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Morphometric Analysis of the Hyoid Bone and its Relationship with Mandible and Neurocranial Structures for Sex Prediction in Autopsy Cases

Análisis Morfométrico del Hueso Hioides y su Relación con las Estructuras Mandibulares y Neurocraneales para la Predicción del Sexo en Casos de Autopsia

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SUMMARY: This study aims to determine the morphology of the hyoid bone in autopsy cases and investigate its relationship with sex, age, height, mandible length, and cranial length, thereby contributing significantly to clinical practice and forensic medicine. Conducted on 75 cases ranging from 18 to 90 years of age, referred to the Tokat Forensic Medicine Institution, the study employed precise digital calipers for length measurements and a precise digital scale for weighing the hyoid bone. The volume of the hyoid bone was calculated using the Archimedes principle. Results indicated that all hyoid bone measurements were significantly higher in males than females ($p<0.001$). High-level correlations were found between hyoid and mandible measurements, including circumference and width ($r>0.800$, $p<0.001$), suggesting a strong morphometric relationship between the hyoid bone and the mandible and other cranial parameters. These findings are expected to contribute substantially to forensic sciences and anthropometry.

KEY WORDS: Autopsy; Height; Hyoid bone; Morphometry; Sex.

INTRODUCTION

The hyoid bone is located at the level of the third cervical vertebra, above the larynx. It consists of a body, a pair of greater horns, and a pair of lesser horns. U-shaped, it attaches to the mandible, clavicle, sternum, and laryngeal cartilages via muscles and ligaments. By supporting the root of the tongue, it plays a crucial role in chewing, speaking, swallowing, and maintaining an open airway (Ito *et al*., 2012; Ichijo *et al*., 2016).

The hyoid bone and the mandible, connected via the suprahyoid muscles, function integratively. Understanding both the anatomical and functional relationships between these two bones, as well as their relationships with various distances within the cranial complex, is important (Ichijo *et al*., 2016). Embryologically, the hyoid bone develops from the second and third pharyngeal arches, while the mandible develops from the first pharyngeal arch (Rodríguez-Vázquez *et al*., 2011). Despite their different embryological origins, their development is influenced by the structural and functional characteristics of the neurocranium, and the vocal, digestive, and respiratory systems (Fabik *et al*., 2021). The literature has limited information regarding the relationship between the hyoid bone and functionally similar structures. The hyoid bone holds significant importance in forensic medicine. Fractures of this bone are used as evidence in cases of hanging, strangulation, or neck trauma (Angoules & Boutsikari, 2013). Additionally, the body of the hyoid bone is crucial for age and sex estimation in fragmented and decomposed bodies, particularly in archaeological and forensic investigations (Amgain *et al*., 2020; Kurbanova *et al*., 2023).

This study aims to examine the morphometric measurement values of the hyoid bone in forensic autopsy cases to understand its structural relationships with the mandible and neurocranial bones. Additionally, it seeks to evaluate the role of the hyoid bone in sexual dimorphism, highlighting its potential contributions to anthropological analyses and its significance in solving forensic cases. By analyzing the role of the hyoid bone in the processes of sex estimation alongside the mandible and cranial complex, this study aims to clarify the impact of the presence or absence of these structures on the accuracy of sex determination.

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MATERIAL AND METHOD

Study Population. This study was conducted on 75 cases from the Anatolian population, aged between 18-90 years, performed in the autopsy hall of Tokat Forensic Medicine Institution since March 2024. Nineteen of the individuals were female, and 56 were male. Cases in which the laryngeal anatomy could be disrupted, such as hanging, drowning, trauma, hyoid bone fractures, decomposed bodies, and individuals under 18 years of age, were not included in the study.

Study Method. During routine autopsy, the hyoid bone was removed by carefully cutting the structures between the hyoid bone and thyroid cartilage. The muscles and ligaments attached to the hyoid bone were then removed, preserving the integrity of the hyoid bone. The skin, subcutaneous adipose tissue, muscles, and connective tissue on the mandible and cranium were removed and made suitable for the measurement of bone parameters.

Measurement Procedure. Valkyrie brand digital electronic caliper with a precision of 0.01 mm was used to measure the length and width of the hyoid bone and mandible. In addition, the thickness of the corpus of the hyoid bone, the length of the greater horn, the interparietal width, and the intertemporal width of the cranium were measured with the same caliper. Swock brand balance with a sensitivity of 0.001 gr was used for weight measurement. The hyoid and mandible angles were determined using an eSynic digital protractor with a precision of 0.3°. Archimedes' principle method was used for volume calculation. For Archimedes' principle, the hyoid bone was placed in a 100 ml graduated cylindrical container filled with water, and the volume values were calculated by measuring the amount of water overflowing. The measurements consisted of 6 widths, 5 lengths, 2 angles, 1 weight, and 1 volume parameter (Figs. 1 to 3). The width and length measurements of the hyoid bone were performed based on the study by Kim *et al.* (2006). Details of the parameters and landmarks used for the measurements are given in Table I. All measurements were performed according to standardized procedures.

Statistical Analysis. Statistical analysis of the data was performed using the IBM SPSS software package (V25). Descriptive statistics (mean and standard deviation) were calculated for each measurement. The conformity of the data to normal distribution was evaluated by Shapiro-Wilk and Kolmogorov-Smirnov tests. Independent sample T-test was used to compare normally distributed data according to paired groups. The relationships between normally distributed quantitative data were evaluated with the Pearson Correlation Coefficient. $p<0.05$ was considered statistically significant.

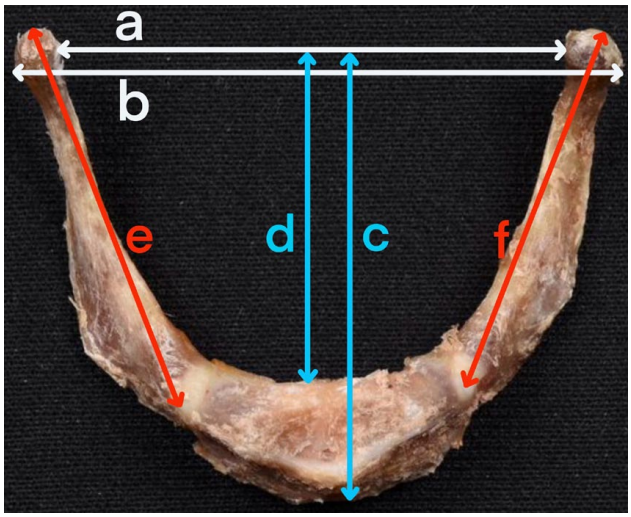

Fig. 1. Hyoid bone measurements. a: hyoid internal width, b: hyoid external width, c: hyoid external length, d: hyoid internal length, e: right greater horn length, f: left greater horn length.

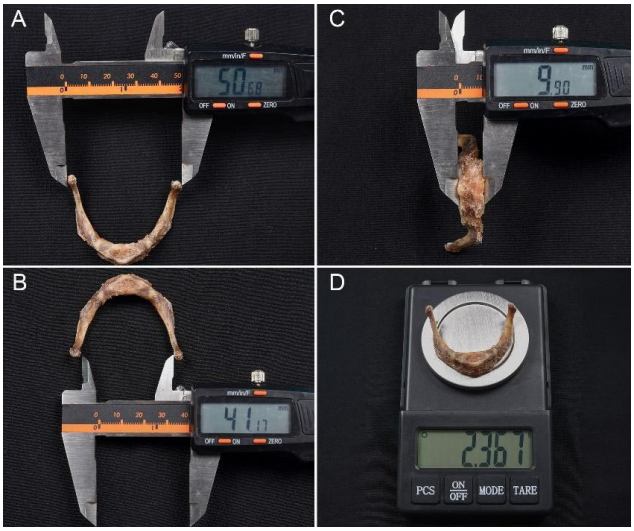

Fig. 2. Hyoid external width (A), internal width (B), corpus thickness (C), weight (D) measurements.

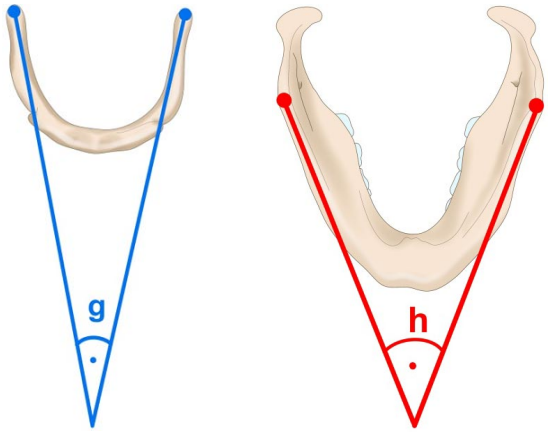

Fig. 3. Hyoid angle (g), mandible angle (h)

Table I. Parameters and landmarks used for measurements.

Widths	
Hyoid external width (b)	The external distance between the distal ends of the right and left greater horns.
Hyoid internal width (a)	The internal distance between the distal ends of the right and left greater horns.
Corpus thickness	The width of the body of the hyoid bone at its central point (perpendicular to the bone surface).
Mandible width	The distance between the right and left gonions.
Interparietal width	The distance between the parietal tubers.
Intertemporal width	The maximum external transverse distance between the right and left temporal bones after calvaria removal.
Lengths	
Hyoid external length (c)	The perpendicular length from the midpoint of the line connecting the distal ends of the right and left greater horns to the anterior center of the hyoid bone body.
Hyoid internal length (d)	The perpendicular length from the midpoint of the line connecting the distal ends of the right and left greater horns to the posterior center of the hyoid bone body.
Greater horn length (e, f)	The distance between the distal end of the greater horn and the lesser horn
Hyoid circumference	The circumference of the hyoid bone between the distal ends of the right and left greater horns.
Mandible circumference	The total circumference of the mandible, measured along its lower margin from the right gonion to the left gonion, passing through the menton.
Angles	
Hyoid angle (g)	The angle measured between the distal ends of the right and left lesser horns by passing over the greater horns, with the protractor ends fixed to these points.
Mandible angle (h)	The angle measured parallel to the base of the mandible by fixing the protractor ends to the right and left gonions.

RESULTS

In our study, there were 56 male individuals (48.61±20.54 years) and 19 female individuals (53.05±20.98 years). The mean age did not show a significant difference between sexes (p=0.420). The average height of males (175.68±7.23 cm) was taller than the average height of females (161.37±5.68 cm) (p<0.001). The weight of male individuals (85.86±17.02) was higher than that of females (78.95±15.77) (p=0.124). The measurements and p values of the hyoid bone are shown in Table II. In all parameters, the measurements of males were found to be higher than those of females (r>0.5, p<0.001) (Table III).

Table II. Distribution of osteometric measurements by sex.

Parameters	Female (n=19)	Male (n=56)	p
Hyoid internal width (mm)	24.47 ± 1.8	40.41 ± 8.00	<0.001
Hyoid external width (mm)	33.53 ± 1.86	49.03 ± 7.56	<0.001
Hyoid internal length (mm)	20.24 ± 0.73	28.02 ± 6.44	<0.001
Hyoid external length (mm)	27.44 ± 1.66	36.99 ± 6.55	<0.001
Corpus thickness (mm)	9.37 ± 0.92	14.15 ± 4.05	<0.001
Greater horn length - right (mm)	20.56 ± 1.03	25.94 ± 3.53	<0.001
Greater horn length - left (mm)	20.56 ± 1.03	25.93 ± 3.52	<0.001
Hyoid circumference (mm)	73.9 ± 1.99	84.38 ± 5.59	<0.001
Hyoid angle (°)	35.16 ± 0.71	36.47 ± 1.11	<0.001
Hyoid weight (g)	2.19 ± 0.36	3.96 ± 1.08	<0.001
Hyoid volume (cm^3)	1.43 ± 0.29	2.72 ± 0.74	<0.001
Mandible circumference (mm)	200.89 ± 4.45	217.72 ± 10.13	<0.001
Mandible width (mm)	148.62 ± 3.64	160.9 ± 7.55	<0.001
Mandible angle (°)	23.97 ± 1.34	31.1 ± 4.1	<0.001
Intertemporal width (mm)	142.25 ± 3.77	152.68 ± 5.99	<0.001
Interparietal width (mm)	119.18 ± 3.84	134.81 ± 8.58	<0.001

Independent sample T-test, Mean ± Standard Deviation.

Table III. Correlation of osteometric measurements with age, height, and weight.

	Age		Height		Weight	
	r	p	r	p	r	p
Hyoid internal width (mm)	-0.325	0.004	0.921	<0.001	0.345	0.002
Hyoid external width (mm)	-0.316	0.006	0.917	<0.001	0.346	0.002
Hyoid internal length (mm)	-0.333	0.003	0.924	<0.001	0.442	<0.001
Hyoid external length (mm)	-0.336	0.003	0.954	<0.001	0.448	<0.001
Corpus thickness (mm)	-0.346	0.002	0.904	<0.001	0.388	0.001
Greater horn length - right (mm)	-0.349	0.002	0.924	<0.001	0.378	0.001
Greater horn length - left (mm)	-0.349	0.002	0.924	<0.001	0.379	0.001
Hyoid circumference (mm)	-0.319	0.005	0.972	<0.001	0.437	<0.001
Hyoid angle (°)	-0.132	0.261	0.735	<0.001	0.346	0.002
Hyoid weight (g)	-0.312	0.006	0.917	<0.001	0.373	0.001
Hyoid volume (cm^3)	-0.290	0.012	0.918	<0.001	0.376	0.001
Mandible circumference (mm)	-0.328	0.004	0.962	<0.001	0.480	<0.001
Mandible width (mm)	-0.322	0.005	0.962	<0.001	0.460	<0.001
Mandible angle (°)	-0.329	0.004	0.967	<0.001	0.422	<0.001
Intertemporal width (mm)	-0.316	0.006	0.957	<0.001	0.512	<0.001
Interparietal width (mm)	-0.299	0.009	0.967	<0.001	0.444	<0.001

Spearman's rho correlation coeffic.

When height was included as a control variable, the significant correlation between weight and other parameters disappeared ($r<0.4$, $p>0.05$). A high-level correlation was found in the correlation analysis between hyoid circumference and mandible circumference ($r=0.977$, $p<0.001$). Similarly, a high-level relationship was detected in the study between hyoid outer width and mandible width ($r=0.893$, $p<0.001$). A high-level relationship was also detected in the analysis between hyoid angle and mandible angle ($r=0.742$, $p<0.001$). High-level correlations were found in the correlation analysis between hyoid inner and outer width, mandible width, interparietal, and intertemporal width parameters ($r>0.800$, $p<0.001$).

DISCUSSION

This study aims to evaluate the morphometric characteristics of the hyoid bone according to sex, age, height, and weight, and to examine the relationships between these parameters. Similar studies on the hyoid bone exist in the literature. However, our study will significantly contribute to the literature due to its comprehensive analysis of the hyoid bone's length, weight, and volume parameters. Understanding the relationship between the hyoid bone and the mandible is important, as these two bones interact anatomically, functionally, and developmentally. In our study, we investigated the relationship between the hyoid bone and the morphology of the mandible and the skull, examining the correlations according to the demographic characteristics of the cases.

Many studies in the literature report that the length parameters of the hyoid bone are greater in males than in females, and these results are consistent with our findings (Ramagalla *et al*., 2014; Savitha *et al*., 2019). Various studies have reported that the outer length of the hyoid bone in males is 39.7±3.2 mm (Kim *et al*., 2006) and 44.6±5.03 mm (Balseven-Odabasi *et al*., 2013), whereas in females these values are lower, being 33.9±6.6 mm and 38.66±5.07 mm, respectively. The width of the hyoid bone in males is reported to be 42.8±12.3 mm (Kim *et al*., 2006) and 45.50±7.31 mm (Balseven-Odabasi *et al*., 2013), while in females it is reported to be 31.6±16.2 mm and 38.47±10.17 mm, respectively (Kim *et al*., 2006; Balseven-Odabasi *et al*., 2013). Our findings also reveal that the morphometric measurements of the hyoid bone show sex-related differences, consistent with the literature. These findings support the usability of the hyoid bone in sex determination and confirm existing knowledge in the literature. Dursun *et al*. (2021) using computed tomography (CT) to examine the hyoid, reported that the angle was narrower in males (36.42±9.24°) compared to females (38.27±9.31°). Similarly, Fakhry *et al*. (2013) found that the hyoid angle was narrower in males (38.78±13.33°) compared to females (44.09±10.97°). Kim *et al*. (2006) measuring on cadavers, reported the angle to be significantly higher in males

(37.8±14°) than in females (20.3±19.2°). We also found the hyoid angle to be significantly wider in males, consistent with the results of Kim *et al*. (2006). However, the difference between sexes in our study was less pronounced.

Leksan *et al*. (2005) reported that the hyoid angle is narrower in both sexes compared to the literature, being wider in males than in females (25.27±13.57° in males, 24.20±14.68° in females). In contrast, Ichijo *et al*. (2016) found no significant difference in the hyoid angle between sexes. We believe that these differences in results could be due to methodological variations, individual differences in measurements among researchers, or bone structure characteristics related to race.

Similar to the findings of our study, many studies in the literature have reported that the hyoid bone weight is higher in males than in females. Kopuz & Ortug (2016) reported the hyoid bone weight as 1.53 grams in males and 0.9 g in females, while Ramagalla *et al*. (2014) reported it as 0.99 g in males and 0.72 g in females. These studies, consistent with our findings in terms of higher hyoid weight in males, show lower results in terms of weight compared to our findings. However, it should be noted that these two studies were conducted on cadavers. We believe that the lower values might be due to changes in bone tissue content related to the fixation process in cadavers.

This difference between sexes parallels our findings. Harun *et al*. (2007) study also indicated that the hyoid bone volume is higher in males compared to females, although no specific values were provided. Ito *et al*. (2012) in a CT study with 3D reconstruction on 310 male and 290 female cases, reported the hyoid bone volume as 4.30 mm^3 in males and 2.94 mm^3 in females. Similarly, using the Archimedes principle, we found the hyoid volume higher in males. However, our results are lower than the literature, possibly due to the higher margin of error in volume measurements conducted through radiological images. Therefore, the direct measurement of our volumes from autopsy cases provides a significant advantage in the reliability of our results.

In a study, a strong positive correlation was found between the anthropometric measurements of the hyoid bone and the height of the cadaver (Amgain *et al*., 2020). Similarly, Urbanová *et al*. (2013), noted that the dimensions of the hyoid bone positively correlated with the individual's height and weight, but this correlation disappeared when gender was controlled. Additionally, Daraze (2018) reported that in Lebanese young adults, the vertical position of the hyoid bone strongly correlated with height, while the horizontal position strongly correlated with weight. Loth *et al*. (2015) 3D geometric morphometric analysis of the hyoid-larynx complex showed that the features of this complex were highly related to sex, height, and weight. Fakhry *et al*. (2013) reported a positive correlation between individuals' height and weight and the lengths of the hyoid bone. In our study, we also found a positive correlation between the morphometric measurements of the hyoid bone and the height and weight of the cases. In partial correlation analysis, we observed that the effect of weight on the measurements disappeared when height was controlled. Our findings were consistent with previous studies in the literature. Our study demonstrates that the morphometric measurements of the hyoid bone are closely related to height and weight. These findings support the notion that the dimensions of the hyoid bone reflect an individual's physical characteristics and can be used as a reference point in forensic examinations.

Previous studies have shown that the length and width of the mandible are greater in males than in females (Kujur *et al*., 2017; Azhari *et al*., 2019). On the other hand, Albalawi *et al*. (2019) reported no significant difference between males and females in the angle measured in the horizontal plane between the gonion and the menton (chin tip) in young adults. In the literature, the mandible angle is measured as the angle between the gonion and the menton. However, since we intended to compare it with the hyoid bone and believed that comparing data measured using the same principle would yield more consistent results, we measured the mandible angle using the same principle we applied for the hyoid bone. Our results demonstrated that the mandible's width, length, and angle are greater in males than in females, and that these parameters are highly positively correlated with those of the hyoid bone. These findings help us to better understand the morphometric relationship between the hyoid bone and the mandible and to elucidate the differences between sexes.

Stature is an important measure of physical identity and is critical in estimating height from body parts in forensic sciences (Pelin *et al*., 2010). Various studies have observed a significant positive correlation between head length and stature, and a regression formula has been derived for estimating height from head length (Mani *et al*., 2019).

Our study also found a positive correlation between the hyoid bone and interparietal and intertemporal distances. This result is consistent with the correlations found between other body parts and height, suggesting that the hyoid bone could be a reliable indicator for height estimation. We believe that this observed positive correlation in our study will provide an important reference point for anatomists, archaeologists, anthropologists, and forensic scientists in the context of height estimation. This finding could be another method for estimating height from incomplete body parts in

forensic medicine. Particularly in cases where limbs are absent, measurements of the hyoid bone may offer a complementary approach to height estimation. The strength of our study lies in evaluating many parameters of the hyoid bone and examining its relationship with mandible, interparietal, and intertemporal width, as well as the individual's height, age, and weight. We believe the comprehensive analysis results will significantly contribute to the literature.

CONCLUSION

In conclusion, the findings of our study have demonstrated a significant relationship between hyoid bone measurements and height estimation. Additionally, the morphometric relationship between the hyoid bone, the mandible, and the cranial bones has been thoroughly examined, revealing differences between sexes. We believe the obtained findings will significantly contribute to forensic science and anthropometry. If future studies with larger sample groups support our findings, the general validity of our conclusions will be enhanced.

Ethical approval. All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Approval for the study was obtained from the Forensic Medicine Institute (21589509/2024/693) and Tokat Gaziosmanpasa University Faculty of Medicine Clinical Research Ethics Committee (83116987/169).

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RESUMEN: Este estudio tiene como objetivo determinar la morfología del hueso hioides en casos de autopsia e investigar su relación con el sexo, la edad, la altura, la longitud mandibular y la longitud craneal, contribuyendo así significativamente a la práctica clínica y la medicina forense. El estudio, realizado en 75 casos de entre 18 y 90 años de edad, remitidos al Instituto de Medicina Forense de Tokat, empleó calibradores digitales de precisión para la medición de la longitud y una báscula digital precisa para el pesaje del hueso hioides. El volumen del hueso hioides se calculó mediante el principio de Arquímedes. Los resultados indicaron que todas las mediciones del hueso hioides fueron significativamente mayores en hombres que en mujeres ($p<0,001$). Se encontraron correlaciones de alto nivel entre las mediciones del hioides y la mandíbula, incluyendo la circunferencia y la anchura ($r>0,800$, $p<0,001$), lo que sugiere una fuerte relación morfométrica entre el hueso hioides y la mandíbula, así como otros parámetros craneales. Se espera que estos hallazgos contribuyan sustancialmente a las ciencias forenses y la antropometría.

PALABRAS CLAVE: Autopsia; Altura; Hueso hioides; Morfometría; Sexo.

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