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Research Article

Sex Estimation with Patella Measurements from CT Images

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Abstract

Aim: This study aimed to investigate sex-based differences in an adult Turkish sample by measuring patellar bone size in an adult Turkish sample.
Material and Method: Patella height, width, and depth were measured in cases who underwent knee computed tomography (CT) at Bolu Abant Izzet Baysal University Training and Research Hospital between 2013 and 2023. A total of 102 cases were evaluated. Patellar dimensions, including the heights, widths, and depths of the cases were measured for each case. Statistical analysis was conducted using SPSS version 26.00.
Results: A total of 102 cases including 62 males and 40 females were analyzed in the study. Patella height, width, and modified depth parameters were found to be significantly higher in males (p<0.001). However, since the depth does not affect the accuracy of sex estimation, only the height and width parameters were used for the analysis. For the male sex prediction, 86.7% sensitivity, 71.1% specificity, and 80.6% accuracy rates were obtained with the analysis using height and width parameters. The following discriminant formula was established: "Sex=1.504xHeight + 1.867xWidth-14.218". Separate models were also developed using height and width parameters. When using only height parameters, male sex was predicted with 80% sensitivity, 73.7% specificity, and 77.6% accuracy. The discriminant formula was formulated as follows: "Sex=2.925xHeight-11.992". Ehen using only the width parameters, the male sex was predicted with 88.7% sensitivity, 75% specificity, and 83.3% accuracy. The discriminant formula was established as: "Sex=2.987xWidth-12.900". The depth parameters provided 85.5% sensitivity, 52.5% specificity, and 72.5% accuracy with male sex. The formula "Sex=2.925xHeight-11.992" was developed.
Conclusion: Our study demonstrated sex dimorphism in the patellar bone within the Turkish population, with males showing significantly larger patellae than females. An accuracy rate of 80.6% was achieved using all patellar measurements. The findings suggest that the patella may serve as a valuable supplementary tool when used alongside other anthropological methods, enhancing the accuracy and reliability in sex estimation.

Keywords: Forensic medicine, forensic anthropology, identification, sex estimation, patellar bone, computed tomography

INTRODUCTION

Forensic identification has gained importance due to the recent rise in migration and conflicts. Identification is essential for legal and humanitarian reasons. It is a legal requirement to establish the cessation of a person's life. Moreover, enabling the deceased's relatives to conduct a funeral ceremony aligning with their beliefs and traditions facilitates the grieving process with minimal harm. The initial phase in the identification of skeletal remains is establishing the biological profile of the skeleton, which includes determining sex, age, height, and ethnicity. The biological sex estimation process reduces the population to be investigated by half. The biological profile is established and then compared with information on missing individuals (1,2).

While sex estimation can be achieved at a rate of 98-100% in cases where the entire skeleton or both the pelvis and skull are preserved, the remains examined in a forensic context may have compromised integrity (1-5). Compact and durable bones become essential for anthropological studies in fragmented, burned, or otherwise damaged cases. The patella has a potential for anthropological analysis thanks to its compact and distinctive structure and location between two solid long bones, such as the femur and tibia (6-9).

Population specificity in forensic anthropology underscores the variation in skeletal morphology across

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different ethnic and regional groups. Sexual dimorphism, while present universally, manifests differently depending on genetic and environmental factors, leading to variations in bone structure and size. Therefore, it can be argued that population-specific standards have become necessary to determine sex from skeletons. However, it is recommended that standards specific to one population should not be used in another population. Therefore, the need for prior information regarding the population group of the skeleton to be examined can be seen as a drawback in using population-specific standards in a forensic context (10-14). This study aims to determine the differences between sexes by measuring the patellar height, width, and depth.

MATERIAL AND METHOD

This study was conducted at Bolu Abant İzzet Baysal University İzzet Baysal Training and Research Hospital (BAIBUTRH). Ethics approval dated 22.09.2023 and numbered 409 was obtained from Bolu Abant İzzet Baysal University Clinical Research Ethics Committee for the study. The study was designed in accordance with the Declaration of Helsinki. Patella height (vertical length of the patella measured between its most superior and most inferior anatomical points), width (transverse width of the patella measured between its most medial and most lateral anatomical points), and depth (anteroposterior thickness of the patella measured from the most anterior to the most posterior anatomical point) were measured in cases who underwent knee computed tomography (CT) at BAIBUTRH between 2013 and 2023. Using G*Power version 3.1.9.6, the required sample size was calculated based on an effect size of 0.15, a power of 0.90, an alpha level of 0.05, and three independent variables, yielding a minimum of 99 participants. A total of 102 individuals were included in the study. All CT images were obtained using a 64-slice scanner (Revolution Evo, GE Healthcare, Milwaukee, Wisconsin, United States) with patients in the supine position, including the entire patella and fibular head in the scan range. Scans were acquired using a high-resolution bone algorithm with a slice thickness of 1.25 mm, a reconstruction interval of 0.625 mm, at 120 kV, and with tube current modulation. Images were post-processed using multiplanar reconstruction and three-dimensional volume rendering (3D VR) techniques on a dedicated workstation (Advantage Workstation 4.3, GE Healthcare, Milwaukee, WI, USA). Observers were allowed to enlarge the CT slices and adjust image contrast and screen brightness during measurements to optimize visualization. A total of 102 cases were accessed. Height measurements could not be made in four cases due to missing sections. The widths and depths of these cases were measured, and analyses were made accordingly. The suitability of the parameters for normal distribution was checked with the Shapiro-Wilk test. Student's t-test or Mann-Whitney U test was used for comparisons according to sex. In the display of parameters, mean, standard deviation, and minimum-maximum values or median and interquartile range were used depending on the distribution. A linear discriminant analysis model was established. SPSS 26.00 program was used in the statistics, and $p<0.05$ was determined as the significance level.

RESULTS

102 cases, 62 males and 40 females were included in the study. The height parameter could not be measured in four cases due to limited access to CT image sections. Fifteen days after the initial measurement, the same operator remeasured 25% of the randomly selected subjects. The Inter/Intra-Class Correlation Coefficient (ICC) was used to assess inter-observer and intra-observer reliability, aiming to minimize result bias. The ICC in this study ranged from 0.987 to 0.996, indicating excellent reliability according to the interobserver reliability classification proposed by Koo and Li (15). Bonferroni transformation (xi=1/x) was applied to the depth parameter that did not show a normal distribution (Statistics: 0.974; p=0.042). It was observed that the modified depth parameter followed a normal distribution (Statistics: 0.987; p=0.421).

Comparisons by sex were made with the Student's t-test. Patella height, width, and modified depth parameters were found to be higher in men ($p<0.001$). Descriptive statistics and analysis results of the measurements are shown in Table 1.

Table 1. Sex wise descriptive statistics of patellar dimensions

	Male				Female				t	p
	Mean	Std	Min	Max	Mean	Std	Min	Max		
Height	4.32	0.36	3.65	5.11	3.74	0.30	3.13	4.40	8.191	<0.001
Width	4.55	0.35	3.69	5.43	3.94	0.32	3.28	4.54	8.737	<0.001
Modified depth	0.46	0.04	0.37	0.57	0.51	0.04	0.41	0.60	-4.888	<0.001

Linear discriminant analysis was run with height, width, and modified depth parameters. When canonical discriminant functions were examined, it was seen that the eigenvalue was 0.985, the canonical correlation was 0.704, Wilks' lambda was 0.504, the chi-square was 64.792 and the p-value was <0.001. It was determined that patellar depth did not affect sex estimation (standardized canonical discriminant function coefficient: -0.007). The analysis was conducted with width and height parameters. The correlation coefficient was measured as 0.520. The male centroid was found to be 0.782, the female centroid was -1.234, and the cut-off value was determined to be -0.226. For the male sex, 86.7% sensitivity, 71.1% specificity, and 80.6% accuracy rates were obtained. Classification statistics are shown in Table 2. The discriminant formula was established as follows:

$$Sex=1.504xHeight + 1.867xWidth-14.218$$

Table 2. Classification table from linear discriminant function analysis for height and width

		Predicted group membership		
		Male	Female	Total
Original	Male	86.7% (52)	13.3% (8)	60
	Female	28.9% (11)	71.1% (27)	38
Cross-validated	Male	85% (51)	15% (9)	60
	Female	28.9% (11)	71.1% (27)	38

Separate models were run for the height and width parameters (0.514 and 0.631, respectively), for which the standardized canonical discriminant function coefficients are substantially high. When the canonical discriminant functions of the model built with the height value were examined, it was seen that the eigenvalue was 0.699, the canonical correlation value was 0.641, Wilks' lambda was 0.589, the chi-square value was 50.612, and the p-value was <0.001. The male centroid was found to be 0.658, the female centroid was -1.040, and the cut-off value was determined to be -0.191. Male sex was detected with 80% sensitivity, 73.7% specificity, and 77.6% accuracy. Classification statistics are shown in Table 3. The discriminant formula was derived as follows:

Sex=2.925xHeight-11.992

Table 3. Classification table from linear discriminant function analysis for height

		Predicted group membership		
		Male	Female	Total
Original	Male	80% (48)	20% (12)	60
	Female	26.3% (10)	73.7% (28)	38
Cross-validated	Male	80% (48)	20% (12)	60
	Female	26.3% (10)	73.7% (28)	38

When the canonical discriminant functions of the model built with the width value were examined, it was seen that the eigenvalue was 0.813, the canonical correlation was 0.670, Wilks' lambda was 0.551, chi-square was 59.227, and the p-value was <0.001. The male centroid was determined as 0.717, the female centroid as -1.112, and the cut-off value was set at -0.197. The male sex was detected with 88.7% sensitivity, 75% specificity, and 83.3% accuracy. Classification statistics are shown in Table 4. The discriminant formula was established as follows:

Sex=2.987xWidth-12.900

Table 4. Classification table from linear discriminant function analysis for width

		Predicted group membership		
		Male	Female	Total
Original	Male	88.7% (55)	11.3% (7)	62
	Female	25% (10)	75% (30)	40
Cross-validated	Male	88.7% (55)	11.3% (7)	62
	Female	25% (10)	75% (30)	40

When the canonical discriminant functions of the model built with the depth value were examined, it was seen that the eigenvalue was 0.268, the canonical correlation was 0.460, Wilks' lambda was 0.798, chi-square was 23.634, and the p-value was <0.001. The male centroid was determined as 0.412, the female centroid as -0.638, and the cut-off value was set at -0.113. The male sex was detected with 85.5% sensitivity, 52.5% specificity, and 72.5% accuracy. Classification statistics are shown in Table 5. The discriminant formula was established as follows:

Sex=23.644x1/Depth-11.310

Table 5. Classification table from linear discriminant function analysis for depth

		Predicted group membership		
		Male	Female	Total
Original	Male	85.5% (53)	14.5% (9)	62
	Female	47.5% (19)	52.5% (21)	40
Cross-validated	Male	85.5% (53)	14.5% (9)	62
	Female	47.5% (19)	52.5% (21)	40

DISCUSSION

In Akhlaghi et al.'s study in Iran, involving 113 cases, it was observed that patella height and width were higher in all cases, while patella depth was found to be higher in men in the 20-39 age group and the ≥65 age group (16). The study of Moneim et al. showed that the patella's height and width were greater in men than in women (17). In the study by Zhan et al. with 300 cases in China, patella height, depth, width, and volume were all larger in men (9). In a study of 161 cases conducted by Rahmani et al. in Iran, patellar height, depth, and width were found to be more significant in men (6). In the study by Peckmann and Fisher, which measured the patella height, width, depth, joint surface width, and height of 200 skeletons, a significant difference was found between the sexes in favor of men in all measurements (8). The study by Michiue et al. in Japan with 220 CT images showed that height, depth, and volume values were larger in men (18). All papers included in the meta-analysis by Fernandez et al. revealed a significant difference between sexes in all patella measurements (19). In a study with a Portuguese sample, males showed larger dimensions in patella sizes (14). In Kemkes-Grottenthaler's study, it was observed that male patellas were larger (13). Teke et al. showed that all measurements of males were greater than females (20). The study by Öner et al. reported that all anteroposterior, craniocaudal, transverse length and volume values were greater in men (21). In our study, we measured all patella sizes to be larger in men, consistent with existing literature.

Although there is a recognized difference between sexes in patella height and width, the distinction is less pronounced for depth. Akhlaghi et al. observed that the accuracy rate for patellar depth measurements (74.3%) was lower compared to width (91.2%) and height (89.4%) (16). Zhan et al. also reported that patella and width accuracy rates

(85.7% and 82.3%, respectively) were higher than patella depth (73.1%) (9). Rahmani et al. correctly classified the sexes 84.5% with patellar width, 75.2% with patellar height, and 65.5% with patellar depth (6). In our study, consistent with the literature, more accurate rates were achieved with width (83.3%) and height (77.6%) measurements than with depth (72.5%). In our study, it was determined that patella depth had almost no effect on sex determination. This could be attributed to the nominal values of patellar height and width being greater than that of depth, potentially resulting in a lower difference between sexes in depth measurements.

In a study conducted on the Iranian population, sex was determined with a rate of 92.9% accuracy using discriminant analysis based on patella measurements (16). A study on the Chinese population demonstrated that accurate estimation, up to 85.7%, could be achieved with patellar volume (9). In Rahmani et al.'s study using MR images, discriminant analysis based on patella width and height classified males correctly at 81.0%, females at 90.2%, and the entire population at a rate of 85.7% (6). In Peckmann and Fisher's study, sex was estimated 85% accurately by discriminant analysis using all variables (8). In another study conducted on the Spanish population, it was shown that the accuracy rate of sex estimation from the patella was up to 82% (22). In a study on the Japanese population, the highest accuracy was achieved with the left patella volume at 87.7%, followed by the right patella volume at 85.5%, the left patella height at 82.3%, and the right patella height at 80.9% (18). Introna et al.'s study on dry bones reported an 83.8% accurate sex determination rate with the analysis performed with maximum width and thickness, while other analyses contained a higher margin of error (12). In Kemkes-Grottenthaler's work, the patella yielded an initial sexing accuracy of 84%, which, when adjusted for methodological considerations like sample size using statistical techniques, the accuracy decreased to only 74–78% (13). Indra et al. were able to achieve an accuracy rate of 83.8% (10). Maio et al. showed that, the maximum height stands out with 77.0% correct sex estimation, reaching 98.0% when applied to the new sample. The linear discriminant function analysis showed 80.2% accuracy after cross-validation and 96.0% when applied to the independent sample (14). The study by Teke et al. determined males with 87% accuracy and females with 91% accuracy. They also achieved prediction accuracy of 86% and 83% for height, 77% and 81% for depth, and 89% and 84% for width in women and men, respectively (20). In the study by Oner et al. using the decision tree algorithm, males were predicted with a rate of 98.2% and females with 98.4% (21). In our study, the rate of 80.6% was attained with the patellar height and width model.

Limitations of the Study

The results in this study, below the 85% accuracy rate achieved in some previous studies, may be attributed to the relatively low number of cases (n=98) and the disparity in the number of female (n=38) and male (n=60) cases. Additionally, the single-center conduct of the study imposes limitations in terms of population diversity.

CONCLUSION

Our study demonstrated sex dimorphism in the patellar bone within the Turkish population, with males showing significantly larger patella than females. In our study, biological sex estimation achieved an accuracy rate of 80.6% using all patella measurements. However, the associated error rate of 19.4% is notably high for forensic anthropological applications and falls below the acceptable threshold for forensic medicine practices. Therefore, the findings indicate that, within the Turkish population, relying solely on the patella for sex determination in forensic contexts is not advisable. However, the patella may serve as a valuable supplementary tool alongside other anthropological methods, enhancing the accuracy and reliability of biological sex estimation. It is essential to recognize that osteometric data are population-specific, and the 80.6% accuracy rate observed in this study requires validation in diverse populations.

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