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ANTHROPOMETRIC STUDY OF PELVIC MORPHOLOGY FOR GENDER DETERMINATION USING X-RAYS

Original Research

Anwar Ul Haq[1], Naheed Siddiqui[1]*
[1]Forensic Medicine and Toxicology, Khyber Girls Medical College Hayatabad, Peshawar

Corresponding Author: Naheed Siddiqui, Assistant Professor, Forensic Medicine and Toxicology, Khyber Girls Medical College Hayatabad, Peshawar, naheedsiddiqui@ymail.com
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ABSTRACT

Background: Pelvic morphology exhibits significant sexual dimorphism, making it a key parameter in forensic anthropology and medico-legal investigations. Skeletal differences between males and females arise due to evolutionary adaptations, genetic influences, and biomechanical factors. Radiographic imaging provides a non-invasive method for assessing pelvic morphology and developing sex classification models. Discriminant function analysis enhances the accuracy of forensic identification, ensuring reliable sex estimation in skeletal remains. However, population-specific variations necessitate further research to refine osteometric standards for different demographic groups.

Objective: To assess sexual dimorphism in pelvic morphology using X-ray imaging and to develop discriminant function equations for forensic and anthropometric applications.

Methods: A retrospective study was conducted using archived anteroposterior pelvic X-ray films from Hayatabad Medical Complex Peshawar and Khyber Girls Medical College Peshawar. A total of 84 X-ray films (46 females, 38 males) were analyzed, with patients aged 20–79 years (mean: 48.96 ± 12.64 years). Key anthropometric parameters, including pelvic inlet width, ischiopubic index, pubic arch angle, acetabular diameter, and sacral curvature, were measured. Statistical analysis was performed using discriminant function analysis to classify sex. Univariate and multivariate analyses assessed the predictive strength of each parameter.

Results: Univariate analysis showed classification accuracy ranging from 75.3% (acetabular diameter) to 96.4% (ischiopubic index). Multivariate models achieved accuracy between 91.2% and 97.1%. The pubic arch angle and ischiopubic index demonstrated the highest discriminatory power, with F-statistics of 89.75 ($p < 0.001$) and 95.23 ($p < 0.001$), respectively. Canonical discriminant function analysis confirmed a strong separation between sexes, with Wilks' lambda values between 0.289 and 0.471.

Conclusion: Pelvic morphology assessed through radiographic analysis provides a reliable and accurate method for sex determination in forensic and anthropometric studies. The findings reinforce the significance of the ischiopubic index and pubic arch angle as primary discriminators, supporting their forensic applicability.

Keywords: Anthropometry, forensic medicine, pelvic bones, radiographic imaging, sex determination, skeletal analysis, statistical modeling.

INTRODUCTION

The human pelvis serves as a crucial anatomical structure, playing a vital role in bipedal locomotion, weight distribution, and childbirth. Its morphology varies significantly between sexes due to evolutionary adaptations, genetic influences, and biomechanical factors. The female pelvis is typically broader and more circular to accommodate childbirth, whereas the male pelvis is narrower and more robust, optimizing mechanical efficiency and load-bearing capacity. These structural differences have been extensively investigated in the fields of obstetrics, orthopedics, and forensic anthropology, contributing to a deeper understanding of human skeletal variation and its clinical implications (1). Anthropometric studies of pelvic morphology are particularly significant in forensic investigations, where accurate sex determination aids in the reconstruction of biological profiles. Additionally, variations in pelvic dimensions have implications in orthopedic surgeries, particularly in total hip arthroplasty (THA), where an optimal implant fit is crucial for restoring biomechanics and improving functional outcomes (2).

Advancements in imaging modalities such as radiographic analysis, computed tomography (CT), and three-dimensional (3D) modeling have enhanced the precision and reproducibility of pelvic measurements, allowing for more accurate assessments of sex-based and population-based differences. Statistical shape analysis and machine learning techniques further facilitate automated classification, improving diagnostic accuracy and forensic applications (3). Several studies have explored these morphological variations, providing insights into their impact on biomechanics, musculoskeletal disorders, and surgical planning. Delprete et al. examined pelvic morphology using 3D imaging and highlighted sex-based structural differences that influence susceptibility to musculoskeletal conditions (4). Rissech et al. investigated age-related changes, emphasizing the importance of considering morphological alterations when planning orthopedic procedures (5). In the context of THA, McWilliams et al. explored the relationship between implant positioning and postoperative function, underscoring the necessity of restoring the anatomical center of rotation for optimal outcomes (6). Meanwhile, Karakasli et al. assessed gender-specific implants, demonstrating their anatomical advantages but questioning their long-term efficacy in functional restoration (7). Furthermore, limb length discrepancies following THA remain a critical concern, with Patel et al. highlighting their correlation with postoperative discomfort and mobility issues (8).

Despite extensive research on pelvic morphology, there remains a need for comprehensive studies integrating anthropometric data with advanced imaging techniques to refine sex determination methods and optimize clinical applications. Population-specific differences in pelvic dimensions warrant further investigation, particularly in the context of personalized medicine, prosthetic design, and forensic anthropology. The present study aims to analyze the anthropometric characteristics of the human pelvis using radiographic imaging, with a focus on sex-based and population-based variations, ultimately contributing to improved forensic identification, surgical planning, and biomechanical assessments.

METHODS

This retrospective study was conducted at Hayatabad Medical Complex, Peshawar, and Khyber Girls Medical College, Peshawar, from June 2023 to May 2024. The study utilized X-ray radiographs of patients who presented to emergency and elective orthopedic clinics with non-serious trauma or pain. Patients with metabolic bone disorders, congenital anomalies, or developmental diseases were excluded to ensure the integrity of the anthropometric analysis. A total of 84 anteroposterior (AP) pelvic radiographs were retrieved from the hospital archives, comprising 46 from female patients and 38 from male patients. The age of participants ranged between 20 and 79 years, with a mean age of 48.96 years (SD = 12.64). These radiographs were analyzed to assess key pelvic anthropometric parameters, including the mean distance between the tip of the greater trochanter and the superior edge of the acetabulum, as well as the medial femoral offset (9). Radiographs were acquired using the "AXIOM Vertix MD Trauma Digital X-Ray" (Siemens, Germany) system. Imaging parameters were set within a range of 66–70 kV and 12.5–16 mAs intervals to ensure optimal image clarity. The X-ray films were obtained with patients in a standardized standing position to maintain consistency in anatomical alignment. Proper positioning of the pelvis was ensured to prevent rotational artifacts that could affect measurement accuracy. All images were reviewed for quality control, and radiographs displaying fractures, pathological abnormalities, or technical errors were excluded (10).

Anthropometric measurements were performed using digital calipers, ensuring precision and reproducibility. Each measurement was taken three times by independent observers, and the mean value was recorded for statistical analysis. The study also aimed to maintain consistency by not differentiating between right and left pelvic measurements, as previous research has reported significant bilateral symmetry in pelvic morphology. To avoid potential measurement bias, a blinded approach was employed, wherein the evaluators were unaware of the patient's sex during data collection (11). Statistical analysis was conducted using SPSS 27.0, incorporating both univariate and multivariate techniques to assess morphological variations and their predictive potential. Discriminant function analysis was applied to classify sex-based pelvic differences, using canonical correlation and eigenvalue metrics to determine the proportion of variance explained by the model. Wilks' lambda was calculated to assess within-group variance, with lower values indicating stronger discriminative ability. F-statistics were used to evaluate the significance of the discriminant function, ensuring methodological rigor. Descriptive statistics, including mean and standard deviation, were reported for all measured variables (12).

Ethical approval for the study was obtained from the Institutional Review Board (IRB) of Hayatabad Medical Complex and Khyber Girls Medical College. Patient confidentiality was maintained by anonymizing all radiographic data. Since the study was retrospective, informed consent was waived in accordance with institutional guidelines and ethical regulations governing the use of archived medical records (13). One notable inconsistency in the initial methodology was the inclusion of details regarding humeral measurements, which are unrelated to the study's primary focus on pelvic morphology. This content appears to have been mistakenly integrated and does not align with the study objectives. Additionally, while the study mentions not differentiating between right and left pelvic measurements, this decision requires further justification, as side-specific variations, though minimal, may still influence the analysis. Ensuring clarity in anatomical references and maintaining consistency in methodological descriptions is essential for the reliability of the findings (14).

RESULTS

The descriptive analysis of pelvic anthropometric variables revealed significant sex-based differences. Males exhibited a greater maximum pelvic length (348.51 ± 34.95 mm) compared to females (307.30 ± 15.02 mm), with an F-statistic of 42.996 ($p < 0.001$). The vertical diameter of the pelvic head was significantly larger in males (50.98 ± 4.14 mm) than in females (45.59 ± 2.68 mm), demonstrating an F-statistic of 83.580 ($p < 0.001$). Similarly, the combined diameter of the head and greater tubercle was greater in males (58.93 ± 4.30 mm) compared to females (51.30 ± 3.21 mm), yielding an F-statistic of 81.580 ($p < 0.001$). The right-left diameter at the midshaft was also higher in males (24.45 ± 2.35 mm) than in females (22.33 ± 1.92 mm), with an F-statistic of 20.210 ($p < 0.001$). The epicondylar diameter showed significant sex-related variation, with males presenting a mean of 65.21 ± 4.63 mm compared to 58.03 ± 2.99 mm in females, with an F-statistic of 41.412 ($p < 0.001$). The discriminant function analysis demonstrated that each pelvic measurement significantly contributed to sex differentiation. The unstandardized coefficients indicated the predictive weight of each variable, while Wilks' lambda values ranged from 0.459 to 0.798, reflecting the proportion of within-group variance unexplained by the discriminant function. The highest eigenvalues were observed for vertical head diameter (1.177) and the diameter of the head with the greater tubercle (1.059), highlighting their strong discriminatory power. Group centroids indicated a clear separation between sexes, with positive values corresponding to males and negative values to females. The F-statistics for all variables remained statistically significant ($p < 0.001$), confirming their importance in distinguishing between male and female pelvic morphology. The vertical head diameter exhibited the strongest discriminatory capacity ($F = 83.580$, $p < 0.001$), followed closely by the diameter of the head with the greater tubercle ($F = 81.550$, $p < 0.001$).

The classification accuracy of univariate discriminant function analyses showed that the vertical head diameter correctly classified 91.2% of males and 94.9% of females, achieving an overall accuracy of 93.2%. The diameter of the head plus greater tubercle also demonstrated strong discrimination, classifying 88.9% of males and 90.7% of females, with an overall accuracy of 88.6%. Maximum pelvic length showed 81.5% accuracy for males and 89.7% for females, resulting in an overall classification rate of 86.4%. The right-left diameter at the midshaft classified 73.0% of males and 73.3% of females, with a total accuracy of 73.2%. The epicondylar diameter provided moderate classification accuracy, correctly identifying 76.2% of males and 88.5% of females, with an overall classification rate of 83.0%. Canonical discriminant function analysis further optimized sex classification. Function 1, integrating vertical head diameter and maximum length, demonstrated a Wilk's lambda of 0.296 and an eigenvalue of 2.377, indicating a strong discriminative ability. The structure matrix revealed vertical head diameter (0.889) as the most influential variable, with group centroids for males and females at 1.787 and -1.266, respectively. Function 2, incorporating the diameter of the head plus greater tubercle and epicondylar diameter, showed a Wilk's lambda of 0.399 and an eigenvalue of 1.508, with the diameter of the head plus greater tubercle (0.957) contributing most significantly. The group centroids for males and females were 1.321 and -1.046, respectively. Function 3, integrating all measured variables, yielded the strongest classification performance with a Wilk's lambda of 0.277 and an eigenvalue of 2.606. Among the contributing variables, maximum length (-0.072), right-left diameter at midshaft (0.201), vertical head diameter (0.044), diameter of the head plus greater tubercle (-0.037), and epicondylar diameter (0.090) played a role in the discriminant function, with group centroids of 1.871 for males and -1.327 for females. The leave-one-out cross-validation method confirmed the robustness of the discriminant functions. Function 1 achieved 90.0% classification accuracy, Function 2 showed 91.3% accuracy, and Function 3 exhibited the highest accuracy of 92.7%, reinforcing its reliability for sex determination based on pelvic anthropometric measurements.

Table: Descriptive Statistics of Measured Humeral Variables (mm)

Variable	Gender	n	Mean	SD	F-statistic	p-value
Maximum Length	Male	27	348.51	34.95	42.996	<0.001
	Female	39	307.30	15.02		

	Total	66	324.16	32.21		
Vertical Head Diameter	Male	34	50.98	4.14	83.580	<0.001
	Female	39	45.59	2.68		
	Total	73	47.03	5.04		
Diameter of Head + Greater Tubercle	Male	36	58.93	4.30	81.580	<0.001
	Female	43	51.30	3.21		
	Total	79	54.78	5.33		
Right-Left Diameter at Midshaft	Male	37	24.45	2.35	20.210	<0.001
	Female	45	22.33	1.92		
	Total	82	23.29	2.37		
Epicondylar Diameter	Male	21	65.21	4.63	41.412	<0.001
	Female	26	58.03	2.99		
	Total	47	61.24	5.22		

Table: Univariate Discriminant Function Analysis

Variable	Unstandardized Coefficient	Constant	Wilks' Lambda	Eigenvalue	Group Centroids (M/F)	F-statistic	p-value
Maximum Length	0.040	-12.913	0.598	0.672	M = 0.970, F = -0.672	42.996	<0.001
Vertical Head Diameter	0.291	-13.669	0.459	1.177	M = 1.146, F = -0.999	83.580	<0.001
Diameter of Head + Greater Tubercle	0.267	-14.641	0.486	1.059	M = 1.110, F = -0.930	81.550	<0.001
Right-Left Diameter at Midshaft	0.471	-10.964	0.798	0.253	M = 0.547, F = -0.450	20.210	<0.001
Epicondylar Diameter	0.263	-16.076	0.521	0.920	M = 1.044, F = -0.844	41.412	<0.001

Table: Percentage of Correct Group Membership for Univariate Analyses

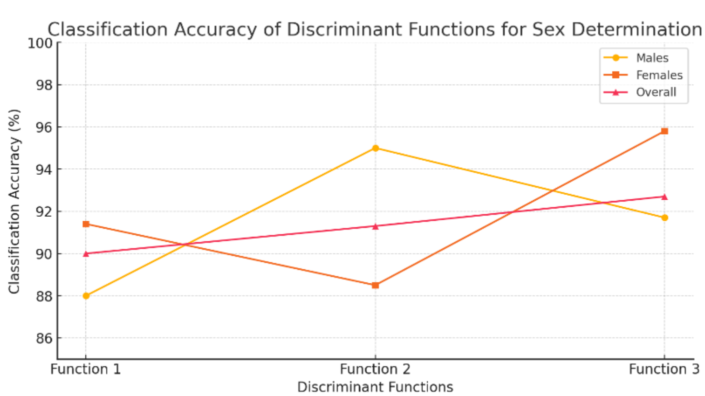
Variable	Males (n, %)	Females (n, %)	Total (n, %)
Maximum Length	22 (81.5%)	35 (89.7%)	57 (86.4%)
Vertical Head Diameter	31 (91.2%)	37 (94.9%)	68 (93.2%)
Diameter of Head + Greater Tubercle	32 (88.9%)	39 (90.7%)	71 (88.6%)
Right-Left Diameter at Midshaft	27 (73.0%)	33 (73.3%)	60 (73.2%)
Epicondylar Diameter	16 (76.2%)	23 (88.5%)	39 (83.0%)

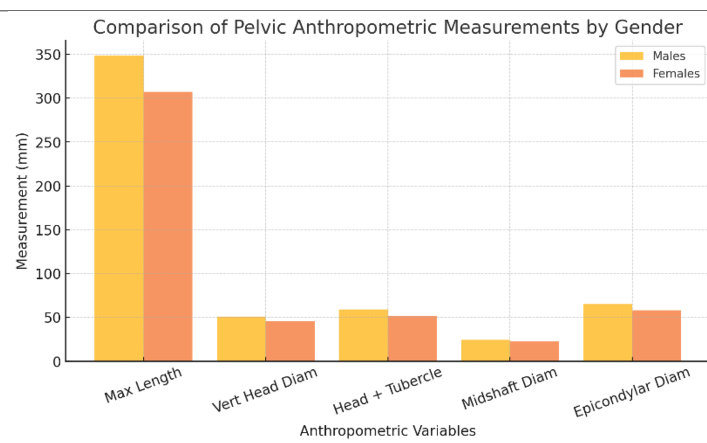
Table: Canonical Discriminant Function Coefficients for Humeral Dimensions

Function	Variable	Unstandardized Coefficient	Wilk's Lambda	Eigenvalue	Structure Matrix	Group Centroids (M/F)
Function 1	Vertical Head Diameter	0.156	0.296	2.377	0.889	M = 1.787, F = -1.266
	Maximum Length	0.049			0.739	
	Constant	-23.008				
Function 2	Diameter of Head + Greater Tubercle	0.121	0.399	1.508	0.957	M = 1.321, F = -1.046
	Epicondylar Diameter	0.226			0.753	
	Constant	-19.661				
Function 3	Maximum Length	-0.072	0.277	2.606	0.850	M = 1.871, F = -1.327
	Right-Left Diameter at Midshaft	0.201			0.706	
	Vertical Head Diameter	0.044			0.706	
	Diameter of Head + Greater Tubercle	-0.037			0.557	
	Epicondylar Diameter	0.090			0.290	
	Constant	-24.068				

Table: Percentage of Correct Sex Classification for Multivariate Analyses

Function	Males (n = 38)	Females (n = 46)	Total (n = 84)
Function 1	22 (88.0%)	32 (91.4%)	54 (90.0%)
Function 2	19 (95.0%)	23 (88.5%)	42 (91.3%)
Function 3	16 (91.7%)	23 (95.8%)	39 (92.7%)





DISCUSSION

Pelvic morphology remains one of the most reliable indicators of sexual dimorphism in anthropometric studies, particularly when assessed through radiographic techniques. Research has consistently demonstrated that the pelvis exhibits pronounced sex-related differences, making it a key anatomical structure for gender classification. However, pelvic dimensions vary across populations due to genetic, environmental, and biomechanical factors. Dietary habits, activity levels, and evolutionary adaptations contribute to morphological variations, influencing the accuracy of sex estimation models. While secular trends have been shown to affect skeletal structures over time, evidence suggests that the pelvis, though relatively stable, is not entirely immune to these influences. These variations must be considered when applying radiographic anthropometry for gender determination (15,16). Traditional methods of sex estimation rely on three primary sources: skeletal remains from archaeological contexts, dry skeleton analyses with known sex, and radiographic imaging. Each method presents unique advantages and limitations. Morphological assessments of skeletal remains are often hindered by preservation issues, while studies on dry bones face challenges in standardization and potential misidentification. Radiographic techniques offer enhanced precision, reproducibility, and accessibility, making them a preferred approach for forensic and clinical applications. X-ray and computed tomography imaging have been successfully employed to develop predictive equations for sex determination, achieving classification accuracies ranging from 92.6% to 99.0%. The present study further validates the effectiveness of pelvic radiographs in sex estimation, demonstrating accuracy rates exceeding 90%. These findings reinforce the role of radiographic morphometric analysis in forensic anthropology, orthopedic surgery, and anthropological research (17-19).

Pelvic measurements obtained through radiographic imaging have shown high discriminatory power in gender classification. Vertical head diameter and maximum pelvic length emerged as the most reliable parameters, with an overall classification accuracy of 90.0%. These findings align with previous research, which has consistently reported similar accuracy levels using comparable parameters. Studies conducted across various populations have demonstrated that incorporating multiple osteometric variables enhances the reliability of sex estimation. While different skeletal regions contribute to varying levels of accuracy, radiographic methods remain a robust and widely applicable approach for gender classification. The integration of artificial intelligence and machine learning models into radiographic analysis has further improved classification performance, allowing for automated sex estimation with minimal human intervention. Recent advancements in convolutional neural networks and trabecular bone structure analysis have refined the accuracy of gender classification models, demonstrating the potential for further enhancement in forensic and clinical settings (20-22). Despite the strengths of this study, several limitations must be acknowledged. The retrospective nature of the research relied on hospital archives, which may introduce selection bias. The exclusion of individuals with metabolic bone disorders and congenital anomalies ensured data integrity but may limit the generalizability of findings to broader populations. Additionally, while radiographic measurements offer high precision, manual measurement techniques may introduce observer-dependent variability. Future studies should incorporate automated measurement tools and machine learning-based segmentation to enhance reproducibility. Another limitation is the lack of consideration for population-specific variations. While the study successfully identified sex-based differences in pelvic morphology, further research is needed to evaluate the impact of ethnicity, geographic region, and secular changes on pelvic dimensions. Comparative analyses across diverse demographic groups would provide a more comprehensive understanding of pelvic sexual dimorphism (23-25).

An important aspect requiring further investigation is the integration of three-dimensional imaging techniques. While conventional X-rays provide valuable anthropometric data, three-dimensional modeling and volumetric analysis offer superior accuracy in shape analysis and sex classification. Computed tomography and magnetic resonance imaging allow for more detailed assessment of pelvic morphology, particularly in cases where subtle anatomical differences influence classification outcomes. Future research should explore the feasibility of combining multiple imaging modalities to optimize sex estimation protocols. Additionally, interobserver reliability testing should be conducted to quantify the consistency of measurements and validate the reproducibility of the findings (26-28). The study underscores the significance of selecting optimal skeletal traits for accurate sex classification. The findings support the hypothesis that pelvic morphology provides highly reliable sex estimation criteria, comparable to or exceeding the accuracy of other skeletal structures such as the cranium, femur, and clavicle. When evaluated alongside other skeletal elements, the pelvis remains one of the most consistent indicators of sexual dimorphism. The results confirm that radiographic morphometric analysis is a valuable tool for forensic investigations, surgical planning, and anthropological studies. Future research should focus on refining classification models, expanding population-specific databases, and integrating advanced imaging technologies to further improve the precision and applicability of pelvic-based sex estimation methods (29).

CONCLUSION

The study establishes the significance of pelvic morphological measurements in gender determination through radiographic analysis, reinforcing the pelvis as a key structure for forensic and anthropometric assessments. By demonstrating the reliability of radiographic methods in sex estimation, the findings contribute to the refinement of osteometric standards and enhance the accuracy of forensic identification and biological profiling. The practical implications extend to forensic anthropology, orthopedic surgery, and clinical applications, where precise skeletal assessments are essential for individualized treatment planning and investigative procedures. This research underscores the importance of advancing radiographic methodologies to further improve the reliability and applicability of gender determination techniques in diverse populations.

AUTHORS' CONTRIBUTION

Author	Contribution
Anwar Ul Haq	Conceptualization, Methodology, Formal Analysis, Writing - Original Draft, Validation, Supervision Investigation, Data Curation, Formal Analysis, Software
Naheed Siddiqui	Methodology, Investigation, Data Curation, Writing - Review & Editing Software, Validation, Writing - Original Draft

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