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Three-dimensional characterization of zygomatic arch morphology and its relation to the articular eminence in a Brazilian population

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SUMMARY

Zygomatic arch and articular eminence are structures from the human skull involved in jaw muscle activity. The aim of the study was to evaluate three-dimensional morphological patterns of the zygomatic arch and its relationships with articular eminence in a Brazilian population. 122 computed tomography scans of human skulls were evaluated. The Mimics 18.0 software (Materialise, NV, Belgium) was used to perform segmentation of images from CT scans. 3D reconstructions of CT scans were imported into Rhinoceros 5.0 software (McNeel & Associates, Seattle, USA), in which linear measurements (mm) were obtained. Statistical analysis was performed in GraphPAD Prism v.8 (San Diego, CA, USA). The normality of the sample was checked by Shapiro-Wilks and significance level of 5% was considered. Based on cross-sectional area classification, out of 116 male zygomatic arches the incidence was 59% of type elliptical (E) and 41% of type blade-like (Bl). Out of 102 female zygomatic arches the incidence was 38% of type E and 62% of type Bl. There was no incidence of type cylindrical (C). Based on the classification proposed in the present study, the incidence for males was 58% of type parentheses (P), 38% of type bracket (B) and 4% of type M-shaped (M); and the incidence for females was 33% (type P), 66% (type B) and 1% (type M). The elliptical and convex body of the zygomatic arch prevailed in males and the blade-like and straight body of the zygomatic arch prevailed in females. There is no relationship between zygomatic arch type and zygomatic arch and articular eminence distances.

Key words: Anatomy – Skull – Temporomandibular joint – Tomography – Zygoma

INTRODUCTION

The zygomatic arch (ZA) is an anatomical structure originating from the union between the zy-

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gomatic process of the temporal bone and the temporal process of the zygomatic bone (Smith and Grosse, 2016). The ZA is known to be the anatomical structure that joins the viscerocranium to the neurocranium (Franks et al., 2016). It is tenuous, elongated and is the site where the masseter muscle has its origin. Because it is a salient bilateral structure, the ZA is susceptible to several types of traumas (Song et al., 2009), such as isolated fractures or being a part of multiple facial fractures (Valdés and Zapata, 2021; Jones and Schmalbach, 2022; Estawrow and Elbarbary, 2022).

In the temporal bone, it arises from a triangular base, extends through the zygomatic process of the temporal bone to the region where the temporal and zygomatic bones communicate, the zygomaticotemporal suture, and then it crosses to articulate with the zygomatic bone through the temporal process of the zygomatic bone. Finally, the body of this last bone delimits the extension of the arch (Testut and Latarjet, 1954).

Adjacent to the ZA, in its part of the zygomatic process of the temporal bone, is the articular eminence (AE), part of the skeletal structures of the temporomandibular joint (TMJ). It consists of dense bone tissue that supports the load of forces that affect this region of the skull base from mandibular movements. The inferior surface of the temporal bone articulates with the mandible. In its lateral part, it is elevated and forms the articular tubercle, which can be also considered the medial root of the ZA (Sicher and Du Brul, 1980).

There are many works involving traumas that occurred in the ZA region (Song et al., 2009; Jones and Schmalbach, 2022), but few characterize its morphology. Examples that perform its local analysis are related to cephalometric measurements (Park et al., 2019) and regarding shape and biomechanics the studies are usually related to species of animals other than humans, such as chimpanzees (Smith and Grosse, 2016).

The shape of the ZA in mammals is quite variable. In a cross-section of this anatomical accident, cylindrical, elliptical and blade-like shapes can be observed. Smith and Grosse (2016) used three types of ZA in their study: cylindrical, elliptical and blade-like. They concluded that there are local effects on the magnitude of the tension force in the ZA caused by its morphological changes.

Certain parameters of masticatory muscles function have been shown to be associated with facial morphology, including electromyographic activity and occlusal force. The cross- sectional areas of these masticatory muscles can also correlate with the corresponding cross- sections of adjacent structures (Righetti et al., 2020), as has already been studied in the mandible through computed tomography (CT) scans, magnetic resonance imaging and ultrasound (Benington et al., 1999; Palinkas et al., 2019). This highlights the importance of studying biomechanical effects on anatomical structures by considering the full set of information, not just isolated structures, to understand craniofacial dynamics (Smith and Grosse, 2016).

The AE, as well as the mandibular fossa and the mandible condyle, undergoes bone remodeling during life (Kranjčić et al., 2016). Studies of the morphological relationship between the AE and the ZA are scarce in the literature. Therefore, considering the topographic relationships of proximity between the ZA and the AE and the mechanical relationships between the activity of the masseter muscle (a mandibular elevator) associated with the mandibular movements provided by the TMJ, the present study suggests the hypothesis that the variations in the shape of the ZA are associated with the variations of the AE. Thus, characterizing the morphology of the ZA and the AE helps to understand biomechanical aspects and guide clinical planning and treatment. So, the aim of this study was to evaluate the three-dimensional morphological patterns of the ZA, as well as the relationships between the morphology of the ZA and the AE in a Brazilian population.

MATERIALS AND METHODS

Ethics approval

The research was analyzed and approved by the Committee of Research Ethics of the University of Campinas (Protocol number CAAE 58958122.7.0000.5418).

Sample

The CT scans belong to an identified osteological collection (contemporary Southeast Brazilian population) of dry human skulls belonging to the Biobank “Prof. Dr. Eduardo Daruge” of Piracicaba Dental School - University of Campinas. The tomographic images were obtained in an Aisteion Multislice 4 CT System device (Toshiba Medical Systems Corporation – Japan), for the skull protocol: 100 mA, 120kV, with 1mm slices.

A total of 122 CT scans of human skulls of both sexes (66 male and 56 female) and both sides (right and left) were evaluated. The age group ranged from 18 to 80 years old, with a mean age of 59.42 years old (standard deviation: 16.71).

For the inclusion criteria of sample, CT scans of dry, intact skulls without fractures or any other macroscopic pathological or surgical alteration were included. The CT scans of skulls with fractures, bone destruction or any other macroscopic pathological or surgical alteration were excluded.

Processing of tomographic images

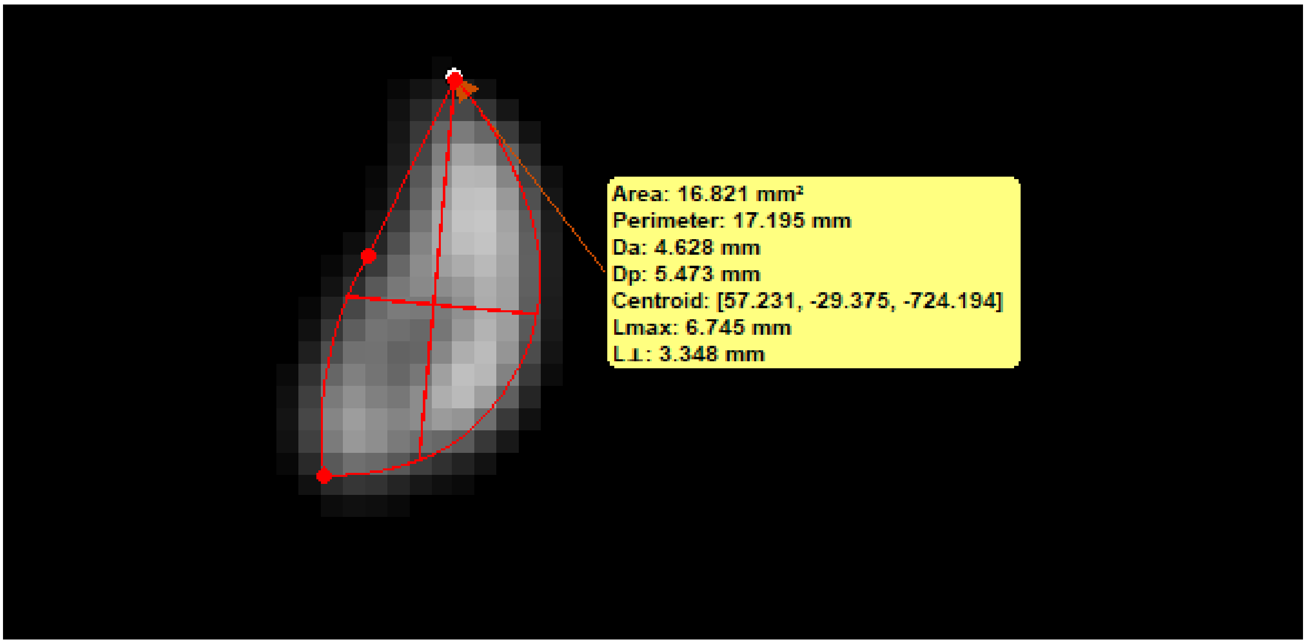
The Mimics 18.0 software (Materialise, NV, Belgium) was used to perform the segmentation of the images of each CT scan. Segmentation consisted of selecting pixels of the bone structure in each tomographic section. This selection was defined by evaluating a threshold of gray scale values to obtain voxels, whose values are in a range according to the bone components of interest. The 3D reconstruction was performed to enable the visualization of these components and each three-dimensional surface was exported in virtual stereolithography (STL) to perform the surface evaluation.

Morphometric analysis on CT scans of dry skulls

The 3D reconstructions of the CT scans were imported into the Rhinoceros 5.0 software (McNeel & Associates, Seattle, USA), in which linear measurements (mm) were obtained for evaluation and morphological characterization of the ZA and AE on both sides (right and left). The values obtained by the software were tabulated for statistical analysis.

The measurements were obtained, in millimeters, regarding the vertical and horizontal diameter of the ZA and the AE distance using the Mimics 18.0 software (Materialise, NV, Belgium) and regarding the ZA distance using the Rhinoceros 5.0 software (McNeel & Associates, Seattle, USA).

To obtain the measurements of the vertical and horizontal diameter of the ZA, it was necessary



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Area: 16.821 mm²
Perimeter: 17.195 mm
Da: 4.628 mm
Dp: 5.473 mm
Centroid: [57.231, -29.375, -724.194]
Lmax: 6.745 mm
L⊥: 3.348 mm
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Fig. 1.- Measurement of the cross-sectional area of the ZA provided by the Mimics 18.0 software (Materialise, NV, Belgium) in a computed tomography scan. Lmax: vertical diameter (maximum diameter passing through the central point of the chosen cross-sectional area), L⊥: horizontal diameter (minimum diameter orthogonal to Lmax).

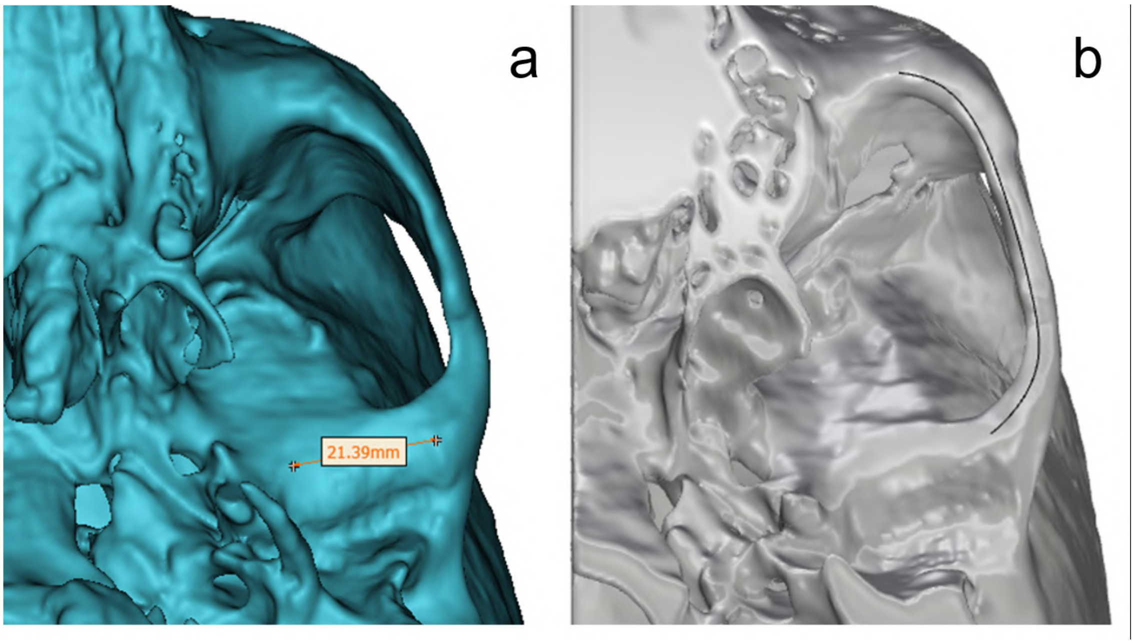

Fig. 2.- Images referring to the acquisition of measurements in 3D models. **a:** measurement of the AE distance, **b:** measurement of the ZA distance.

to define the cross-sectional area for its measurement. It was defined by choosing the lowest point in the region of the zygomaticotemporal suture.

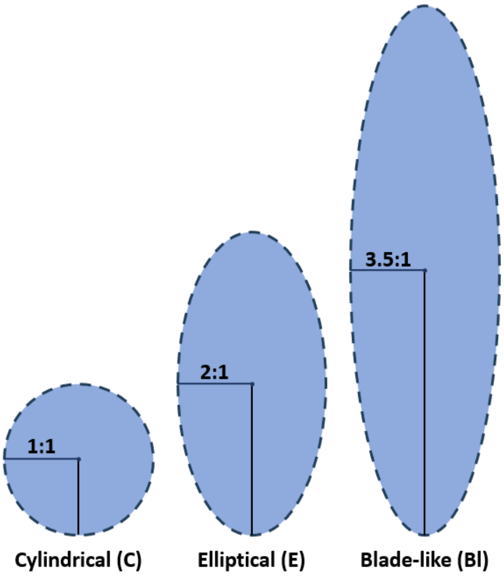

Fig. 3.- Cross-sectional classification of ZA by Smith and Grosse (2016). The shapes of the image represent the types with their respective proportions: Cylindrical (1:1), Elliptical (2:1) and Blade-like (3.5:1). To classify the sample of the present study, it was necessary to calculate the proportion between the maximum diameter, in milimeters, passing through the central point of the chosen cross-sectional area and the minimum diameter, in milimeters, orthogonal to it. With the resulting ratio, each cross-sectional area of zygomatic arch was classified according to the proximity with Cylindrical, Elliptical or Blade-like ratios. Image adapted from Smith and Grosse (2016).

The vertical diameter of the ZA was defined as the maximum diameter passing through the central point of the chosen cross-sectional area, and the horizontal diameter as the minimum diameter orthogonal to the maximum diameter obtained (Fig. 1).

The AE distance (Fig. 2) consists of the length from its lateral end to its medial end in an inferior view of the skull. The lateral end is the region of volume increase of the inferior and posterior part of the ZA, also known as the articular tubercle. The medial end is the region of articulation (sphenosquamous suture) of the temporal bone with the sphenoid bone closest to the axis of the LA.

The ZA distance (Fig. 2) consists of the length from its anterior end to its posterior end in an inferior view of the skull, the anterior end being the region close to the lowest point of the zygomaticomaxillary suture and the posterior end being the region closest and lateral to the articular tubercle.

Classification of the zygomatic arch regarding its cross-sectional area

Measurements of the vertical and horizontal diameter of the ZA were used to classify the ZAs according to the study by Smith and Grosse

(2016) (Fig. 3), in which the authors characterized three types of ZA: cylindrical (cylindrical, C), elliptical (elliptical, E) and blade- like (blade-like, Bl) with proportions of 1:1; 2:1 and 3.5:1 of the vertical and horizontal radius of the cross-sectional area of the ZA, respectively.

To classify the ZAs in the sample, the proportion between the vertical diameter and the horizontal diameter was calculated, and then the classification was made according to the closest proximity of the value obtained to the proportions of each type. In the present study, there was no incidence of morphological type C, so a classification of two morphological types (E and Bl) was considered.

Classification of the zygomatic arch regarding its morphology

In the Rhinoceros 5.0 software (McNeel & Associates, Seattle, USA), a linear representation of the ZA was drawn on each CT scan considering the anteroposterior morphology in an inferior view of the skull. Analyzing the linear shape obtained and the 3D reconstruction of each ZA, the classification according to the ZA morphology was obtained, consisting of parentheses (parentheses, P), bracket (bracket, B), and M-shaped (M-shaped, M) (Fig. 4). Silhouettes obtained from ZAs with a milder degree of curvature at the beginning and end (greater than 90°) and a body close to a convex aspect were classified as parentheses; silhouettes obtained from ZAs with a more accentuated degree of curvature at the beginning and end (near or less than 90º) and a body similar to a straight line were classified as bracket; finally, silhouettes obtained from ZAs with part of the body directed medially to the infratemporal fossa, regardless of the degree of curvature at its beginning and end, were classified as M-shaped.

Data analysis

After collecting all the data, they were tabulated in the Microsoft Office Excel® package. Statistical analysis was performed using GraphPAD Prism v.8 software (San Diego, CA, USA). The normality of the sample was checked by Shapiro-Wilks. Descriptive statistics were performed for each measurement in each sex and type. Measures of the morphological types of evaluated anatomical structures (ZA and AE) were compared using the Mann-Whitney test. For the classification with two morphological types, the Mann-Whitney test was also performed. For the classification with three morphological types, the Kruskal-Wallis test with multiple comparisons by Dunn's test was used. The Two-way ANOVA test was performed, with multiple comparisons by Sidak's test, in each measure evaluated to verify the relationship between sexes and the types found in each side. In all analyses, a significance level of 5% was considered.

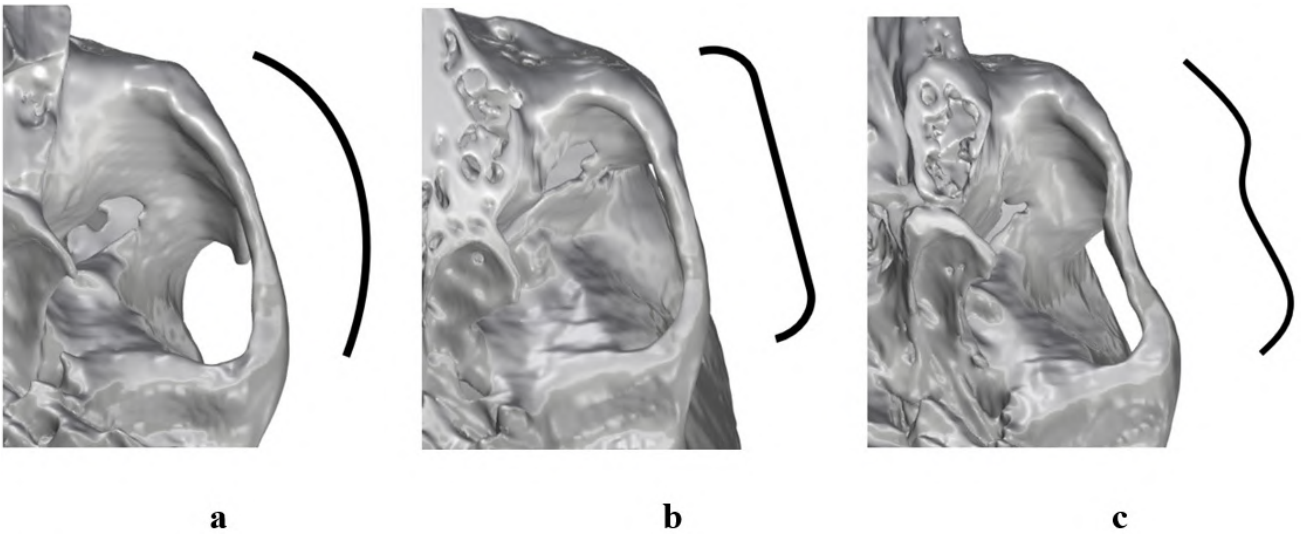

Fig. 4.- Representative images of the types of ZA regarding the anteroposterior morphology in inferior view. **a:** Parentheses type (P), **b:** Bracket type (B), **c:** M-shaped type (M).

RESULTS

Of the 122 CT scans evaluated, 110 CT scans were used to study the morphology of the ZA and AE, 52 (47%) of which were female and 58 (53%) were male. Sides of 2 CT scans (one on the left and one on the right) that showed variation in the morphology of the mandibular fossa with a bone opening in its concavity were excluded.

It was possible to classify the ZAs according to the method by Smith and Grosse (2016) with the results obtained from measuring the cross-sectional area. In the analysis in question, there was no incidence of the cylindrical type in the studied sample.

Of the 116 male ZAs, the incidence was 59% of type E and 41% of type Bl. Of the 102 female ZAs, the incidence was 38% of type E and 62% of type Bl. There was no incidence of type C in both sexes. The incidence of each type can be seen in Fig. 5.

After measuring the ZA distance, its silhouette and its 3D reconstruction were analyzed and then classified according to the method proposed in the present study. The incidence of each type can be seen in Fig. 6.

Based on the method proposed in the present study, the incidence for males was 58% (type P), 38% (type B) and 4% (type M); and the incidence for females was 66% (type B), 33% (type P) and 1% (type M).

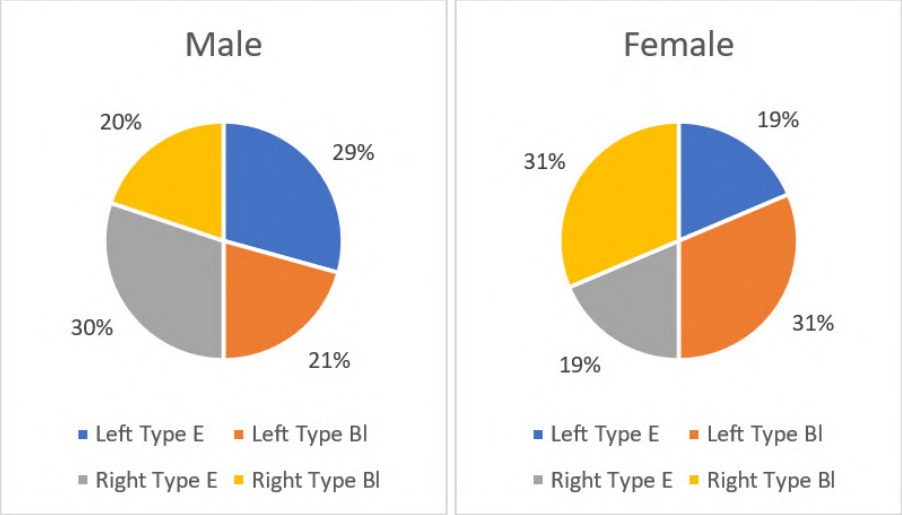

Fig. 5.- Incidence of types of ZA according to Smith and Grosse (2016) by sex. E: Elliptical type, Bl: Blade-like type.

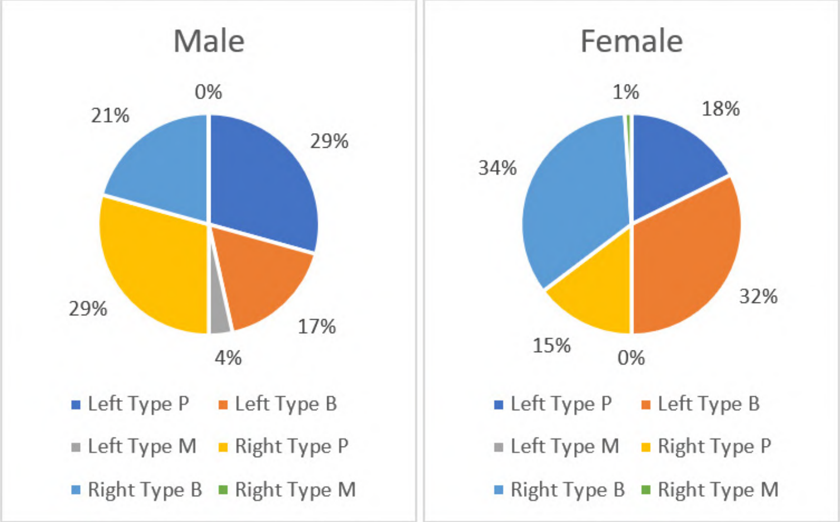

Fig. 6.- Incidence of types of ZA according to the method proposed by the present study by sex. P: Parentheses type, B: Bracket type, M: M-shaped type.

Zygomatic Arch Distance

For type E of ZA, the Median distance was 53.02 mm on the left side and 52.62 mm on the right side. For type Bl of ZA, the Median distance was 51.53 mm on the left side and 52.83 mm on the right side (Table 1). On both sides (left and right), when comparing measurements of morphological types E and Bl (Mann-Whitney test), no significant differences were found (left side P = 0.0628; right side P = 0.9171) (Table 1).

For type P of ZA, the Median distance was 51.81 mm on the left side and 51.51 mm on the right side. For type B of ZA, the Median distance was 52.14 mm on the left side and 52.99 mm on the right side. For type M of ZA, the Median distance was 58.73 mm on the left side and 58.25 mm on the right side (Table 2). When comparing the measures of the morphological types P, B and M (Kruskal-Wallis test), significant differences were found for the left side (P= 0.0310) while for the right side no differences were detected. Multiple comparisons by Dunn's test performed between the means of each morphological type on each side showed significant differences on the left side when comparing type P vs type M (P= 0.0456) and B vs M (P= 0.0252). For the other comparisons, there were no significant differences (Table 2).

For the classification of two morphological types, to assess the difference between the sexes within the same type, for the left side, the Two-way ANOVA test showed a significant difference when comparing the ZA distance between males and females (P = 0.0002), while, when comparing the morphological types E and Bl within the same sex, significant differences were not detected (P = 0.4469). Multiple comparisons by the Sidak test performed in both sexes between the means of each type showed significant differences when comparing type E between sexes (P = 0.0132) and type Bl between sexes (P = 0.0148). Thus, there was a tendency for the ZA distance to be greater in males than in females in both morphological types (Fig. 7). For the right side, the Two-way ANOVA test showed a significant difference when comparing the ZA distance between males and females (P = 0.0009), while, when comparing the morphological types E and Bl within the same sex, significant differences were not detected (P = 0.5108). Multiple comparisons by the Sidak test performed in both sexes between the means of each type showed significant differences when comparing type Bl between sexes (P = 0.0025). Thus, on the right side, the ZA distance is greater in males than in females in Bl morphological type (Fig. 7).

For the classification of three morphological types, to assess the difference between the sexes within the same type, for the left side, the Two-way ANOVA test showed a significant difference when comparing the ZA distance between males and females (P = 0.0004), while, when comparing the morphological types P and B within the same sex, significant differences were not detected (P = 0.6633). The morphological type M was not included in the comparisons, as it was not found in the evaluated sample. Multiple comparisons by the Sidak test performed in both sexes between the means of each type showed significant differences when comparing type P between sexes (P = 0.0186) and type B between sexes (P = 0.0240). Thus, there was a tendency for the ZA distance to be greater in males than in females in both morphological types (Fig. 8). For the right side, the Two-way ANOVA test showed a significant difference when comparing the ZA distance between males and females (P = 0.0001), while, when comparing the morphological types P and B within the same sex, significant differences were not detected (P = 0.1206). The morphological type M was not included in the comparisons, as it was not found in the evaluated sample. Multiple comparisons by the Sidak test performed in both sexes between the means of each type showed significant differences when comparing type P between sexes (P = 0.0067) and between types B (male) and P (female) (P = 0.0053) (Fig. 8).

Articular Eminence Distance

For type E of AE, the Median distance was 16.88 mm on the left side and 17.30 mm on the right side. For type Bl of AE, the Median distance was 16.88 mm on the left side, and 17.18 mm on the right side (Table 1). On both sides (right and left), when comparing measurements of morphological types E and Bl (Mann-Whitney test), no significant differences were found (left side P = 0.9362; right side P = 0.5449) (Table 1).

Table 1. Means, standard deviations (SD), quartiles and medians (in millimeters) of zygomatic arch distance and articular eminence distance per side in each category of two morphological types of zygomatic arch.

Measurement	**Ea (mm)**						**Bla (mm)**					
Zygomatic arch distance	Mean (SD)	Minimum	25% Percentile	Median	75% Percentile	Maximum	Mean (SD)	Minimum	25% Percentile	Median	75% Percentile	Maximum
Left	52.90 (4.472)	43.53	50.57	53.02	56.51	61.89	51.55 (4.550)	44.45	48.14	51.53	54.18	64.49
Right	52.28 (3.664)	43.37	49.78	52.62	54.43	59.79	52.26 (4.417)	44.78	49.29	52.83	55.23	63.37
Articular eminence distance												
Left	17.02 (1.971)	12.46	15.90	16.88	18.62	21.55	17.06 (2.198)	12.87	15.88	16.88	18.07	23.12
Right	17.63 (2.409)	13.82	15.60	17.30	18.95	24.56	17.24 (2.248)	12.02	15.52	17.18	18.81	22.18

[a] E: Elliptical type of zygomatic arch; Bl: Blade-like type of zygomatic arch.

Table 2. Means, standard deviations (SD), quartiles and medians (in millimeters) of zygomatic arch distance and articular eminence distance per side in each category of three morphological types of zygomatic arch.

Measurement	**Ea (mm)**						**Bla (mm)**						**M[b] (mm)**					
Zygomatic arch distance	Mean (SD)	Minimum	25% Percentile	Median	75% Percentile	Maximum	Mean (SD)	Minimum	25% Percentile	Median	75% Percentile	Maximum	Mean (SD)	Minimum	25% Percentile	Median	75% Percentile	Maximum
Left	52.21 (4.699)*	44.07	48.52	51.81	55.00	64.49	51.71 (4.077)*	43.53	48.78	52.14	54.61	61.18	58.80 (4.087)*	53.89	54.99	58.73	62.69	63.86
Right	52.10 (4.554)	44.35	48.26	51.51	55.34	63.37	52.31 (3.553)	43.37	50.14	52.99	54.32	60.80	58.25 (0.000)	58.25	58.25	58.25	58.25	58.25
Articular eminence distance																		
Left	17.30 (2.176)	12.46	16.01	17.23	18.53	23.12	16.65 (1.947)*	12.87	15.33	16.55	17.38	22.05	18.84 (1.197)*	17.49	17.71	18.78	20.02	20.30
Right	17.58 (2.569)	12.02	15.55	17.48	18.90	24.56	17.27 (2.113)	13.22	15.60	17.16	18.81	22.24	19.99 (0.000)	19.99	19.99	19.99	19.99	19.99

* Statistical difference between types.

b P: Parentheses type of zygomatic arch; B: Bracket type of zygomatic arch; M: M-shaped type of zygomatic arch.

For type P of AE, the Median distance was 17.23 mm on the left side and 17.48 mm on the right side. For type B of AE, the Median distance was 16.55 mm on the left side and 17.16 mm on the right side. For type M of AE, the Median distance was 18.78 mm on the left side and 19.99 mm on the right side (Table 2). When comparing the measures of the morphological types P, B and M (Kruskal-Wallis test), significant differences were found for the left side (P = 0.0153), while for the right side no differences were detected. Multiple comparisons by Dunn's test performed between the means of each morphological type on each side showed significant differences on the left side when comparing type B vs. M (P= 0.0408). For the other comparisons, there were no significant differences (Table 2).

For the classification of two morphological types, to assess the difference between the sexes within the same type, for the left side, the Two-way ANOVA test showed that there was no significant difference when comparing the AE distance between males and females (P= 0.4707), nor when comparing the morphological types E and Bl within the same sex (P = 0.8098). The multiple comparisons by the Sidak test performed

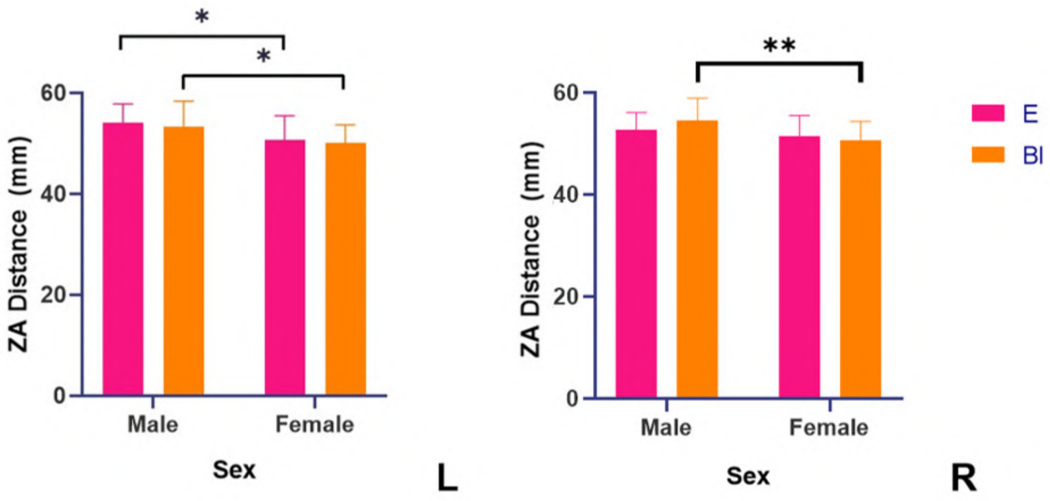

Fig. 7.- Mean ZA distance (mm) by sex in each morphological type (E and Bl). For the left side: type E – male versus female: P = 0.0132; type Bl – male versus female: P = 0.0148. For the right side: type Bl – male versus female: P = 0.0025. * and ** Statistical difference between sexes.

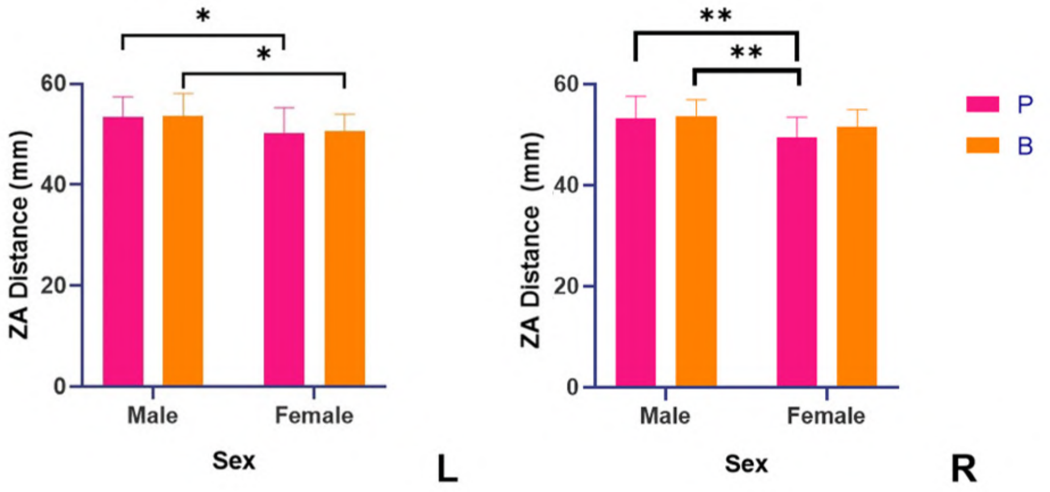

Fig. 8.- Mean ZA distance (mm) by sex in each morphological type (P and B). For the left side: type P – male versus female: P = 0.0186; type B – male versus female: P = 0.0240. For the right side: type P – male versus female: P = 0.0067; type B – male versus type P – female: P = 0.0053. * and ** Statistical difference between sexes.

in both sexes between the means of each type showed that there were no significant differences when comparing type E between sexes (P = 0.8281) and type Bl between sexes (P = 0 .8674) (Fig. 9). For the right side, the Two-way ANOVA test showed that there was no significant difference when comparing the AE distance between males and females (P= 0.5044), nor when comparing the morphological types E and Bl within the same sex (P = 0.3020). The multiple comparisons by the Sidak test performed in both sexes between the means of each type showed that there were no significant differences when comparing type E between sexes (P=0.9587) and type Bl between sexes (P> 0.9999) (Fig. 9).

For the classification of three morphological types, to assess the difference between the sexes within the same type, for the left side, the Two-way ANOVA test showed that there was no significant difference when comparing the AE distance between males and females (P = 0.9436), nor when comparing the morphological types P and B within the same sex (P = 0.1164). The morphological type M was not included in the comparisons, as it was not found in the evaluated sample. The multiple comparisons by the Sidak test performed in both sexes between the means of each type showed that there were no significant differences when comparing type P between sexes (P = 0.9059) and type B between

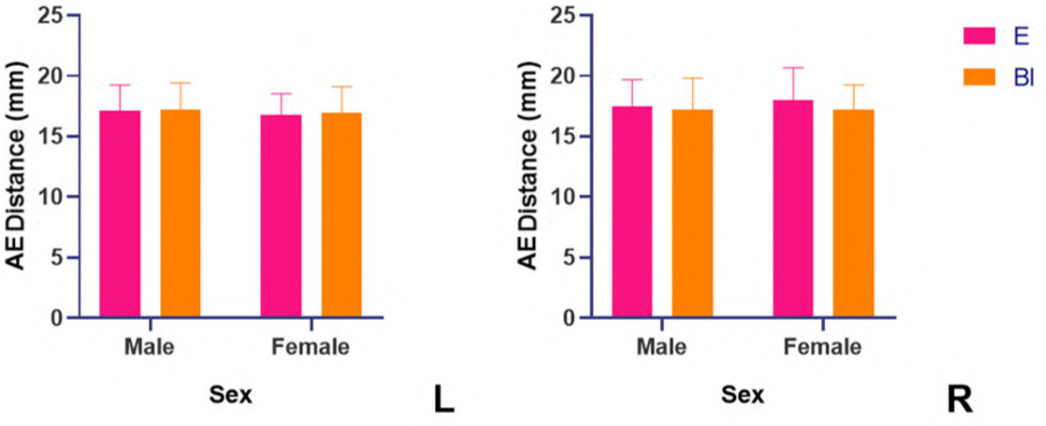

Fig. 9.- Mean AE distance (mm) by sex in each morphological type (E and Bl). There were no statistical differences.

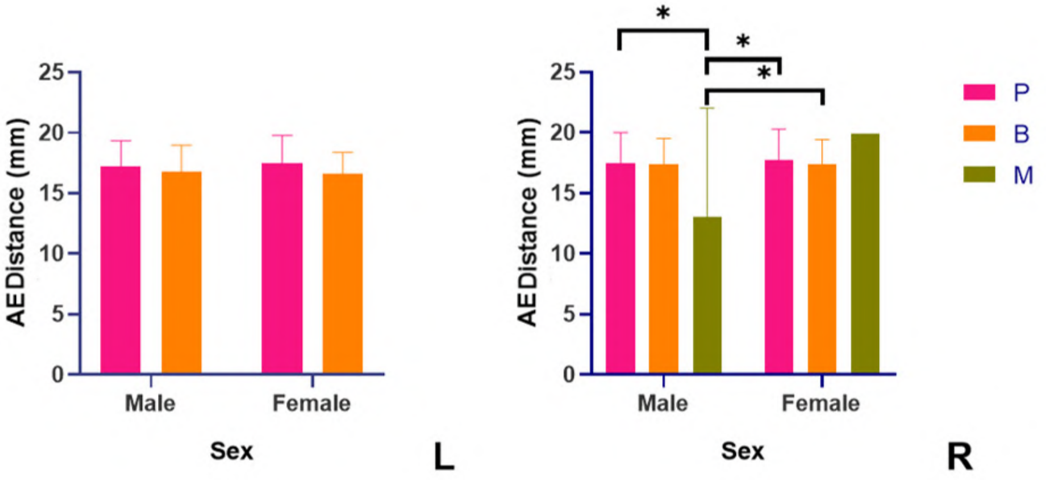

Fig. 10.- Mean AE distance (mm) by sex in each morphological type (P and B). For the right side: type P – male versus type M – male: P = 0.0374; type M – male versus type P – female: P = 0.0368; type M – male versus type B – female: P = 0.0484. * Statistical difference between sexes.

sexes (P = 0 .9428) (Fig. 10). For the right side, the Two-way ANOVA test showed that there was significant difference when comparing the AE distance between males and females (P = 0.0300). When comparing the morphological types P, B and M within the same sex (P = 0.7329) no difference was detected. The multiple comparisons by the Sidak test performed in both sexes between the means of each type showed significant differences when comparing types P and M within male sex (P=0.0374), between types M (male) and P (female) (P = 0.0368) and between types M (male) and B (female) (P = 0 .0484) (Fig. 10).

DISCUSSION

The study proposed to morphologically evaluate two anatomical structures, the ZA and the AE, for their individual characteristics and the possible relationships between them in a Brazilian population.

When applying the classification proposed by Smith and Grosse (2016), it is possible to observe that in the studied sample there was no incidence of the cylindrical type; therefore, the ZAs presented only the elliptical type or the blade-like type. This may be related to the direction of traction that the masseter muscle exerts on the ZA. Such a characteristic was previously described, in which the force performs torsion on the ZA through its long axis, and this tends to invert the lower edge of the arch and evert its upper edge (Hylander and Johnson, 1997).

For the percentage incidence of the classifications used, it is noted that in the classification by Smith and Grosse (2016) there was a greater tendency for type Bl in females and a greater tendency for type E in males. While in the classification proposed in the present study there was a greater tendency to type B in females and a greater tendency to type P in males. Therefore, in the sample analyzed, the female sex presented, for the most part, blade- like ZA morphology and straight body, and the male sex, mostly, elliptical ZA morphology and convex body. Thus, studies on the relationship between these two classifications and, thus, between the morphology of the cross-sectional area with the anteroposterior ZA distance, are necessary to verify the relationship between the morphology of the ZA and the sexes.

There was no statistical difference for the classification of the cross-sectional area of the ZA between the sides, both for ZA distance and AE distance. However, type M of the classification proposed in the present study was involved in all the statistical differences found. For the ZA distance, there was a difference on the left side when comparing the type P with the M and the B with the M. These two differences may be associated with the deviation of the body of the ZA towards the medial direction in the type M, since it has the shape of the ZA, which naturally increases its length because of the longer path it has when producing such a deviation. In types P and B, it does not occur, being a direct path in both.

This deviation in type M can be related to the activity of the masseter muscle because this mastication muscle has its origin in the inferior border of the ZA and insertion in the external surface of the mandibular ramus (Sicher and Du Brul, 1980). There are hypotheses suggesting that the differential distribution of muscle tension exerted by the areas of insertion in the mandibular ramus, angle and coronoid process has important consequences, since they involve large areas of bone and must affect biomechanical events in more distant areas, such as the TMJ and possibly the ZA. Presumably they affect growth patterns, but the characteristics are not well defined (McNeill, 1997).

Research involving the anteroposterior morphology of the ZA, as the classification proposed by this study suggests, and the facial morphology in the vertical dimension (Collett and West, 1993; Franco et al., 2013) are of great interest, because, in general, the cross- sectional areas of the masseter, lateral and medial pterygoids and temporal muscle are positively correlated with the bigonial and bizygomatic amplitudes, inferring that one might expect the elevator muscles to be thicker in brachycephalics (McNeill, 1997). It is possible to correlate the anteroposterior morphology of the ZA with the facial biotypes. According to McNeill (1997), the cross-sectional areas of the muscle are also affected by muscle utilization and by the growth of the individual.

For the AE distance, there was a difference on the left side when comparing type B with type M, which may be related to the biomechanical activity of mastication. It is possible that there is a relationship between the difference occurring on a specific side, since there are studies that relate the proportion of masseter muscle strength between the working side and the balancing side during chewing with the texture of the food. This proportion is lower with hard foods and higher with soft foods (Hylander et al., 1992). Furthermore, it is possible that the arch morphology may influence the AE due to its anatomical proximity since the posterior part of the ZA is adjacent to the AE. However, it is emphasized that further studies are needed to analyze these relationships.

Statistically, the results of the ZA distance showed a difference between sexes in the Smith and Grosse (2016) classification, both in type E and in type Bl. However, there was no difference between the two types found in the same sex. The ZA distance is greater in males than in females in both morphological types for the left side and this size difference appears in the cross-sectional area classification of the ZA for the right side. This may be related to the existing sexual differences in the skull, which refer to the lower power of the female musculature associated with the smaller volume that the female skull presents (Sicher and Du Brul, 1980).

For the classification proposed in the present study, the results of the ZA distance also showed difference between sexes, both in type P and in type B. There was no difference between the two types found in the same sex. The ZA distance is also greater in males than in females in both morphological types and sides.

Associating the results of the two classifications, it is possible to conclude that the ZA distance is greater in males than in females in the studied sample. This information may be useful for anthropometric studies, such as sexual dimorphism, since the ZA distance showed difference between sexes in both classifications.

As regards to sex, males had a higher incidence of type E and females had a higher incidence of type Bl, according to the cross-sectional area classification of the ZA. Males also had a higher incidence of type P and females had a higher incidence of type B, according to the new classification proposed by the present study. There is no relationship between ZA type and ZA and AE distances. However, as a limitation of the study, it is needed to seek anthropological variability once it is carried out in a sample that covers the population of a specific region of Southeast Brazil. Thus, it is important to expand the methodology to samples in other countries and/or to other regions within the same country.

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