	0.869	−0.780	0.411	80.6	79.7	96
	HAF	0.360	0.135						
	MAFB	0.425	0.206						
	Constant	-	−15,148						
4	MAXH	0.699	0.229	0.783	−0.703	0.389	77.48	77.4	100
	MAXB	0.397	0.122						
	Constant	-	−14.388						
5	MAXH	0.754	0.247	0.823	−0.739	0.370	80.2	78.83	96
	MAFB	0.450	0.218						
	Constant	-	−14.111						

MAXH: maximum height; MAXB: maximum breadth; MAXT: maximum thickness; HAF: height of articular facet; MAFB: medial articular facet breadth; LAFB: lateral articular facet breadth; O: original sample (CEI/XXI); CV: cross validation; V: Control sample (CEI). If y-value > sectioning point, the individual is classified as male; If y-value < sectioning point, the individual is classified as female.

Final considerations

This is the first study of the patella for sexual estimation in the Portuguese population. The discriminant function equation including all the variables is proposed for sex estimation, obtaining the highest classification accuracy, 80.2% after cross validation, and, when applied to the independent sample, it reached 96% accuracy. This method aims to assist sex estimation in Forensic Anthropology and can be used in the Portuguese population. The results are consistent with existing patella studies in other populations, but further studies should be done in order to improve this method. The methods developed in this bone have a strong population specificity and should not be applied in other populations without being previously tested. Whenever possible, it should be used in articulation to other methods to minimize the error and maximize the certainty of the estimation.

Authors' contributions

Cláudia Maio took the measurements, was the main responsible for the research and wrote the article. David Navega provided the majority of the statistical treatment. Eugénia Cunha conceived the project, supervised the research and co-wrote the article. All the authors contributed to the final text and approved it.

Compliance with ethical standards

This study was approved by the Scientific Commission of the 21st Century Identified Skeletal Collection. It is a retrospective study where any new osteological material was recovered on purpose.

Disclosure statement

None declared.

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