Gender Determination Using the Hyoid Bone: A Discriminant Function Analysis

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Abstract- The hyoid bone, with its unique morphology, offers a valuable alternative for gender determination in cases where traditional indicators like the pelvis and skull are compromised. This study aimed to investigate the relationship between gender and hyoid bone dimensions using CT scan images. This retrospective study analyzed 120 neck CT scans to investigate the relationship between gender and hyoid bone dimensions. RadiAnt DICOM Viewer software was used for evaluation. Measurements included width, length, and proximal and distal widths of the greater horns of the hyoid bones on both sides. Statistical analysis employed a range of techniques, including independent t-tests, paired t-tests, Spearman's rank correlation, and discriminant analysis, with a significance level of 0.05. This retrospective study analyzed 120 neck CT scans from 60 women (mean age 48.92±13.53 years) and 60 men (mean age 53.97±17.05 years). In examining the dimensions of the hyoid bone, all variables except the distal width of the greater horn on both sides (RDD, LDD) were found to have statistically significant differences between the two sexes. The classification of individuals by sex was correctly determined in 85% of cases using discriminant function analysis. Stepwise analysis identified hyoid body length and width as the most significant predictors, demonstrating 81.7% and 85% accuracy in classifying men and women, respectively. In our study population, measurements of body length and width at the hyoid bone proved highly reliable indicators of sex differentiation.

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Introduction

Gender identification is a cornerstone of human identification, providing essential information for a comprehensive understanding of an individual's identity (1,2). While pelvic and skull bones are traditionally used for this purpose, their potential damage or incompleteness necessitates alternative methods (3,4). The hyoid bone, often available from autopsies or unidentified skeletons, emerges as a valuable resource for both gender determination and the diagnosis of antemortem neck injuries (5-7).

Craniocervical components may have been preserved in archaeological remains or in accidents related to natural disasters (8). The hyoid bone is a U-shaped bone located in the midline of the neck. It plays a critical role in speech, respiration, mastication, deglutition, and maintaining an open airway during sleep (9,10). This bone provides support for the base of the tongue and the floor of the mouth and is involved in the movements of the muscles that facilitate the opening and closing of the mouth (11). The hyoid bone has distinct morphological features, notably a pair of greater horns, which allow for rapid identification. The morphometric characteristics of the hyoid bone can contribute to determining the biological profile of remains, including gender, as several studies have demonstrated gender-specific dimorphism in certain aspects of this bone (12-15).

Several studies have used hyoid bone measurements to estimate age and sex, primarily relying on direct

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measurements or autopsy images (12,13,16,17). Additionally, computed tomography (CT) images (4,18) and X-ray films with various radiation techniques (19) have been employed for this purpose. It is important to note that studies have shown significant inter-population and inter-regional variability in the linear dimensions of the hyoid bone (12-16).

This study aims to develop simple, practical equations for determining gender from CT scans of the hyoid bone, which are anticipated to be valuable for forensic investigations.

Materials and Methods

Study design

In this retrospective study, 204 CT scans of the neck were retrieved from the archives of a private radiology clinic and reviewed between October and March 2022. The study protocol was approved by the Ethical Committee of Mashhad University of Medical Sciences (IR.MUMS.DENTISTRY.REC.1400.139). All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008.

The inclusion criteria included high-quality images with complete visualization of the hyoid bone and individuals aged 18 years and older. Exclusion criteria included any pathological disorders, acquired or congenital abnormalities, fractures, trauma, or other conditions affecting the hyoid bone region.

Based on the inclusion and exclusion criteria, a total of 127 scans were ultimately selected for the study. All CT scan images were acquired using a Sensation 16-slice MDCT device (Siemens SOMATOM AG Medical Solutions, Erlangen, Germany) with the following imaging parameters: kVp=120 kV, mA=320 mA, and collimation=12 x 0.75 mm. The RadiAnt DICOM Viewer software was used to reconstruct the images using the hard-tissue kernel.

Measuring the dimensions of the hyoid bone

All measurements were performed in the axial plane, corrected by slice-by-slice tracing of coronal and sagittal sections.

Six variables were measured for each hyoid bone (Figure 1):

1. Hyoid body length (BL): The linear distance between the most anterior lateral points of the hyoid body.
2. Hyoid width (HW): The linear distance between the most lateral points at the ends of the greater horns of the hyoid.
3. Left proximal width (LPW): The maximum width of the proximal end of the left greater horn.
4. Right proximal width (RPW): The maximum width of the proximal end of the right greater horn.
5. Left distal diameter (LDD): The maximum width of the distal end of the left greater horn.
6. Right distal diameter (RDD): The maximum width of the distal end of the right greater horn.

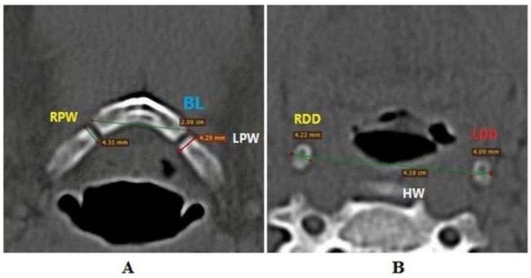

Figure 1. Variables measured in the axial section of the hyoid bone belonging to a 20-year-old man. A): RPW, BL, and LPW values are 4.32 mm, 20.8 mm, and 4.29 mm, respectively. B): RDD, HW, and LDD values are 4.22 mm, 41.8 mm, and 4.09 mm, respectively

Statistical analysis

Statistical analyses were performed using PASW Statistics 18 software. The Kolmogorov-Smirnov test was used to assess the normality of quantitative data. Independent t-tests, paired t-tests, Spearman's rank correlation, chi-square tests, and discriminant function analysis were employed to analyze data as appropriate. The significance level for all statistical tests was set at 0.05.

Table 1. Descriptive findings of the patients' age based on gender.

	Male	Female	Total
Number of samples (%)	60 (50)	60 (50)	120 (100)
Minimum	20	20	20
Maximum	87	75	87
Mean±SD	53.97±17.054	48.92±13.532	51.44±15.538
95% CI	49.56 ; 58.37	45.42 ; 52.41	48.63 ; 54.25

S.D: Standard deviation; Cl: Confidence interval

Results

The Kolmogorov-Smirnov test confirmed a normal distribution for all quantitative variables (Age, BL, HW, RPW, LPW, RDD, LDD) and for these variables when stratified by gender (*P*>0.05).

Comparison of the patients' ages based on gender

Based on the inclusion and exclusion criteria, 204 CT scan images were examined. Of these, 120 images belonged to 60 women (50%) with an average age of 48.92±13.53 years and 60 men (50%) with an average age of 53.97±17.05 years. The overall average age of all subjects was 51.44±15.53 years. As shown in Table 1, the minimum age for both genders was 20 years.

As shown in Table 1, an independent t-test revealed no significant difference in the average age between male and female participants (*P*=0.71).

Comparing the proximal and distal width dimensions of the greater horn on both sides of the hyoid

Paired t-tests revealed no significant differences in the proximal or distal width of the greater horn on either side of the hyoid bone (*P*>0.05).

Comparison of hyoid dimensions in the two sexes

Independent t-tests revealed significant differences between males and females for all variables listed in Table 2 except RDD and LDD (*P*=0.01).

Discriminant function analysis

Discriminant function analysis was employed to classify gender based on the quantitative variables. The results demonstrated the effectiveness of these variables in gender discrimination. Using all quantitative variables in the discriminant function analysis (Enter method), 85% of individuals were correctly classified (Table 3). A positive difference score (D) indicated a higher likelihood of being male, while a negative score suggested female gender.

The results of the discriminant function analysis produced the following equation, which can be used to classify individuals into male or female groups based on the measured variables:

Discriminant Score $(D)=(0.29\times BL)+(0.12\times HW)+(-0.154\times RPW)+(0.45\times LPW)+(-0.22\times RDD)+(-0.21\times LDD)-11.903$

The stepwise method was used to select the most influential variables for gender discrimination. Only BL and HW were retained in the final model (Table 4). This model achieved a classification accuracy of 81.7% for males and 85% for females.

Table 2. Compare the average of the studied indicators in the two sexes

Variable	Male (Mean±SD)	Female (Mean±SD)	***P**
BL (mm)	25.91±2.01	22.25±3.15	<0.001
HW (mm)	46.10±4.86	40.85±4.69	<0.001
RPW (mm)	5.31±0.70	4.80±0.64	<0.001
LPW (mm)	5.36±0.81	4.74±0.50	<0.001
RDD (mm)	4.59±0.78	4.44±0.64	0.278
LDD (mm)	4.66±0.86	4.47±0.70	0.198

* Independent t-test, BL: Body length, HW: Hyoid width, RPW: Right proximal width, LPW: Left proximal width, RDD: Right distal diameter, LDD: Left distal diameter

Table 3. Discriminant analysis function using the studied quantitative variables to separate gender between men and women

	BL	**HW**	**RPW**	**LPW**	**RDD**	**LDD**	**Constant**
Unstandardized coefficients	0.291	0.123	-0.154	0.453	-0.224	-0.209	-11.903
Discriminant score (D) = (0.291×BL) + (0.123×HW) + (-0.154×RPW) + (0.453×LPW) + (-0.224×RDD) + (-0.209×LDD) + (-11.903)							
Functions at group centroids		Male				Female	
		0.923				-0.923	
			Predicted Group Membership				
Gender			Male		Female		Total
Original	Count (%)	Male	51(85)		9 (15)		60 (100)
		Female	9 (15)		51(85)		60 (100)

BL: Body length, HW: Hyoid width, RPW: Right proximal width, LPW: Left proximal width, RDD: Right distal diameter, LDD: Left distal diameter

Table 4. Discriminant analysis function using the stepwise method

	BL		HW	Constant	
Unstandardized Coefficients	0.293		0.127	-12.592	
	Discriminant Score (D) = (0.293×BL) + (0.127×HW) + (-12.592)				
Functions in a group Centroids		Male		Female	
		0.871		-0.871	
		Predicted Group Membership			
Gender		Male		Female	Total
Original	Count (%)	Male	49 (81.7)	11 (18.3)	60 (100)
		Female	9 (15)	51 (85)	60 (100)

BL: Body length, HW: Hyoid width

Discussion

The study found that male participants had significantly larger hyoid bone dimensions than females. Discriminant function analysis using all six variables achieved an overall classification accuracy of 85%. The stepwise method identified hyoid body length and width as the most influential variables for gender discrimination, achieving classification accuracies of 81.7% for males and 85% for females. In a 2022 study by Köse *et al.*, (10) in the Turkish population, significant gender differences were observed for all hyoid bone dimensions except LDD. Our findings align with these results, as we also found no significant gender differences in LDD or RDD.

A study by Torimitsu *et al.*, (4) on the Japanese population (2018), reported significant gender differences in all hyoid bone dimensions. In contrast, our study found no significant differences in RDD or LDD, suggesting the absence of racial variation. In a previous study by Savitha *et al.*, (20) on the Indian population (2019), men exhibited significantly larger hyoid bone widths (39.08±7.74 mm) compared to women (36.10±7.21 mm). These findings are consistent with our results, which also demonstrated a significant gender difference in hyoid width.

In a study by Balseven *et al.*, (21) on the Turkish population, men exhibited significantly larger hyoid bone dimensions than women. These findings are consistent with our results. Amgain *et al.*, (22) conducted a study in South India (2020) and reported that the mean hyoid body length was significantly larger in men (22.51±3.73 mm) compared to women (20.27±1.75 mm). These findings align with our results, which also demonstrated a statistically significant gender difference in hyoid body length.

A previous study by Köse *et al.*, (10) identified BL as the most influential variable for gender discrimination, accounting for 81.35% of the predictive power. Torimitsu *et al.*, (4) further highlighted the importance of HL, which had an even greater influence of 88.2%. Additionally, the BL variable's impact percentage was estimated at 86.1%. Our study supports these findings, as BL and HW were also identified as the most effective variables for distinguishing between males and females. Our findings align with previous research by Köse *et al.*, (10) and Amgain *et al.*, (22), demonstrating a lack of significant differences in LPW, RPW, LDD, and RDD between the left and right sides of the hyoid bone.

This study highlights the potential of CT scans of the hyoid bone as a valuable tool for gender determination. By employing discriminant function analysis, we were able to effectively classify individuals based on quantitative variables, reducing the need for invasive procedures such as autopsies. Future studies should investigate the effects of RDD and LDD across different races to gain a more comprehensive understanding of the factors influencing gender determination and age estimation based on hyoid bone dimensions. Moreover, the use of 3D CT scans with bone simulation can improve the accuracy of comparisons with studies that employed traditional direct measurement techniques.

This study highlights the potential of CT scans of the hyoid bone as a non-invasive and accurate method for gender determination. The use of BL and HW as key variables in discriminant function analysis demonstrates the effectiveness of this approach. By reducing the need for autopsies, CT scans can offer a valuable alternative for forensic investigations.

Limitations

The study analyzed a total of 120 CT scans, which may limit the generalizability of the findings. A larger and more diverse sample could provide a more comprehensive understanding of hyoid bone dimensions across different populations. Also, excluding individuals with pathological conditions or abnormalities may limit the applicability of the findings to real-world forensic scenarios where such conditions are common. Moreover, while various statistical methods were employed, potential confounding variables were not fully explored, which could affect the accuracy of gender classification.

Future study

Future research should include a larger sample size encompassing various demographics, including age, ethnicity, and geographical location, to validate the findings and improve generalizability. Also, conducting longitudinal studies could provide insights into how hyoid bone dimensions may change over time and their implications for gender determination in forensic contexts. Moreover, investigating hyoid bone dimensions across different populations and comparing them with existing literature could help identify inter-population variations and refine gender determination methods. Future studies should explore the influence of additional factors such as age, body mass index (BMI), and other anatomical variations on hyoid bone dimensions to refine gender classification models. Further research can focus on developing predictive models that incorporate multiple variables beyond just hyoid dimensions for more accurate gender determination in forensic applications.

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