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Research Paper

Sex Estimation from Patellar Anthropometric Parameters: An MRI-Based Study in Iranians

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ABSTRACT

Background: Accurate sex estimation from skeletal remains is crucial in forensic anthropology, particularly when complete skeletons are unavailable. The patella is a dense sesamoid bone resistant to postmortem damage. Therefore, it offers potential for sex determination. This study aimed to evaluate the accuracy of patellar morphometric parameters for sex estimation in an Iranian population using magnetic resonance imaging (MRI).

Methods: This descriptive cross-sectional study was conducted on Iranian individuals aged over 18 years referred to our Hospital for knee MRI. Patellar height was measured on midsagittal slices, while width and thickness were assessed on axial slices showing maximum width. Measurements were performed using PACS software. Independent t-tests, ROC curve analysis, and classification statistics were used to determine discriminatory power.

Results: A total of 225 individuals (110 females and 115 males) were enrolled. The age range was 18–80 years, with a mean age of 45.82 ± 14.83 years. All three measurements were different between men and women, and the differences were statistically significant. Men had larger patellae. Height was the most accurate predictor; it correctly identified sex about 88% of the time. Width was correct about 80% of the time, while thickness was correct in about 74%. The present study revealed that the diagnostic accuracy was excellent for height. It was good for width and fair for thickness.

Conclusion: This study indicates that Patellar measurements are useful for estimating sex in our population. This bone may be used as a substitute when other parts of the skeleton are not available.

Introduction

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Sex estimation from skeletal remains is a key step in the identification of human remains. It is essential in forensic medicine, biological anthropology, and archaeology. It also supports demographic studies and legal investigations. Traditionally, sex estimation relies on direct observation and manual measurements. These methods are useful, but they depend strongly on the examiner's experience and skill. In recent decades, modern imaging techniques have become more common. These include computed tomography (CT) and magnetic resonance imaging (MRI) [1]. They provide high accuracy and allow three-dimensional reconstruction of skeletal structures. In many situations, they perform better than traditional methods and are now widely used in forensic practice.

In sex determination, the pelvis and skull are considered the most reliable skeletal indicators. The pelvis can reach very high accuracy, and the skull also performs well, especially when both are assessed together [2]. However, in real-world cases, these bones are not always available. Natural disasters, wars, severe accidents, or postmortem damage may destroy or remove them. In such situations, single bones that resist postmortem damage become very important for sex estimation. Many studies have examined different bones for sex estimation. The patella has received less attention, but it has features that may make it useful for this purpose.

The patella is the largest sesamoid bone in the body. It lies in front of the knee joint, within the quadriceps tendon and connects to the tibial tuberosity through the patellar ligament. Because of its dense structure and protected position, the patella is often preserved in decomposed or fragmented remains [3]. It can therefore be a valuable element for sex estimation when other bones are unavailable.

Studies in different populations have shown that patellar height, width, and thickness differ significantly between males and females. These dimensions can be used as indicators for sex estimation [4–6]. However, population-specific differences may be related to genetic, environmental, or lifestyle factors.

Most previous studies have focused on single measurements. Only a few have explored combined models. Evidence suggests that combining variables can improve discrimination and increase accuracy [7, 8].

The present study uses MRI as a non-invasive and accurate method. It evaluates sex estimation based on patellar measurements in an adult Iranian population and provides population-specific data for forensic applications.

Materials and Methods

This descriptive cross-sectional study included Iranian individuals aged 18 years and older. They were referred to Shafa Yahyaeian Hospital in Tehran for knee magnetic resonance imaging (MRI). The recruitment period was from October 2024 to October 2025. The Ethics Committee of Iran University of Medical Sciences approved the study protocol (IR.IUMS.FMD.REC.1403.165), and all procedures were conducted in accordance with the Declaration of Helsinki.

Exclusion criteria were as follows: severe osteoarthritis, joint replacement, patellar fracture, skeletal anatomical abnormalities, knee infection, and poor-quality slices.

All magnetic resonance imaging was performed on a Siemens MAGNETOM Avanto 1.5-Tesla (1.5T) scanner using a standard knee coil. Axial proton density fat-saturated (PD FAT SAT) turbo spin-echo (TSE) sequences were acquired without contrast. Additional sagittal T2-weighted images were obtained to confirm the anatomy. These sequences and planes were selected to provide clear visualization of the patella and its cortical and articular surfaces.

Three patellar parameters were measured: patellar height, patellar width, and patellar thickness. Patellar height was measured on a midsagittal slice. It was defined as the greatest distance between the superior and inferior poles of the patella. Patellar width and thickness were measured on the axial slice that showed the greatest patellar width. Patellar width was the maximum mediolateral distance. Patellar thickness was measured by drawing a line from the mid-anterior surface to the interfacet point. All measurements were performed using the picture archiving and communication system (PACS) and its built-in digital caliper tools. Two observers (the second and third authors) performed the measurements independently.

To assess measurement reliability, a random sample of 25 MRIs was re-measured. Each observer repeated the measurements after an interval of 10 days to evaluate intra-observer agreement, and inter-observer agreement was assessed by comparing measurements between the two observers.

All eligible subjects who met the inclusion and exclusion criteria during the study period were included, resulting in a convenience sample of 225 individuals (110 females and 115 males). This sample

size is larger than that of a previous MRI-based patellar study in an Iranian population, which examined 161 subjects [4], and was therefore considered sufficient and comparable to similar morphometric investigations of the patella.

Data analysis was performed using Statistical Package for the Social Sciences (SPSS, version 18; IBM Corp., Armonk, NY, USA). An independent t-test was used to evaluate the predictive power of each parameter for sex determination. Receiver operating characteristic (ROC) curve analysis and classification tables were also applied to assess model accuracy and performance. A p-value of less than 0.05 was considered statistically significant.

Results

A total of 225 individuals (110 females and 115 males) were enrolled in this study. The age range was 18 to 80 years. The mean age was 45.82 ± 14.83 years. Significant differences were observed between males and females in maximum patellar height, width, and thickness (all $P < 0.001$; Table 1).

Table 1. Means and standard deviations (SD) of patellar anthropometric parameters by sex.

Patellar Parameter	Female (n=110)		Male (n=115)		P-value
	Mean (mm)	SD (mm)	mean (mm)	SD (mm)	
Hight	43.10	2.69	37.75	2.54	0.001
Width	44.16	3.09	38.93	3.10	0.001
Thickness	20.07	1.70	17.68	1.88	0.001

* All measurements are in millimeters.

Figure 1 shows the ROC curves for maximum patellar height, width, and thickness as predictors of sex. The corresponding areas under the ROC curve (AUC) are presented in Table 2. Optimal cut-off points were determined from the ROC curves for each parameter. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy were calculated for each cut-off (Table 3).

Table 2. Area under the receiver operating characteristic (ROC) curve for maximum patellar height, width, and thickness.

Patellar Parameter	AUC	Standard Error	95% CI (min–max)
Hight	0.935	0.016	0.967 - 0.904
Width	0.881	0.022	0.924 - 0.838
Thickness	0.821	0.027	0.875 - 0.768

* All measurements are in millimeters

In the overall study population, maximum patellar height showed the highest accuracy for sex determination (88.44%), followed by width (79.56%) and thickness (74.22%; Table 3).

Discussion

The establishment of a reliable biological profile from decomposed skeletal remains fundamentally depends on accurate sex estimation. Nevertheless, marked variation has been reported in both the magnitude and overlap of sexual dimorphism across different populations, including those in close geographical proximity [9]. The present study was designed to evaluate the utility of patellar dimensions for sex estimation in an Iranian population. Our findings showed that all three parameters eg. height, width, and thickness, were significantly larger in males than in females.

Among these, patellar height demonstrated a marked sexual difference and predicted sex with an accuracy of 88.4%, which is comparable to values reported in recent studies. In a Portuguese sample, maximum patellar height alone yielded 77.0% correct sex estimation. A multivariable discriminant model achieved 80.2% accuracy after cross-validation and 96.0% in an independent validation sample [10]. In a medieval Turkish sample, maximum patellar height showed 85.6% accuracy [11], which is close to our finding. Patellar height is closely related to overall limb length and body stature, which are strongly sexually dimorphic. Males typically have greater long-bone lengths and larger joint surfaces. These differences are transmitted to the patella, particularly in its superoinferior dimension, which scales with femoral morphology and the extensor mechanism of the knee.

Patellar width was significantly greater in males than in females. It predicted sex with 79.56% accuracy. This aligns with earlier studies. For example, a South African sample reported approximately 79% accuracy using patellar width [12]. A later Turkish study reported 81.4% accuracy for width alone [11]. More recent machine learning work in an Italian population also confirmed significant sexual dimorphism in patellar width, with validation accuracies ranging from 0.71 to 0.95, depending on the model and sample [13]. In fact, populations with greater average stature and more pronounced sex differences in body size may show larger absolute differences in patellar dimensions, potentially increasing the accuracy of sex estimation. Conversely, in populations with greater overlap in body

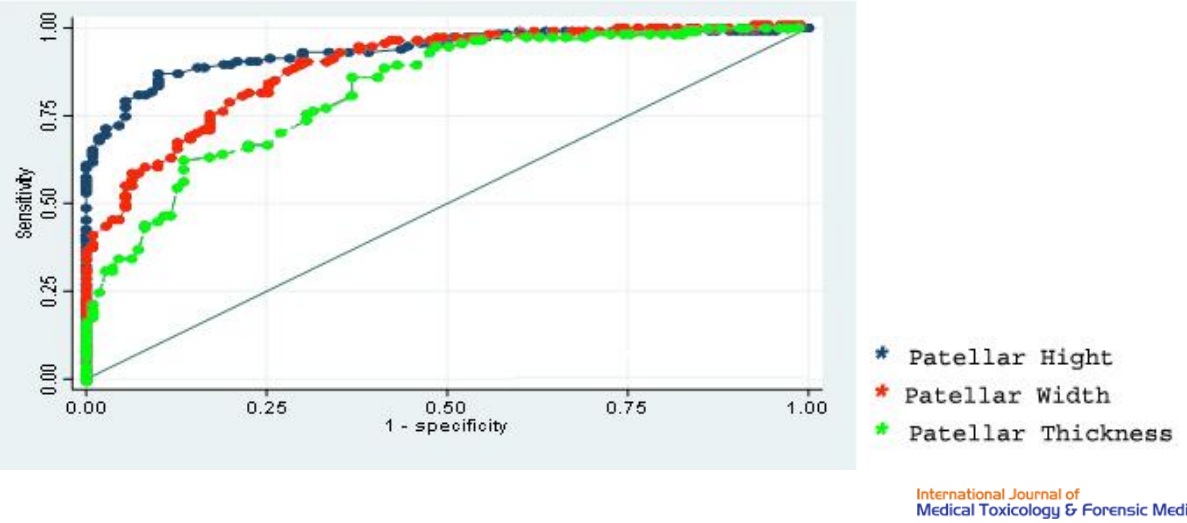

Figure 1. Receiver operating characteristic (ROC) curves showing the predictive value of maximum patellar height, width, and thickness for sex estimation.

size between males and females, or with high intra-population variability due to heterogeneous genetic or environmental influences, the discriminative power of patellar measurements may be reduced

Patellar thickness differed significantly between the sexes, yielding a predictive accuracy of 74.22% for sex determination. This supports the broader forensic literature indicating that the patella is sexually dimorphic, although thickness alone usually performs slightly less than other patellar indices (11). Biomechanically, this finding is plausible. Patellar thickness is more influenced by mechanical loading and functional conditions. Therefore, it may show greater variability among individuals of the same sex. In contrast, height and width are more structural parameters. They tend to reflect more pronounced sexual differences. In a Chinese sample, maximum patellar thickness showed the lowest accuracy among patellar variables. However, it still achieved a useful accuracy of 73.1% (14). In a Southern Italian sample, a discriminant function using patellar width and thickness achieved 83.3% accuracy. This suggests that thickness becomes more informative when combined with another patellar parameter [15]. Unlike height and width, which are more closely tied to overall skeletal size, thickness is more susceptible to remodeling in response to mechanical loading, occupational activities, sports participation, and degenerative changes. Such functional adaptations can increase intra-sex variability, particularly in populations with diverse lifestyles.

Although our results indicate acceptable accuracy for sex estimation from the patella in the Iranian population, previous studies have reported substantial individual variation in this bone [14]. Such variation may reduce the accuracy of sex estimation in real forensic cases.

Several limitations should be acknowledged. First, the study was cross-sectional and conducted at a single center. This may limit the generalizability of the findings to the broader Iranian population. Second, the sample included individuals referred for knee MRI. They may not fully represent the general population in terms of health status, physical activity, or socioeconomic background. Third, inter- and intra-observer reliability were assessed, but intraclass correlation coefficients (ICCs) were not reported. ICCs would provide a more quantitative measure of measurement agreement. Finally, the study relied exclusively on MRI-based measurements. While this approach offers high accuracy and is non-invasive, it may not be directly comparable to studies using dry

Table 3. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of patellar anthropometric parameters for sex determination.

Patellar Parameter	Cut-off (mm)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Hight	40.7	86.96	90	90	86.8	88.44
Width	40.8	86.96	71.82	76.3	84	79.56
Thickness	19.6	62.61	86.36	82.7	68.8	74.22

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PPV, positive predictive value; NPV, negative predictive value. All measurements are in millimeters.

bones. This could limit comparability across different forensic contexts.

Conclusion

In this Iranian population, all three patellar parameters were significantly larger in males than in females. Patellar height showed the highest discriminatory accuracy. These results support the use of patellar anthropometry as a reliable adjunct for sex estimation in forensic cases. This is especially useful when the pelvis and skull are unavailable or severely damaged. Additional studies in other Iranian ethnic groups are needed. Such work would test the robustness of these findings across diverse genetic and environmental backgrounds.

Ethical Approval

The study protocol was approved by the Ethics Committee of Iran University of Medical Sciences (IR.IUMS.FMD.REC.1403.165).

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Conflicts of Interest

The authors report there are no competing interests to declare.

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