Original Article

Correlation of hyoid bone morphology with age and sex in forensic identification

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ABSTRACT

The hyoid bone, a solitary U-shaped skeletal feature located in the anterior neck, has increasingly being studied for its forensic value in detecting sex and age. Variations in its morphometric properties and fusion patterns could be useful identification markers in medico-legal investigations. The purpose of this study was to investigate the relationship between chosen morphometric parameters of the hyoid bone, its fusion status, chronological age, and biological sex, and to assess the predictive utility of morphometric variables for sex prediction. A cross-sectional analytical study was conduted on 120 adult hyoid bones (60 males and 60 females) aged 20 to 85 years. Linear morphometric parameters, including body length, grater cornu length, and overall hyoid length were measured. Fusion of the body and grater cornua was classified as unfused, moderately fused, or completely fused. Male hyoid bones exhibited grater mean body and cornu lengths compared to female specimens (p < 0.001). Total body length showed strong sexual dimorphism, with greater mean values in males. Sexes differed in total length. Fusion stauts showed a progressive increase with aging, with greater proportion of fusion was observed after 50 years of age. Logistic regression results showed an overall estimation sex classification accuracy of 87%. Linear morphometric variables showed strong correlation with age, while the fusion status showed a positive association with increasing age. The hyoid bone shows notable morphology variations between sexes and age-related fusion changes. Combined morphometric measurements may serve as useful indicators for sex determination predictors, while fusion evaluation can assist in broad age shopping.

KEYWORDS: Hyoid bone; Sexual dimorphism; Forensic identification; Morphometric parameters.

INTRODUCTION

The hyoid bone is a distinctive U-shaped skeletal structure located in the anterior cervical region at approximately the third and fourth cervical vertebrae. Unlike other bones, it does not directly articulate with adjacent bones, but rather suspended by muscular and ligamentous attachments which facilitate critical physiologic functions like swallowing and phonation. Owing to its anatomic position and relatively resistance to the postmortem degradation, the hyoid bone has gained considerable interest in forensic anthropology, especially in fragmentary or incomplete skeletal remains cases [1].

Determining biological sex represent a critical step in forensic identification. Traditionally, Pelvis and skull provides most reliable indicators in the forensic diagnostics of sex determination however, these asymmetric bones may not always be present. Consequently, smaller and more resilient bones such as hyoid have been increasingly investigated to aid sex estimation. Recent morphometric studies have demonstrated strong sexual dimorphism in hyoid charcterstics with males typically displaying longer body length and second rostral elements (cornua) than females [2,3].

In additional to gender related changes, the hyoid

bone also undergoes morphological changes with aging. Progressive ossification and fusion toward the ultimate union of grater cornua with body increases with age, although the timing and extent of fusion varies by population [4]. Recent imaging technology has seen its greatest advancement, particularly computed tomography (CT) and cone-beam CT (CBCT), have further enhanced accuracy of morphometric measurement and 3D imaging of hyoid morphology with increased reproducibility in the research settings [5,6].

Population heterogeneity is a critical issue in forensic practice. Differences in morphometric means across ethnic groups highlight the importance of establishing region specific reference standards [7]. Recent years have seen the emergence of digital modelling and machine learning paradigms for improving predictive performance, specifically verging towards multivariate frameworks rather than one-off measures evaluation [8]. Nonetheless, there are very few studies that consider age association and sexual dimorphism in the same analytical context. Hence, the present study has been carried out to evaluate i) hyoid bone morphology and its relation with age and sex ii) practical importance of hyoid bone in medicolegal identification.

MATERIALS AND METHODS

This cross-sectional analytical study was conducted to evaluate the relationship of hyoid bone morphometry and demographic parameters relevant to forensic identification. A total of 120 adult hyoid bones (60 male and 60 female) ranging from 20 to 85 years were examined. Demographic information, including age and sex were obtained from recorded documents available at the time of evaluation.

Prior to morphometric assessment, all specimens were inspected for preservation quality and structural integrity. In order maintain consistency and traceability, each bone was assigned a unique identifying code.

Inclusion Criteria: Adults above the age of 20 years, availability of documented biological sex and chronological age, structurally intact hyoid bone with clearly identifiable anatomical landmarks and no obvious abnormalities / deformities that could compromising measuring accuracy.

Exclusion Criteria: Fractures or structural issues with the hyoid bones, pathological, congenital, or severe degenerative changes, and extensive degradation obscures anatomical landmarks were excluded from the study.

Morphometric Measurements

Morphometric measurements were taken with a digital vernier caliper (precision 0.01 mm). To improve reliability each parameter was measured twice by the same observer, and the average values were used for analysis. The criteria measured were maximum body length of hyoid bone, grater cornu length, and combined total length of hyoid bone. In addition to morphometric measurements, the degree of fusion of the body and the grater cornua was assessed. Fusion status was graded as unfused (0), moderately fused (1), or fully fused (2). For analytical purpose, age was divided into four groups (20-34, 35-49, 50-64, and ≥65 years) for comparison purposes.

Statistical Analysis: Descriptive statistics were derived as mean ± SD. Independent sample t-tests were used to investigate sex differences. Pearson's correlation coefficient assessed the correlations between age and continuous morphometric parameters. Using chi-square analysis, the relationship between age groups and fusion status was analysed. The combined morphometric factors were evaluated for sex estimation using logistic regression modelling. Statistical significance was established at $p < 0.05$.

RESULTS

A total of 120 adult hyoid bones were examined, including 60 were male, and 60 were female. The average age in males was 53.08 ± 18.94 years, whereas females had a mean age of 50.77 ± 19.34 years. Age distribution between both sexes was similar, and each age group represented an equitable number across demographic classifications. Significant sexual dimorphism was observed in all parameters of hyoid bone. Males had a mean body length of 40.03 ± 2.93 mm, whereas females had a much shorter average of 36.24 ± 2.98 mm ($p < 0.001$). Similarly, males had a mean grater cornu length of 33.16 ± 2.38 mm, whereas females had 29.09 ± 2.41 mm ($p < 0.001$). Males had considerably longer hyoids (73.19 ± 4.21 mm) compared to females (65.33 ± 4.37 mm) ($p < 0.001$). These data show a consistent and statistically significant increase of all linear dimensions in males (Table 1).

Table 1. Comparison of Hyoid Bone Morphometric Parameters between Males and Females

Parameter (n = 60)	Male	Female	P-Value
Gender	53.08±18.94	50.77±19.34	
Body Length (mm)	40.03 ± 2.93	36.24 ± 2.98	<0.001
Greater Cornu Length (mm)	33.16 ± 2.38	29.09 ± 2.41	<0.001
Total Length (mm)	73.19 ± 4.21	65.33 ± 4.37	<0.001

Pearson correlation analysis was found weak positive relationships between age and assessed morphometric parameters. These low correlation coefficients suggest that the linear dimensions of the hyoid bone. However the liner morphometric dimensions of the hyoid bone show minimal variation with aging (Table 2).

Table 2. Pearson Correlation of Age with Morphometric Variables

Variable	Pearson r with Age
Body Length	0.064
Greater Cornu Length	0.041
Total Length	0.052

A multivariate logistic regression analysis was used to assess the predictive power of combined morphometric factors for sex estimation. When numerous parameters are evaluated together, the results show strong discriminate performance (Table 3).

Table 3. Logistic Regression Performance Metrics

| Metric	Value
Accuracy	0.87
True Negative	12
False Positive	3
False Negative	2
True Positive	13

Assessment of fusion of the hyoid body and grater cornua showed a gradual age-related trend. This pattern shows a distinct transition from unfused to entirely fused states as age increases (Table 4).

Table 4. Fusion Status by Age Group

Age Group	Unfused (0)	Partial (1)	Fused (2)
20–34	18	6	2
35–49	10	8	6
50–64	4	7	15
65+	2	5	17

Overall, the majority of the bones are unfused, followed by fully fused specimens. This representation supports the observation that, whereas fusion rates increase with age, a significant number of specimens remain unfused in the general adult population (fig 1).

Figure 1. Distribution of fusion status in the study population

Overall Fusion Status Distribution

- Unfused (0): 50%
- Partial (1): 14.2%
- Fused (2): 35.8%
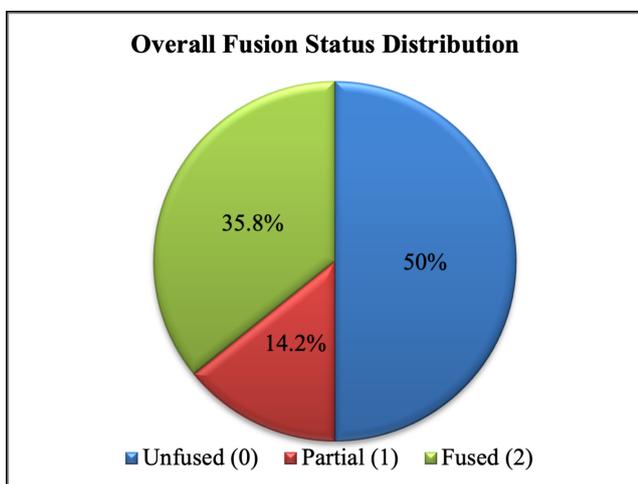
DISCUSSION

This study provides quantifiable evidence for sexual dimorphism in hyoid bone morphometery due to significantly longer body and cornu lengths in male specimens. These findings are in consistent with previous population-based studies that reported parallel sex-related differences in linear dimensions [9, 10]. The magnitude of differences supports a rationale for this application of hyoid measures as an adjunctive method in forensic sexual estimation. Furthermore, the use of multivariate statistical modelling was found to provide better results when compared with using individual parameters. The logistic regression model applied at this study achieved an overall prediction accuracy of 87%, which is comparable with previous findings that reported categorization rates from 75% to 90% [11]. This result highlights the importance of considering morphometric aspects for forensic identification.

Age-related variations in fusion patterns were observed, with higher rates of total or complete zygomatico-maxillary complex fusions observed in older age groups. Similar age-related trends of ossification have been observed on radiological and osteological investigations [12]. However, the variablility exists in the timing and extent of fusion precludes its use for age estimation [13]. Fusion assessment should be seen as a useful signal that categorizes a person within broad age ranges rather than definitive marker of exact age.

Advances in imaging has improved, particularly multidetector CT and CBCT enabling three-dimensional morphometric studies to be more accurate and reproducible [14]. On the other hand, emerging analytical approaches including geometric morphometrics and artificial intelligence-based models have as new tools to achieve accuracy in sex prediction [15, 16]. However, biological variance in populations is still an important limitation, which warrants regional validation of forensic anthropology predictive models [17]. The results of this study support the forensic utility of hyoid morphometry, while emphasize the importance and integrating multiple skeletal indicators is essential for achieve robust and consistent identification outcomes [18].

CONCLUSION

The morphometric study of the hyoid bone shows a pronounced sexual dimorphism, and when using combination characteristics can be a useful predictor of sex. Linear measurements are uncorrelated with chronological age, whereas fusion status presents a gradual age-related pattern that can assist in making broad-age estimations. The hyoid bone is therefore an important supplementary feature in forensic

identification, particularly when the major skeletal markers are not present. Such additional population-based and imaging-supported researches can enhance prediction accuracy with potential for medico-legal application.

CONFLICT OF INTEREST: The authors declare no conflicts of interest.

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