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Variations of the human hyoid bone and its clinical implications

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SUMMARY

The aim was to determine the variations in shape of the human hyoid bone in terms of symmetry, isometry and anisomorphism. These parameters are useful for surgeons and/or forensic anthropologists. Sixty-two human hyoid bones (31 male and 31 female) belonging to the Instituto Anatómico Forense (I.A.F.) of Madrid (Spain) were dissected. The data collected were analysed using the chi-square test.

The specimens were classified into five different patterns: U-shaped (16.7%), open (47.6%), triangular (9.5%), horseshoe-shaped (7.1%) and trapezoidal (19%). Types were distinguished according to the different shapes of the two halves (isomorphic 67.7% and anisomorphic 32.3%), the length of the greater horn (isometric 37% and anisometric 63%), and the transverse distances between the horns (symmetry 24.2% and asymmetry 75.8%). A thorough understanding of these anatomical variations could be useful for clinicians and forensics in interpreting the morphology of the hyoid bone.

Key words: Neck – Larynx – Hyoid muscles – Pharyngeal arches – Hyoid bone

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INTRODUCTION

The hyoid is a U-shaped bone located in the ventral aspect of the neck around the C4 level, ranging topographically from C3 to C5/6 (Standring, 2008; Mirjalili, 2010). It is located between the root of tongue and the thyroid cartilage (Mukhopadhyay, 2010). Some classical anatomy textbooks have described the hyoid bone as symmetric, horseshoe-shaped or U-shaped (Tubbs et al., 2016). Nonetheless, a universally accepted morphological classification for this bone has proven elusive, leading to diverse categorizations in the literature consulted (Leksan et al., 2005).

Despite the absence of such a classification, some authors have attempted to classify the hyoid bone according to its shape (Koebke et al., 1979; Papadopoulos et al., 1989; Pollanen and Chiasson, 1996; Pollanen and Ubelaker, 1997), while others have used precise measurements of the different parts of the bone, with numerical values serving as the main parameter for classification (Miller et al., 1988). These differing methodologies employed reflect the ongoing quest to understand the hyoid bone's morphology.

Furthermore, the anatomical variations of this bone structure have become even more significant due to the emergence of advanced imaging technologies in recent times.

In view of the abovementioned differences in the literature, the aim of our work was to assess the variations in the shape of the hyoid, and to compare the frequencies of certain morphological characteristics in our sample with those in the literature.

MATERIALS AND METHODS

A total of 62 human hyoids from autopsied corpses belonging to the Instituto Anatómico Forense (I.A.F.) de Madrid, Spain, were dissected (31 males and 31 females, ranging from 19 to 91 years of age, mean male 63.5, mean female 72.3 years). Written informed consent was obtained by those donating their bodies to science as required by the scientific institution.

During the dissection, a midline incision was made on the neck from a median point 15 mm below the chin (*mentum*) to the incisura jugularis. The suprahyoid and infrahyoid muscles were dissected and reflected, exposing the front part of the larynx. Subsequently, the hyoid together with the larynx were excised en bloc, removing the supra- and infra-hyoid muscles, pharynx, trachea, oesophagus, and thyroid gland.

Hyoids were fixed in 10% formalin. After removal, the infrahyoid and inferior constrictor muscles, ligaments, membranes, and neurovascular structures were microdissected under a surgical Zeiss-OPM1 microscope at original magnification X4 to X6. Consecutively, the bones were cleaned, first by mechanical dissection and then by maceration for 10 days in 5% sodium hypochlorite (diluted to 50%). Finally, the hyoids were bleached by exposure to sunlight, with or without prior immersion in 110-volume hydrogen peroxide, or by 3% ammonium hydroxide.

The hyoid shapes were classified and independently verified by two experienced anatomists. The chi-square test was used for statistical analysis; $p<0.05$ was considered statistically significant.

Following the identification of patterns and statistical analysis, the results were compared with previously published studies. This led to a new classification system with special reference to clinical practice and usability.

RESULTS

The morphology of the hyoid bone could be classified into five basic patterns. We assigned different names based on the approximate appearances of the forms as drawn (Fig. 1).

Patterns of the hyoid bone

1) **U- shape:** The anterior contour of the bone is semicircular, and its diameter coincides with the distance between the greater horns. The greater horns follow a straight or oblique line in an antero-posterior direction with the form of the letter U. The U-like shape was found in 7/42 (16.7%) of our isomorphic hyoids sample (Table 1) (Figure 1A).

1) **Open:** This has common characteristics with the U-like shape, but the greater horns follow a

Fig. 1.- Basic morphological patterns based on the shape of the whole hyoid bone. This image shows 5 different patterns: **A** (U shape), **B** (Open), **C** (Triangular), **D** (Horseshoe shape) and **E** (Trapezoidal).

Table 1. Incidence of different patterns of the hyoid bones (U shape, open, triangular, horseshoe and trapezoidal) in males and females among isomorphic hyoids. Nº: number of hyoid bones.

SEX	**U shape** Nº %	**Open** Nº %	**Triangular** Nº %	**Horseshoe** Nº %	**Trapezoidal** Nº %
MALE	2 4,8	11 26,2	1 2,4	2 4,7	7 16,7
FEMALE	5 11,9	9 21,4	3 7,1	1 2,4	1 2,3
TOTAL	**7 16,7%**	**20 47,6%**	**4 9,5%**	**3 7,1%**	**8 19%**

medial-lateral oblique direction, diverging from each other to create an open form. The open shape was the most frequent in our isomorphic hyoids sample (20/42, 47.6%) (Table 1) (Fig. 1B).

2) **Triangular:** As its name indicates, this is triangular, its sides being the major horns and its base the largest transverse distance between them. The triangular shape was found in 4/42, 9.5% of our isomorphic hyoids sample (Table 1) (Fig. 1C).

3) **Horseshoe-shape:** The distal-posterior ends of both greater horns are closer together than in the U-shape, so the contour of the bone is more curved and closed. The horseshoe shape was less common in our isomorphic hyoids sample (3/42, 7.1%) (Table 1) (Fig. 1D).

4) **Trapezoidal:** As its name indicates, the ventral contour of the hyoid viewed from a cranio-caudal perspective resembles this sample (8/42, 19%) (Table 1) (Fig. 1E).

Types of the hyoid bone

During this classification of the hyoid, it was observed that the morphological characteristics are not always the same on both sides; the two sides of the same bone could be distinct. We have used the term "type" to refer to the following variations to clarify this new classification:

1) Types based on the different shapes or patterns of the two halves (isomorphy). This could be split into:
   a) Isomorphic, when the two halves follow the same pattern; this was the most frequent type (42/62, 67.7% of the total cases) (Table 2) (Fig. 2A).
   b) Anisomorphic, when the halves follow different patterns (20/62, 32.3%) (Table 2) (Fig. 2B).
2) Types based on the length of greater horn (isometry). The following could be distinguished:
   a) Isometric hyoid, when the tips of both greater cornua fell on the same horizontal line (23/62, 37%) (Table 3) (Fig. 2 A).

Table 2. Incidence of types based on the different shapes of the two halves, distinguishing isomorphic and anisomorphic hyoid bones.

SEX	**ISOMORPHIC** Nº %	**ANISOMORPHIC** Nº %	**TOTAL** N %
MALE	**23 37.1** (74,2)	**8 12,9** (25,8)	**31 50**
FEMALE	**19 30.6 (**61,3)	**12 19,4** (38,7)	**31 50**
TOTAL	**42 67,7%**	**20 32,3**	**62 100**

b) Anisometric hyoid, when the tips of both greater cornua did not coincide on the same axis; this was the most frequent type (39/62, 63% of the total cases) (Table 3) (Fig. 2 B).

3) Types based on the transverse distances between the greater horns (symmetry):

a) Symmetric, when the middles of all the transverse diameters fell on the sagittal axis (15/62, 24.2%) (Table 4) (Fig. 3A).

b) Asymmetric, when the middles of all the transverse diameters did not fall on the sagittal axis; this was the most frequent type (47/62, 75.8% of the total cases) (Table 4) (Fig. 3B).

According to this classification, the most common hyoid bone morphology in our sample was isomorphic, asymmetric, and anisometric (32.25%). Considering these three characteristics, only 14.52% of our sample were simultaneously isomorphic, iso-

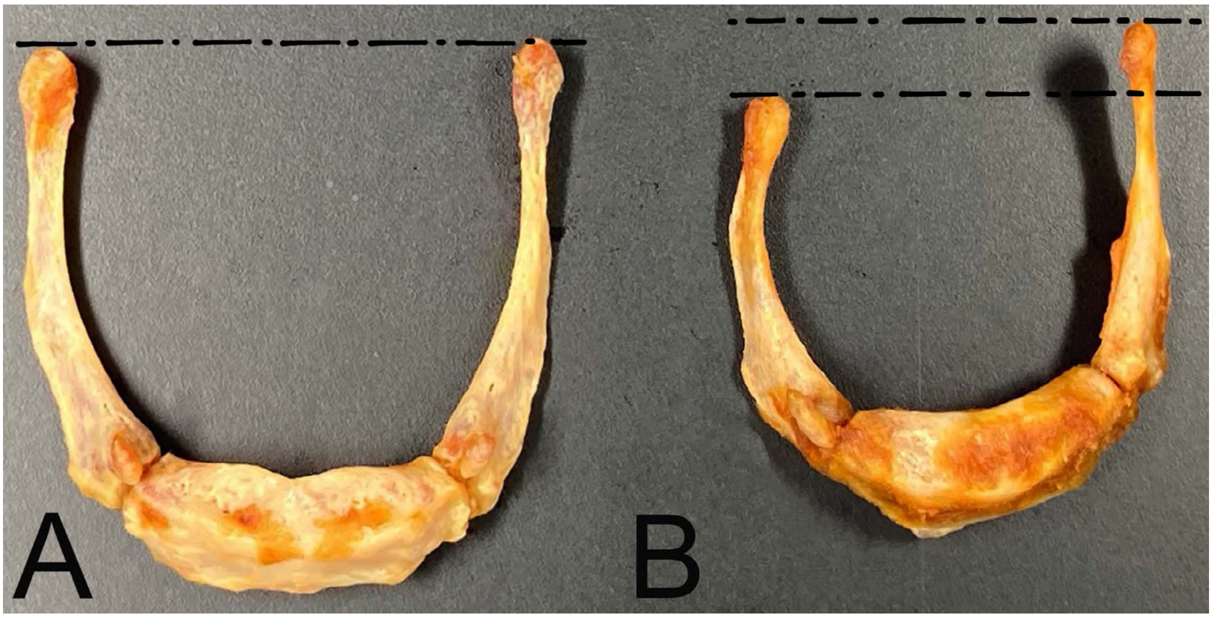

Fig. 2.- Hyoid types based on the morphology of the two halves and the different lengths of the greater horn. According to the morphology of the two halves, the hyoid bone could be divided into isomorphic (**A**) and anisomorphic (**B**). Fig. 2B corresponds to a right Horseshoe shape and left U shape. According to the different lengths of the greater horn of the hyoid bone, it could be divided into isometric (**A**) and anisometric (**B**). The lines show the similar (**A**) or different lengths (**B**). Fig. 2A corresponds to the hyoid bone of the fig. 1A.

Table 3. Incidence of types based on the length of greater horn, distinguishing isometric and anisometric hyoid bones.

SEX	ISOMETRIC Nº %	ANISOMETRIC Nº %	TOTAL Nº %
MALE	**9 14,5** (29)	**22 35,5** (71)	**31 50**
FEMALE	**14 22,5** (45,2)	**17 27,5** (54,8)	**31 50**
TOTAL	**23 37**	**39 63**	**62 100**

Table 4. Incidence of types based on the transverse distances between the greater horns, distinguishing symmetric and asymmetric hyoid bones.

SEX	SYMMETRIC Nº %	ASYMMETRIC Nº %	TOTAL Nº %
MALE	**8 12,9** (25,8)	**23 37,1** (74,2)	**31 50**
FEMALE	**7 11,3** (22,6)	**24 38,7** (77,4)	**31 50**
TOTAL	**15 24,2**	**47 75,8**	**62 100**

Fig. 3.- Hyoid types based on the distances between the greater horns of the two halves of the hyoid bone. It could be divided into symmetric (**A**) and asymmetric (**B**). In the asymmetric hyoid (Fig. 3B) the numbers 1 and 2 represent the different transverse distances, 1 longer than 2. Fig. 3A corresponds to the hyoid bone of the fig. 1A.

metric, and symmetric. Therefore, one side of the hyoid bone differed from the other in at least one characteristic in most of our sample (85.48%).

DISCUSSION

For clarity, we have divided the discussion in the same sections as the results (patterns of the hyoid bone, and types of the hyoid bone divided into three characteristics).

Patterns of the hyoid bone

Our results are quite like those of Papadopoulos et al. in relation to the U-shape (16.7% and 18.4% respectively), but there is no coincidence in the open shape (47.6% and 26.3%, respectively), which is the most frequent pattern in our series, as in the other authors presented in Table 5 (Papadopoulos et al., 1989).

Also, the frequency of the horseshoe shape in our sample (7.1%) does not coincide with that of Papadopoulos et al. (1989) (21.1%).

The frequency of the trapezoidal shape is the same in the Stosić-Domnić et al. (1973) series (19%) and ours (19%). This morphological type has not been described by other authors in the literature consulted, apart from Stosić-Domnić et al. (1973) (Table 5).

Most of articles do not specify the type of population used in their studies, but only the country to which the study belongs. This lack of information results in a huge variability in the populations studied across the different countries, as shown in Table 5. Therefore, it is difficult to compare the results of the present studies in terms of population (Table 5) (Stosić-Domnić et al., 1973; Koebke et al., 1979; Papadopoulos et al., 1989; Pollanen and Ubelaker, 1997).

Table 5. Comparison of present work with previous studies regarding the pattern or shape of the hyoid bones.

PATTERN OR SHAPE	Stosić-Domnić et al. 1973	Koebke and Saternus, 1979	Papadopoulos et al. 1989	Pollanen and Ubelaker 1997	Present work, 2022
Population	Croatia	Germany	Greece	United States	Spain
U shape	30.5%	35%	18.4%	55%	16,7%
Open	50.5%	41%	26.3%	45%	47,6%
Triangular	---	---	5.3%.	---	9,5%
Horseshoe	---	13%	21,1%	---	7,1%
Trapezoidal	19%	---	---	---	19,0%

Types of the hyoid bone

1) Types distinguished by the shapes or patterns of the two halves (isomorphic and anisomorphic):

Our anisomorphic hyoid was found in 32.3% (12.9% in males and 19.4% in females), comparable with the D-type of Papadopoulos et al. (1989) (28.3%), or to the asymmetrical type of Koebke and Saternus (1979) (11%). Although anisomorphic hyoids are more frequent (32.3%) in our sample than in the works of Papadopoulos et al. and Koebke and Saternus, we agree with Koebke and Saternus (1979) that the combination of open shape and U-shape (defined as B and U types) was the most frequent mixed form.

2) Types based on the length of greater horn (isometry):

Morphological anisometry was not mentioned in the literature until the study by Papadopoulos et al. (1989), which showed that 59.3% of the hyoids were anisometric (26.3% male, 23% female). In our total sample, anisometry (62.9%) predominated over isometry, as Papadopoulos et al. found in 1989.

In the work of Papadopoulos et al. (1989), the χ^2 test showed no significant sex difference in anisometry (52.6% male and 47.4% female) ($P > 0.1$), the distribution being similar. In our sample, there were more anisometric (71%) than isometric (29%) hyoids in males, while the proportions were more nearly equal in females. In the total of isometric hyoids, the females had the highest frequency (60.9%). In the work of Papadopoulos et al. (1989), the percentages of anisometric hyoids were closely similar in males and females; in our study, there was a higher percentage of anisometry in males, and similar percentages of isometry and anisometry in females. However, as in Papadopoulos et al., analysis of the relevant percentage difference (Fisher's exact statistic) could not establish sexual dimorphism in relation to the morphological trait anisometry. In terms of clinical significance, our data concerning hyoid types based on the length of the greater horn (isometry or anisometry) could be related to the clicking larynx, which could be caused by an enlarged greater horn of the hyoid bone (hyoid syndrome) (Heuveling et al., 2018).

3) Types based on the transverse distances between the greater horns (symmetry):

Although in some classical treatises on Human Anatomy (Testut, 1986; Paturet, 1951; Bouchet and Cuilleret, 1979) the hyoid is described as a symmetrical bone, Papadopoulos et al. (1989) found asymmetry in 47.4% of cases (26.3% in males and 21.1% in females). In his work, the χ^2 test showed no significant sex difference in asymmetry; 52.6% of male and 42.1% of female bones were asymmetric ($P > 0.1$). However, in our study, asymmetrical hyoids predominated (75.8%: 37.1% male and 38.7% female). Asymmetry predominated both in males (74.2%) and, with a slightly higher percentage, in females (77.4%). In the asymmetrical hyoids there was no clear sex predominance (48.9% were male and the remaining 51.1% female).

According to the relevant analysis of the percentage difference, there was no dimorphism in relation to the morphological trait asymmetry.

Pollanen and Chiasson (1996) mentioned that one anatomical feature that could be relevant in assessing hyoid fractures in cases of strangulation is the asymmetry of the greater horns, since asymmetric hyoids could be more susceptible to fracture if the compressive forces are distributed preferentially over one horn. Kasprzak et al. (1993) found by interferometric analysis of the hyoid under tension that asymmetry could be important in the site of fracturing: the deformation forces inferred from this method were not uniformly distributed over the hyoid. From a clinical point of view, this hyoid asymmetry could be related to asymmetry in the functional activity of the muscles that insert into it and therefore related to activities such as articulation of sounds, swallowing or mastication (Urbanová et al., 2014; Hong et al., 2017).

Ethical approval details

The individuals had given their written informed consent for their use for scientific purpose prior to death. According to National Law, scientific institutions (in general Institutes, Departments or Divisions of Medical Universities) are entitled to receive the body after death mainly by means of a specific legacy, which is a special form of last will and testament. No bequests are accepted without the donor having registered their legacy and been given appropriate information upon which to make a decision based upon written informed consent (policy of ethics); therefore, an ethics committee approval was not necessary (Konschake et al., 2014).

Author's contribution

HL, QS, KM, TRS, OL, SA, SJ, ME did substantial contributions to the conception and design of the work, the acquisition, analysis, and interpretation of data for the work; also to drafting the work and revising it critically for important intellectual content; KM and SJ did a final approval of the version to be published; also an agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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