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Osteometric sex assessment on shoulder region: a radiodiagnostic study

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ABSTRACT

Background: Sex estimation from skeletal remains is a fundamental component of forensic and anthropological investigations. Although the pelvis is considered the most reliable skeletal element for sex estimation due to its pronounced sexual dimorphism, it may be unavailable or unsuitable for analysis in fragmented or incomplete remains. This study aimed to evaluate the osteometric utility of the shoulder complex as an alternative anatomical region for sex estimation.
Methods: This retrospective study analyzed computed tomography (CT) images of 217 adults (113 males, 104 females) aged 18–55 years. A total of 12 morphometric measurements and one proportional index were obtained from the humerus, scapula, and clavicle. Multivariable logistic regression and receiver operating characteristic (ROC) analyses were performed to identify significant predictors and determine optimal cut-off values for sex estimation.
Results: The area under the ROC curve for the humeral head diameter and glenoid cavity width variables were found to be statistically significant. When a cut-off value of 41.95 mm was applied to the measurements of the humeral head diameter variable, the observed sensitivity was 83.2% and specificity was 88.5%, while a cut-off value of 27.85 mm was applied to the measurements of the glenoid cavity width, the observed sensitivity was 82.3% and specificity was 90.4%.
Conclusion: Humeral head diameter and glenoid cavity width demonstrated strong discriminatory performance for sex estimation. These CT-based shoulder complex measurements provide reliable, population-specific cut-off values and may serve as practical tools in forensic and anthropological cases involving fragmented skeletal remains or isolated upper extremity structures.

1. Introduction

The estimation of biological sex from skeletal remains is a fundamental component of both forensic and archaeological investigations. Sex estimation methods rely on morphoscopic traits and statistically significant differences in skeletal dimensions between males and females [1,2]. These approaches are essential not only for assessing sexual dimorphism but also for understanding broader biological, social, and evolutionary patterns.

Traditionally, sex estimation has focused primarily on the pelvis and cranium, which are regarded as the most reliable skeletal regions due to their pronounced sexual dimorphism [1,2]. However, in forensic and archaeological contexts, these structures are often fragmented, absent, or otherwise unsuitable for analysis. Consequently, postcranial skeletal elements have gained increasing importance as alternative sources for sex estimation. Long bones such as the humerus, femur, and clavicle, as well as flat bones including the scapula and ribs, in addition to vertebrae, have demonstrated substantial utility in this regard [2–11].

Among postcranial structures, the humerus is particularly valuable because of its robust morphology and high likelihood of preservation.

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Similarly, the scapula has received increasing attention in morphometric studies, with consistent evidence demonstrating larger dimensions in males than in females, reflecting clear sexual dimorphism [12]. Furthermore, compact anatomical structures such as the glenoid cavity are frequently preserved and therefore provide additional utility for sex estimation in incomplete skeletal remains [13]. Although the individual bones of the shoulder region have been investigated previously, existing studies have largely evaluated these structures in isolation. To the best of our knowledge, no prior study has comprehensively assessed the shoulder complex as an integrated anatomical unit within a single analytical framework. Addressing this gap, the present study evaluates morphometric measurements derived exclusively from the shoulder region, including both the proximal humerus and scapular components, for sex estimation. Specifically, this study aims to develop a logistic regression model and establish population-specific cut-off values for sex estimation based solely on shoulder complex measurements. This integrated approach may provide a practical and reliable alternative in forensic and archaeological cases where conventionally preferred skeletal elements are unavailable. Furthermore, this approach may offer particular forensic value in cases involving isolated upper extremity remains, such as traumatic limb loss or accidental amputation, where sexually dimorphic features of the upper limb may substantially contribute to biological sex estimation and identification.

2. Material and methods

2.1. Imaging and data collection

This retrospective study was performed in line with the principles of the Declaration of Helsinki, and ethical approval was obtained from Kırşehir Ahi Evran University Health Sciences Scientific Research Ethics Committee on April 2, 2024 (Decision No: 2024–08/54).

This study was conducted at the Radiology Outpatient Clinic of Kırşehir Ahi Evran University Training and Research Hospital. A retrospective analysis was performed using CT images of 217 patients (113 males and 104 females) aged between 18 and 55 years, all of whom were registered in the hospital's PACS (Picture Archiving and Communication System) archive. Individuals older than 55 years were excluded from the study to minimize potential confounding effects on bone morphometric measurements. This decision was based on the increased prevalence of metastatic bone tumors in individuals over 60 years of age (with a rising incidence after 50 years), the high frequency of primary osteoporosis in the 50–75 age group, and the increased incidence of primary glenohumeral osteoarthritis among individuals aged 50–55 years [14–16]. These conditions may influence external osseous morphometry and could thereby compromise the validity of morphometric analyses [17]. Additionally, patients with implants in the shoulder region, a history of upper extremity surgery, fractures, dislocations, or soft tissue pathologies in the upper extremity bones were also excluded. All CT image measurements were performed by a single observer. The observer underwent a structured setup and training process under the supervision of an experienced radiologist. During this phase, the observer was trained in measurement techniques and standardized according to the study protocol. After completing the training and demonstrating sufficient skill, the observer performed all measurements included in this study at one-week intervals. Intraobserver agreement was evaluated using two-way random-effects, absolute-agreement intraclass correlation coefficients (ICC [1,2]). Overall, the measurements demonstrated excellent reliability, with ICC values exceeding 0.94 for all parameters. CT scans were performed using Toshiba Alexion 16-slice and General Electric (GE) Lightspeed 128-slice CT scanners following standard protocols. A total of 12 morphometric variables were measured. The precise definitions, abbreviations, and anatomical descriptions of all measured variables are provided in Table 1. The specified measurements were obtained at three different time points, with three repetitions. The final metric value was determined by averaging these three measurements.

Table 1
Standardization and abbreviations of measured variables.

Variables	Standardization
Humeral head diameter (HHD)	The distance at which the caput humeri diameter was widest in the coronal plane was measured [18,19].
Humeral head height (HHH)	It was measured as the longest perpendicular distance to the diameter of the caput humeri in the coronal section where the caput humerus is at its widest [20–22].
Surgical neck diameter (SND)	Measurements were taken from the coronal section where the collum chirugicum is at its narrowest [10].
Glenoid cavity height (GCH)	In the coronal section, measurements were taken from the section with the longest distance between the lower and upper points of the glenoid cavity [20,22].
Acromion height (AH)	The height was measur ed. in the section where the thickest acromion image was located in the coronal plane [23].
Height of the lateral part of the clavicle (CH)	It was measured in the section where the lateral part of the clavicle had the longest distance. The measurement was taken from the lateral part due to its proximity and articulation to the shoulder region [23,24].
Intertubercular Sulcus Depth (ISD)	The perpendicular distance to the line drawn between the walls of the sulcus intertubercularis was measured from the deepest point of the groove in the axial section where the depth of the sulcus intertubercularis was the greatest [25].
Intertubercular Sulcus Width (ISW)	The maximum width between the medial and lateral walls of the sulcus intertubercularis was measured in axial section [26].
Glenoid cavity depth (GCD)	In axial CT sections, it was measured as the vertical distance from the midpoint of the glenoid cavity to the line connecting both ends in the section where the concavity of the glenoid cavity is the greatest [27,28].
Glenoid cavity width (GCW)	Measurement was taken with the line connecting both ends in the axial section where the concavity of the glenoid cavity is at its maximum [27].
Coracoid process width (CPW)	The measurement was taken from the widest section of the coracoid process, approximately 4 mm above the junction of the coracoid process and the glenoid space [29].
Glenoid index (GI)	It was found by multiplying the ratio of the glenoid cavity width to the glenoid cavity height by 100 [30,31].

Measurements were extracted from the DICOM files in millimeters (mm) and degrees (°) using the PACS software (Figs. 1 and 2).

2.2. Statistical analysis

Statistical analyses were conducted using the SPSS software package (IBM SPSS Statistics for Windows, Version 29.0, Armonk, NY: IBM Corp., USA). The normality of continuous variables was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests, while the assumption of homogeneity of variances was evaluated using Levene's test. Depending on whether the assumptions were met, comparisons between two groups were carried out using either the Independent *t*-test or the Mann-Whitney *U* test. Descriptive statistics were reported as mean ± standard deviation for variables meeting parametric assumptions, and as median (minimum–maximum) and frequency (n) for those not meeting these assumptions. To identify morphometric variables significantly associated with sex and to determine their predictive performance for sex estimation, multivariable logistic regression analysis was performed. The Forward Conditional method was used to estimate the most accurate predictive logistic model. ROC analysis was performed on the variables that demonstrated a statistically significant effect on sex prediction according to the results of logistic regression analysis. For multivariable logistic regression and ROC analyses, sex was coded as a

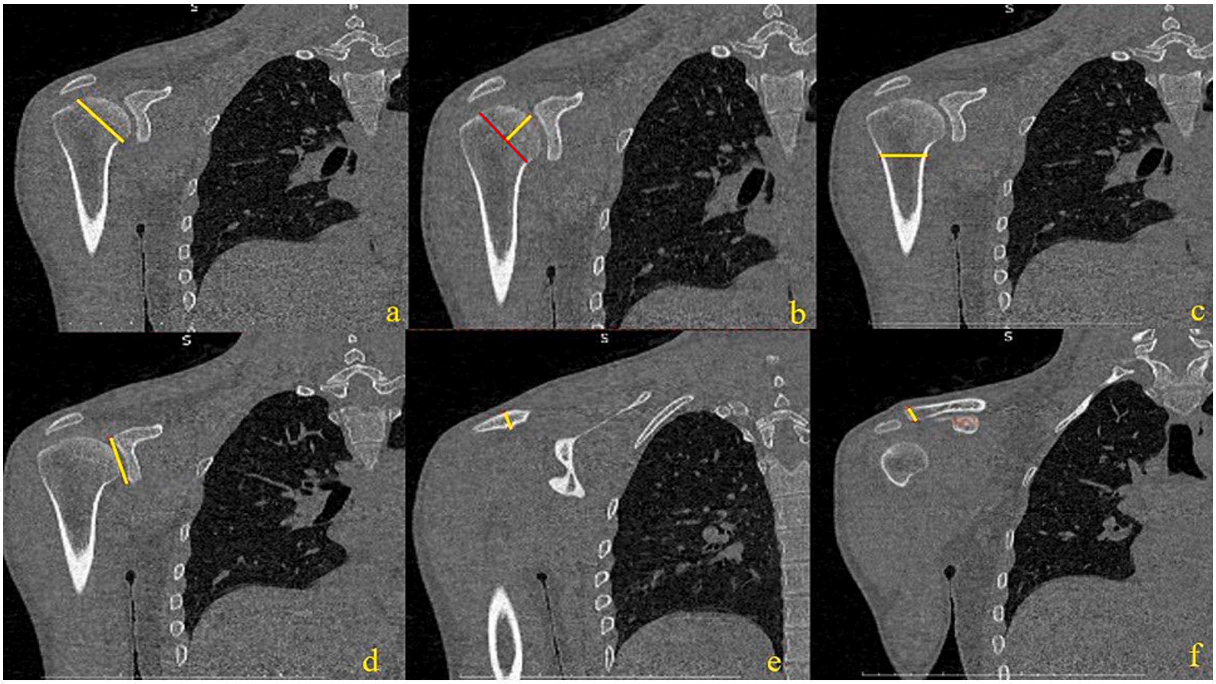

Fig. 1. Representation of variables measured in coronal section on radiological images. a: HHD, b: HHH (red line indicates humeral head diameter reference line), c: SND, d: GCH, e: AH, f: CH. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

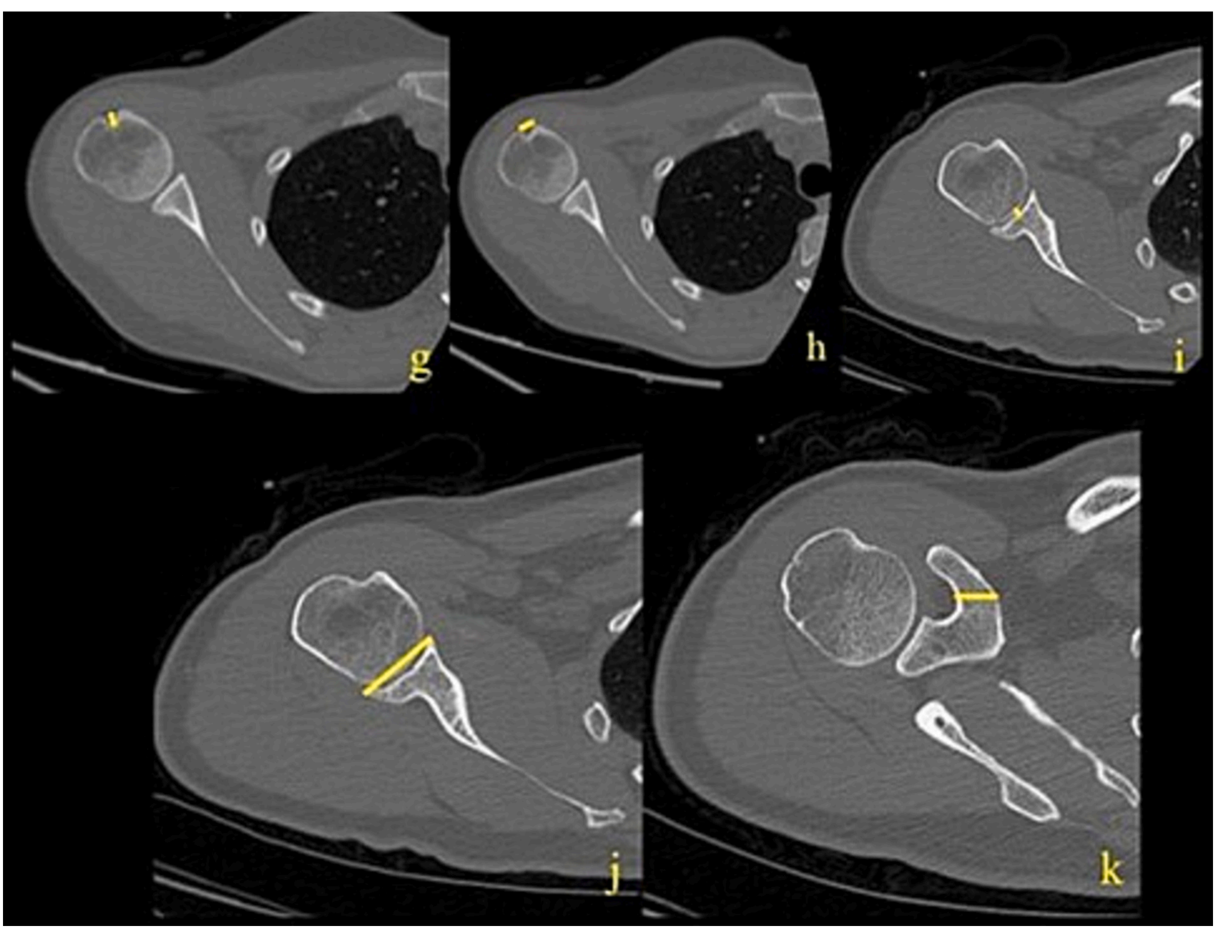

Fig. 2. Representation of variables measured in axial section on radiological images. g: ISD, h: ISW, i: GCD, j: GCW, k: CPW.

binary categorical variable, with female coded as 1 and male coded as 2. Female served as the reference category; therefore, increasing predicted probabilities and parameter values above the identified cut-off thresholds indicated a greater likelihood of male classification. The statistical significance, sensitivity, specificity, and area under the curve (AUC) values corresponding to the identified cut-off points were evaluated. A *p*-value of less than 0.05 was considered indicative of statistical significance in all analyses. Sample size was calculated by performing Priori power analysis. In power analysis, Slope H1 = 0.105, $\alpha = 0.05$, Power(1-β err prob) = 0.95, Slope H0 = 0, Std dev σ_x = 1, Std dev σ_y = 0.42 were taken. The minimum sample size needed was calculated as 197. 217 subjects, which is 10% more than the calculated sample size, were used. Power analysis was performed using the G*Power (3.1.9.7) package program [32].

3. Results

A total of 217 individuals participated in the study, including 104 females and 113 males. Descriptive statistics and group comparisons of the variables measured in female and male participants are presented in Table 2. The mean age was 39.85 years in females and 33.55 years in males, with an overall mean age of 36.57 years for the total sample. In total, 123 right and 94 left upper extremities were evaluated. When stratified by sex, measurements were obtained from 63 right and 41 left upper extremities in females, and from 60 right and 53 left upper extremities in males. 12 measurements in total were obtained from the humerus, clavicle, and scapula. Statistically significant differences were observed between sexes for all measured variables ($p < 0.01$). (Table 2).

Multiple logistic regression analysis was conducted to assess whether the variables that showed significant differences had a predictive effect on sex estimation. As a result of this analysis, a logistic regression model was developed, with the corresponding coefficients presented in Table 3. The model was constructed using the Forward Conditional method. It achieved an overall prediction accuracy of 89.9%. The model demonstrated good calibration according to the Hosmer–Lemeshow goodness-of-fit-test ($X^2 = 4.96$ $p > 0.05$), indicating an adequate fit to the observed data.

Table 2
Descriptive statistics of variables by sex.

Variables	Female (*n* = 104)	Male (*n* = 113)	Total (*n* = 217)	*p*
Age (year)	39.85 ± 11.28	33.55 ± 10.77	36.57 ± 11.44	**<0.001**[&]
Humeral head diameter (HHD)	39.41 ± 2.49	44.35 ± 2.86	41.98 ± 3.65	**<0.001**[&]
Humeral head height (HHH)	16.41 ± 2.02	18.86 ± 2.21	17.69 ± 2.45	**<0.001**[&]
Surgical neck diameter (SND)	27.4 (17.8–32.8)	30.7 (19.1–38.4)	29 (17.8–38.4)	**<0.001***
Glenoid cavity height (GCH)	31.56 ± 2.73	35.33 ± 2.86	33.52 ± 3.37	**<0.001**[&]
Acromion height (AH)	10.15 ± 1.84	11.87 ± 1.99	11.04 ± 2.10	**<0.001**[&]
Height of the lateral part of the clavicle (CH)	11.98 ± 2.06	13.76 ± 1.95	12.91 ± 2.19	**<0.001**[&]
Intertubercular Sulcus Depth (ISD)	4.5(2.7–6.7)	4.9 (1.4–10.3)	4.7 (1.4–10.3)	**<0,001***
Intertubercular Sulcus Width (ISW)	10.05 (6.3–17)	11.6 (7.3–27.1)	10.8 (6.3–27.1)	**<0.001***
Glenoid cavity depth (GCD)	1.7(0.2–7)	1.9(0.5–5.9)	1.9(0.2–7)	**0.003***
Glenoid cavity width (GCW)	25.6 ± 2.09	29.69 ± 2.17	27.73 ± 2.95	**<0.001**[&]
Coracoid process width (CPW)	12 (7.3–17.1)	14.9 (9.4–21)	13.2 (7.3–21)	**<0.001***
Glenoid index (GI)	12.37 ± 1.18	11.94 ± 1.09	12.14 ± 1.16	**0.006**[&]

*: Mann Whitney U, &: Independent t-test, p: significance level, All metric measurements are in milimeters. Descriptive statistics were expressed as mean ± standard deviation for variables meeting parametric test assumptions, and as median (minimum–maximum) for variables not meeting these assumptions.

Table 3
Logistic regression analysis results.

Variables	B	S.E.	p	OR	95% C.I. for (ExpB)
Humeral head diameter (HHD)	0. 474	0.104	<0.001	1.607	1.310–1.971
Glenoid cavity height (GCH)	0.221	0.092	0.016	1.248	1.042–1.494
Intertubercular Sulcus Width (ISW)	0.366	0.133	0.006	1.442	1.112–1.870
Glenoid cavity width (GCW)	0.498	0.142	<0.001	1.645	1.245–2.175
Coracoid process width (CPW)	0.372	0.121	0.002	1.451	1.145–1.839
Constant	- 49.86	7.31			

B: regression coefficient, S.E.:standard error, p: p-value, OR: odds ratio, 95% C.I.:95% confidence interval, Exp(B): exponentiated regression coefficient, Sex coding: Female = 1 (reference category), Male = 2.

Further examination of the multiple logistic regression results (Table 3) revealed that the variables GCH, GCW, ISW, CPW, and HHD had a statistically significant effect on sex estimation. The odds ratios presented in the table indicate the magnitude of the effect that an increase or decrease in each independent variable has on the likelihood of the dependent outcome. Among the variables included in the model, two odds ratio values stand out (Table 3). A one-unit increase in GCW increases the likelihood of the bone being classified as male by 1.645 times (OR: 1.645, 95% CI: 1.245–2.175, $p < 0.001$). Similarly, a one-unit increase in HHD increases the likelihood of classification as male by 1.607 times (OR: 1.607; 95% CI: 1.310–1.971; $p < 0.001$).

Following the logistic regression analysis, Receiver Operating Characteristic (ROC) analysis was conducted to evaluate whether the variables that significantly contributed to the model possessed diagnostic cut-off values for sex estimation. Upon examining the areas under the ROC curves, it was found that HHD and GCW demonstrated significant diagnostic performance (Table 4).

The area under the ROC curve (AUC) for the HHD variable was found to be statistically significant (AUC: 0.905, 95% CI: 0.864–0.946, $p < 0.001$) (Fig. 3). The sensitivity (83.2%) and specificity (88.5%) observed when a cut-off value of 41.95 mm was applied to the HHD measurements suggest that the HHD variable has significant diagnostic utility for sex estimation. This cut-off point of 41.95 mm facilitates an accurate, sensitive, and specific classification for sex estimation (Fig. 3).

Similarly, the AUC for the GCW variable was also statistically significant (AUC: 0.913, 95% CI: 0.875–0.951, $p < 0.001$) (Fig. 3). With a cut-off value of 27.85 mm applied to the GCW measurements, the sensitivity (82.3%) and specificity (90.4%) indicate that the GCW variable holds substantial diagnostic value for sex estimation. This cut-off point of 27.85 mm offers a reliable, sensitive, and specific classification in the context of sex estimation (Fig. 3).

On the other hand, although the GCH, ISW, and CPW variables demonstrated a statistically significant effect on sex estimation, an analysis of the areas under the ROC curve revealed that these variables did not provide diagnostic cut-off values with sufficient sensitivity and specificity to be utilized in sex estimation ($p > 0.05$).

4. Discussion

In forensic anthropology and medico-legal practice, long bones have frequently been utilized as alternative skeletal elements for sex estimation when the pelvis, considered the most reliable structure for this purpose, is unavailable or unsuitable for examination [10,13]. Within this context, the shoulder girdle has gained increasing attention due to its anatomical robustness and relative preservation in fragmented or compromised remains.

The scapula, humerus, and clavicle have each been widely studied

Table 4
ROC analysis results.

Variables	AUC	95.0% C.I.	*p*	Cut-off	Sensitivity	Specifity
HHD	0.905	0.864–0.946	<0.001	41.95	0.832	0.885
GCW	0.913	0.875–0.951	<0.001	27.85	0.823	0.904

C.I: Confidence Interval, AUC: Area Under Curve, Humeral head diameter: HHD, Glenoid cavity width: GCW.
Sex coding: Female = 1 (reference), Male = 2. Values above the cut-off indicate higher probability of male classification.

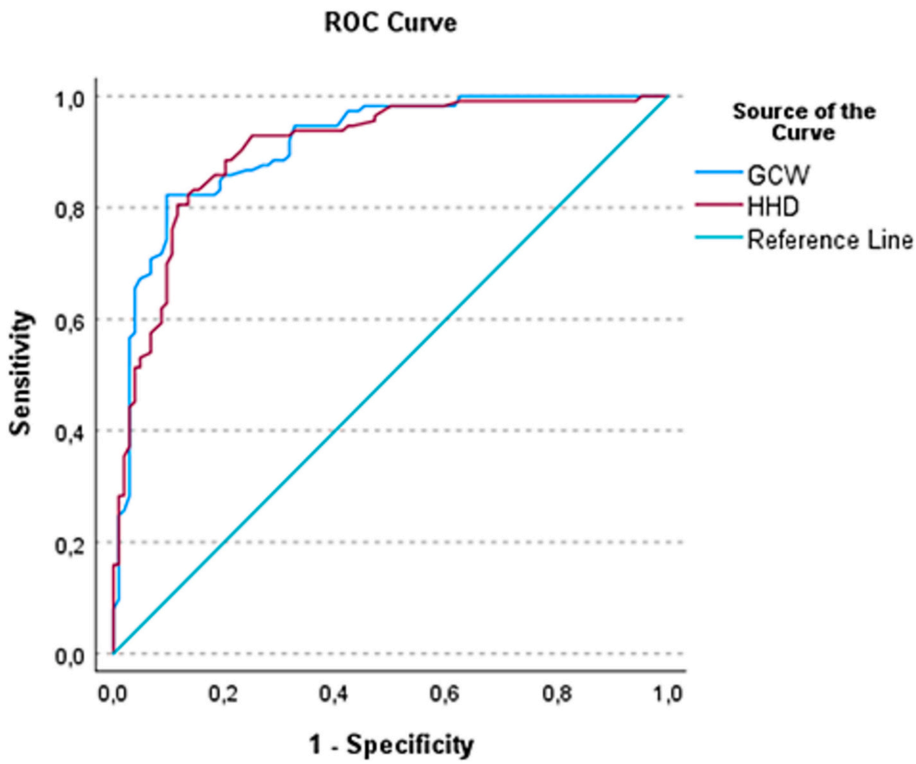

Fig. 3. ROC curve of the variable of humeral head diameter (HHD) and glenoid cavity width (GCW).

for sex estimation across diverse populations, including those from Thailand, United States, South Africa, Japan, Germany, China, Spain, Chile, Greece, Korea, and India [2–6,11,33–37]. Although these studies have established the forensic utility of individual shoulder region components, a notable gap remains in the literature regarding their collective evaluation as a single anatomical and functional complex. Addressing this gap, the present study investigated the shoulder region as an integrated unit using CT-based morphometric analysis for sex estimation.

While previous studies have primarily focused on isolated analyses of these bones, the current study assessed them collectively within a single predictive model. The analyses conducted in the present study revealed that HHD, GCH, GCW, ISW, and CPW significantly contribute to sex prediction, but only HHD and GCW demonstrated diagnostically useful threshold values derived from the ROC curve.

Among all evaluated parameters, humeral head diameter (HHD) emerged as one of the strongest predictors of sex. The identified cut-off value of 41.95 mm yielded 83.2% sensitivity and 88.5% specificity, with an AUC of 0.905 (Table 4). These results are highly consistent with previous literature across different populations and methodologies. As summarized in Table 5, reported HHD cut-off values generally range between 40.1 and 42.6 mm in CT, MDCT, and dry bone-based current studies. The close agreement of our results with Greek Cypriot, Mexican, Indian, and Egyptian studies supports the reproducibility and reliability of HHD as a sexually dimorphic marker across populations [3,33,34,38,39].

As a period-based study, Dittrick et al. demonstrated that humeral head cut-off values varied across different archaeological periods, decreasing from 47.00 mm in the Early Horizon sample to 43.92 mm in the Middle and Late Horizon samples [40]. These results suggest that temporal changes in skeletal morphology may influence osteometric thresholds, underscoring the importance of population and period specific standards in sex estimation.

Similarly, glenoid cavity width (GCW) demonstrated excellent discriminatory performance, with a cut-off value of 27.85 mm, sensitivity of 82.3%, specificity of 90.4%, and AUC of 0.913. GCW showed the highest diagnostic performance among scapular measurements in the present study. Previous studies reported comparable GCW cut-off values of 28.5 mm in the Egyptian population and 26.7 mm in the Italian population [24,41]. The similarity of these results further supports GCW as a robust and reproducible parameter for sex estimation.

The collective analysis of the shoulder girdle provides an important methodological advantage. Although multiple variables entered the logistic regression model, forward conditional selection identified only the most informative predictors, thereby reducing redundancy among correlated measurements. This result supports the concept that evaluating the shoulder girdle as a functional anatomical unit improves identification of the most discriminative morphometric parameters.

In conclusion, CT-based morphometric analysis of the shoulder girdle provides valuable parameters for sex estimation. Among all evaluated variables, HHD and GCW demonstrated the highest diagnostic performance and yielded practical cut-off values with high sensitivity

Table 5
Comparative summary of previous studies evaluating humerus and scapula morphometric parameters for sex estimation across different populations.

Study (Author, Year)	Population/ Method	Bone/Measurement	AUC	Cut-off (mm)	Sensitivity (%)	Specificity (%)	p
Baer et al., 2025	Greek Cypriot, CT	Humerus (Maximum vertical head diameter)	0.89[a] 0.91[b] 0.88[c] 0.89[d]	42.1	85.7	83.0	NR
Phetnui et al., 2026	Thailand, CT	Humerus (MCH, SIDH, WH)	0.978	NR	90.0	96.0	<0.01
Menéndez Garmendia et al., 2025	Mexico, CT	Humerus (Humeral Head Vertical Diameter)	NR	42.0	NR	NR	0.000
Bharadwaja, 2024	India, Cadaver	Humerus (Maximum Diameter of The Humeral Head)	NR	42.6	NR	NR	NR
		Humerus (Vertical Diameter of The Humeral Head)	NR	41.7	NR	NR	NR
		Humerus (Transverse Diameter of The Humeral Head)	NR	39.9	NR	NR	NR
Lashin et al., 2024	Egypt, MDCT	Humerus (Vertical Diameter of Caput)	0.859	>40.1 mm	82.4	74.6	<0.001
Dittrick & Suchey, 1986	USA, Dry Skeletal	Humerus (Vertical Diameter Of The Humeral Head)	NR	43.92*, 47.0**	NR	NR	NR
Kandeel et al., 2024	Egypt, CT	Scapula (Glenoid cavity breadth)	0.858[e], 0.860[f]	28.5[e], 28.5[f]	84.8[e], 83.3[f]	72.8[e], 78.3[f]	<0.001
		Scapula (Glenoid cavity height)	0.868[e], 0.867[f]	34.5 [e], 34.5 [f]	80.3[e], 78.8[f]	79.7[e], 79.7[f]	<0.001
Morandini et al., 2026	Italy, Dry Skeletal	Scapula (Glenoid cavity breadth)	NR	26.7	NR	NR	NR
		Scapula (Glenoid cavity height)	NR	35.8	NR	NR	NR
Present study	Türkiye, CT	Humerus (Humeral head diameter)	0.905	41.95	83.2	88.5	<0.001
		Scapula (Glenoid cavity width)	0.913	27.85	82.3	90.4	<0.001

* : Early Horizon sample.
** : MiddleLate Horizon sample.
[a] : Binary Logistic Regression, Left.
[b] : Linear Discriminant Analysis, Left.
[c] : Binary Logistic Regression, Right.
[d] :Linear Discriminant Analysis, Right; MCH: midshaft circumference of humerus, SIDH: superior– inferior diameter of humeral head, WH: Weight of the humerus.
[e] : Right.
[f] : Left Side; AUC: Area Under Curve;p: significance level

and specificity. These results support the forensic utility of shoulder girdle measurements, particularly in cases involving fragmented remains or isolated upper extremities. Further validation in larger, multicenter cohorts with broader age representation is warranted to enhance the generalizability and forensic applicability of these population-specific osteometric standards.

Limitations

Several limitations of the present study should be acknowledged. Although individuals aged ≥55 years were excluded to minimize the influence of age-related degenerative changes on shoulder morphology, a statistically significant age difference persisted between the female and male groups, with females being older on average. Thus, while the study design partially mitigates age-related confounding, its effect cannot be fully excluded. In addition, anthropometric data such as height and weight were unavailable; given their known influence on skeletal dimensions, this represents another potential source of confounding. Future studies incorporating age-adjusted models and comprehensive anthropometric variables are needed to enhance the robustness and generalizability of these results.

Ethics approval

This retrospective study was performed in line with the principles of the Declaration of Helsinki. Ethical approval for the study was obtained from the Kırşehir Ahi Evran University Health Sciences Scientific Research Ethics Committee on April 2, 2024 (Decision No: 2024–08/54).

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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