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JADIR DONIZETTI DA SILVA

MORFOLOGIA TRIDIMENSIONAL DO ARCO ZIGOMÁTICO DE MACACOS DO GÊNERO CEBUS

ZYGOMATIC ARCH THREE-DIMENSIONAL MORPHOLOGY OF CAPUCHIN MONKEYS OF THE GENUS CEBUS

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Dissertação apresentada à Faculdade de Odontologia de Piracicaba da Universidade Estadual de Campinas como parte dos requisitos exigidos para a obtenção do título de Mestre em Biologia Buco-Dental, na Área de Anatomia.

Dissertation presented to the Piracicaba Dental School of the University of Campinas in partial fulfillment of the requirements for the degree of Master in Oral Biology, in the area of Anatomy.

Orientador: Prof. Dr. Alexandre Rodrigues Freire

ESTE TRABALHO CORRESPONDE À VERSÃO FINAL DA DISSERTAÇÃO DEFENDIDA PELO ALUNO JADIR DONIZETTI DA SILVA, E ORIENTADO PELO PROF. DR. ALEXANDRE RODRIGUES FREIRE.

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PROF. DR. ALEXANDRE RODRIGUES FREIRE

PROFª. DRª. JULIANA HADDAD

PROF. DR. EDUARDO DARUGE JUNIOR

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RESUMO

O arco zigomático é uma estrutura anatômica que é a origem do músculo masseter em mamíferos, a exemplo dos seres humanos e espécies de macacos. Estudar a sua morfologia é essencial para entender a biomecânica do crânio e sua relação com características que identificam o indivíduo. O presente estudo avaliou a morfologia tridimensional do arco zigomático dos macacos Cebus através de microtomografias computadorizadas. Foram utilizados 13 crânios secos de *Cebus apella* com origem do Sudeste brasileiro, sendo 6 masculinos e 7 femininos. As microtomografias computadorizadas foram obtidas no microtomógrafo SkyScan 1178 e então as imagens foram importadas para o software NRecon (Bruker, Bélgica) para a conversão na escala de cinza e obtenção do formato DICOM. Em seguida, as imagens foram segmentadas no software Mimics 18.0 (Materialise, NV, Belgium) e então exportadas em estereolitografia para que a superfície dos arcos zigomáticos fosse avaliada no Rhinoceros 5.0 (McNeel & Associates, Seattle, USA). Foram obtidas medidas quanto o diâmetro máximo e mínimo da área transversal e quanto à distância anteroposterior do arco zigomático. Com as medidas transversais, o arco foi classificado em cilíndrico (C), elíptico (E) ou laminar (Bl). Após tabulação dos dados no Excel®, foi realizada a análise estatística no software GraphPAD Prism v.8 (San Diego, CA, USA). O teste Two-way ANOVA com múltiplas comparações pelo teste de Sidak foi escolhido para verificar a relação entre os sexos e os tipos. O nível de significância foi de 5%. No sexo masculino, houve incidência do lado esquerdo de 25% do tipo E e 25 % do tipo Bl e do lado direito de 33% do tipo E e 17% do tipo Bl. No sexo feminino, houve incidência do lado esquerdo de 14% do tipo E e 36% do tipo Bl e do lado direito de 14% do tipo E e 36% do tipo Bl. O comportamento dos músculos mastigatórios dos *Cebus apella* podem estar relacionados às diferentes formas do arco zigomático encontradas, pois eles possuem relação direta com esta estrutura anatômica.

Palavras-chave: Zigoma, *Cebus apella*, Microtomografia por Raio-X.

ABSTRACT

The zygomatic arch is an anatomical structure that is the origin of the masseter muscle in mammals, such as humans and monkey species. Studying its morphology is essential to understand the biomechanics of the skull and its relationship with characteristics that identify the individuals. The present study evaluated the three-dimensional morphology of the zygomatic arch of Cebus monkeys using microcomputed tomography. 13 dry skulls of *Cebus apella* originating from Southeastern Brazil were used, consisting of 6 males and 7 females. The microcomputed tomography scans were obtained using a SkyScan 1178 scanner and then the images were imported into the NRecon software (Bruker, Belgium) for conversion to gray scale and obtaining the DICOM format. Then, the images were segmented in Mimics 18.0 (Materialise, NV, Belgium) software and then exported in stereolithography so that the surface of the zygomatic arches could be evaluated in Rhinoceros 5.0 (McNeel & Associates, Seattle, USA) software. Measurements were obtained regarding the maximum and minimum diameter of the transversal area and the anteroposterior distance of the zygomatic arch. Using transversal measurements, it was classified as cylindrical (C), elliptical (E) or blade-like (Bl). After tabulating the data in Excel®, statistical analysis was performed by GraphPAD Prism v.8 software (San Diego, CA, USA). The Two-way ANOVA test with multiple comparisons using the Sidak test was chosen to verify the relationship between sexes and types. The significance level was 5%. In males, there was an incidence on the left side of 25% of type E and 25% of type Bl and on the right side of 33% of type E and 17% of type Bl. In females, there was an incidence on the left side of 14% of type E and 36% of type Bl and on the right side of 14% of type E and 36% of type Bl. The behavior of the masticatory muscles of *Cebus apella* may be related to the different shapes of the zygomatic arch found, as they have a direct relationship with this anatomical structure.

Keywords: Zygoma, *Cebus apella*, X-ray Microtomography.

SUMÁRIO

1. INTRODUÇÃO

Dentre os primatas não-humanos, poucos estudos têm sido realizados com os macacos da família Cebidae, macacos *Cebus apella* que habitam as Américas Central e do Sul (Szabuniewicz et al., 1971). *Cebus apella* é um primata que vive, naturalmente, em bandos de 8-16 indivíduos, com um ou mais machos, em florestas tropicais, e com ampla distribuição no Brasil (Silva e Ferreira, 2002).

A característica craniofacial exibida pelo *Cebus apella* como o osso cortical espesso e uma face larga estão associadas à presença de grandes músculos da mastigação, o que permite a produção e a dissipação de altas forças mecânicas mastigatórias. Sabe-se que o *Cebus apella* produz forças de mordida de grande intensidade, que variam de acordo com os dentes envolvidos. De acordo com esses estudos, as adaptações morfológicas parecem não restringir apenas à dieta do Cebus apella (Makedonska et al., 2012).

Em comparação com outras espécies platirrinas, tanto *Cebus apella* quanto *Cebus olivaceus* exibem músculos masseter e temporal ligados mais anteriormente, e ambas as espécies são caracterizadas por esmalte molar espesso (Wright, 2005).

De acordo com Wright (2005), a abertura de alimentos mecanicamente desafiadores com a dentição anterior requer a capacidade de raspar ou morder poderosamente com os incisivos, de perfurar com os caninos e de carregar estaticamente um tecido entre os dentes enquanto isso é feito puxando para trás com os músculos da nuca e das costas, ou mantendo a cabeça imóvel e afastando-se do rosto com as mãos e os membros superiores.

A literatura relata que o *Cebus apella* pode ser capaz de produzir e suportar forças mastigatórias maiores do que seus congêneres (Wright, 2005). No entanto, os estudos atuais não fornecem os dados necessários para identificar o quão adaptados os ossos do esqueleto craniofacial destes macacos é para suportar as maiores cargas e como esses padrões se relacionam com sua ecologia alimentar.

Smith e Grosse (2016) verificaram que a forma do arco zigomático dos mamíferos é notavelmente variável, variando de quase cilíndrico a semelhante a uma lâmina em secção transversal. Com base na geometria, pode-se supor que o arco seja uma viga subestrutural cuja capacidade de resistir à deformação está relacionada à forma da secção transversal. Os autores modificaram os arcos zigomáticos de Pan troglodytes, subespécie de chimpanzé, para averiguar a biomecânica através de modelos para análise de elementos finitos.

O arco zigomático desempenha um papel crítico no sistema mastigatório dos mamíferos. Formado pela união do processo zigomático do osso temporal e do processo temporal do osso zigomático, é dessa estrutura que se origina o músculo masseter, principal elevador da mandíbula (Smith e Grosse, 2016).

Watanabe et al. (2024) realizaram uma comparação entre os tipos da classificação proposta por Smith e Grosse (2016) que considerou a área transversal do arco zigomático em crânios humanos secos. Com isso, foi possível encontrar incidências de um tipo específico em cada sexo que poderiam estar relacionadas com a característica inerente que cada um possui. Além disso, os autores propuseram uma classificação inédita que se baseia no formato do arco zigomático em uma vista inferior do crânio humano, que também apresentou diferenças sexuais com uma incidência maior de um tipo específico em ambos. Assim, é interessante realizar esse modelo de estudo comparativo em outras espécies para averiguar a relação morfológica de uma estrutura cranial com características da amostra, como o sexo.

Embora a importância do arco zigomático para a função mastigatória não seja contestada, as consequências mecânicas precisas destas aparentes diferenças de forma permanecem não esclarecidas em algumas espécies. Assim, o presente estudo avaliou a morfologia tridimensional do arco zigomático de macacos do gênero Cebus em microtomografias computadorizadas.

2. ARTIGO

Title: Zygomatic arch three-dimensional morphology of capuchin monkeys of the genus Cebus

Artigo submetido ao periódico ***European Journal of Anatomy*** (Anexo 2)

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ABSTRACT

The zygomatic arch is an anatomical structure present in humans and monkey species. This study evaluated the three-dimensional morphology of the zygomatic arch of Cebus monkeys through microcomputed tomography scans. 13 dry skulls of Cebus apella from Southeastern Brazil were examined, 6 male and 7 female. The images were segmented in Mimics 18.0 (Materialise, NV, Belgium) software. Measurements were performed in Rhinoceros 5.0 (McNeel & Associates, Seattle, USA). With the transversal measurements, the zygomatic arch was classified as cylindrical (C), elliptical (E) or blade-like (Bl). Statistical analysis was performed by GraphPAD Prism v.8 software (San Diego, CA, USA) to compare measurements with types and sex. The Two-way ANOVA test with multiple comparisons using the Sidak test was employed to verify the relationship between sexes and types. The significance level was 5%. In males, there was an incidence on the left side of 25% of type E and 25% of type Bl and on the right side of 33% of type E and 17% of type Bl. In females, there was an incidence on the left side of 14% of type E and 36% of type Bl and on the right side of 14% of type E and 36% of type Bl. The behavior of Cebus apella and its oral habits involving masticatory muscles may be related to the different shapes of the zygomatic arch found, as they have a direct relationship with this cranium structure.

Keywords: Zygoma, *Cebus apella*, X-ray Microtomography.

INTRODUCTION

The zygomatic arch is a structure in the mammalian skull that joins two bones, the temporal and the zygomatic, the latter being articulated with the maxilla, the frontal and temporal bones (Estawrow and Elbarbary, 2022). The zygomatic arch has a long and narrow shape, with its longest axis in the anteroposterior direction. This anatomical structure is the origin of the masseter muscle, a jaw elevator, and is therefore important for mandibular movements (Smith and Grosse, 2016), having a critical role in the mammalian masticatory system.

There are still few conclusions about the bone response of the zygomatic arch in relation to the forces that affect the skull, unlike what happens with other structures belonging to it (Franks et al., 2016). Despite this, the zygomatic arch is part of a region of the face that is very susceptible to mechanical trauma (Song et al., 2009) that can alter the opening and closing of the mouth (Valdés and Zapata, 2021) and interfere with the facial shape and cause restrictions in the movement of the mandibular condyle or the coronoid process. These deformations can cause dental malocclusion and sensory distortions, such as decreased sensitivity in this region of the face by damaging, for example, the infraorbital nerve (Jones and Schmalbach, 2022; Estawrow and Elbarbary, 2022).

Among primates besides humans, few studies have been carried out with monkeys from the Cebidae family, *Cebus apella* monkeys that inhabit Central and South America (Szabuniewicz et al., 1971). *Cebus apella* is a primate that naturally lives in groups of 8-16 individuals, with one or more males, in tropical forests, and is widely distributed in Brazil (Silva and Ferreira, 2002).

The craniofacial characteristics exhibited by *Cebus apella* such as thick cortical bone and a wide face are associated with the presence of large chewing muscles, which allows the production and dissipation of high chewing mechanical forces. It is known that *Cebus apella* produces very intense bite forces, which vary according to the teeth involved. According to these studies, morphological adaptations do not appear to be restricted to the *Cebus apella* diet alone (Makedonska et al., 2012).

Compared to other platyrrhine species, both Cebus apella and Cebus olivaceus exhibit more anteriorly attached masseter and temporalis muscles, and both species are characterized by thick molar enamel (Wright, 2005).

According to Wright (2005), mastication of mechanically challenging foods with the anterior dentition requires the ability to scrape or bite powerfully with the incisors, to pierce with the canines, and to statically carry the food between the teeth while doing so by pulling toward it back with the muscles of the neck and back or keeping the head still and moving away from the face with the hands and upper limbs.

The literature reports that *Cebus apella* may be capable of producing and withstanding greater chewing forces than its congeners (Wright, 2005). However, current studies do not provide the data necessary to identify how adapted the bones of the craniofacial skeleton of these monkeys are to withstand the greatest loads and how these patterns relate to their feeding ecology.

Smith and Grosse (2016) found that the shape of the mammalian zygomatic arch is remarkably variable, ranging from nearly cylindrical to blade-like in cross-section. Based on the geometry, it can be assumed that the arch is a substructural beam whose ability to resist deformation is related to the cross-sectional shape. The authors modified the zygomatic arches of Pan troglodytes, a subspecies of chimpanzee, to investigate biomechanics through models of finite element analysis and through it they achieved those morphological changes can produce local effects on the strain magnitude of the force applied to the zygomatic arch.

Watanabe et al. (2024) carried out a comparison between the types of classification proposed by Smith and Grosse (2016), which considered the cross-sectional area of the zygomatic arch in dry human skulls. With this, it was possible to find incidences of a specific type in each sex that could be related to the inherent characteristic that each one has. Furthermore, the authors proposed an unprecedented classification that is based on the shape of the zygomatic arch in an inferior view of the human skull, which also showed sexual differences with a higher incidence of a specific type in both. Therefore, it is interesting to carry out this comparative study model in other species to investigate the morphological relationship of a cranial structure with characteristics of the sample, such as biological sex.

Although the importance of the zygomatic arch for masticatory function is not contested, the precise mechanical consequences of these apparent differences in shape remain unclear in some species. Thus, the present study evaluated the three-dimensional morphology of the zygomatic arch of monkeys of the genus Cebus using microcomputed tomography.

MATERIALS AND METHODS

The research was analyzed by the Committee of Research Ethics of the University of Campinas and exempted from ethical analysis and assessment (ANEXO 1).

Sample

The skulls of 13 adult capuchin monkeys (Order: Primate; Family: Cebidae; Genus: Cebus; Species: Cebus apella), with an average weight of 2-3 kg, were used for this study. Skulls of Cebus apella monkeys obtained from the Capuchin Monkey Breeding Center of the School of Dentistry of Araçatuba, São Paulo State University (Unesp) “Júlio de Mesquita Filho” in Araçatuba, SP, Brazil were used. This Center is regularized, through legal authorization, by the Brazilian Institute of Environment and

Renewable Natural Resources (IBAMA). All necessary permits were obtained for the present study.

The animals were captured from the wild and were assumed to have feeding behaviors typically described for the species. Thus, the animals were kept in dense forest surrounding the University, under natural light and fed a controlled diet consisting of eggs, fruits, granulated food with protein and dry corn; water was provided ad libitum.

After natural death in the forest, the skulls were collected and dissected for the study. No monkeys were euthanized during the study.

Acquisition of microcomputed tomography scans

The skulls were scanned on a SkyScan 1178 microtomography scanner (SkyScan 1178, Bruker) at 65 Kv at high resolution (1024 × 1024 × 1024 pixels) and pixel size of 84 µm. The images obtained were imported into the NRecon software (Bruker, Belgium) for conversion to grayscale and then to DICOM format.

Processing of microtomographic images

The Mimics 18.0 software (Materialise, NV, Belgium) was used to segment the images from each microcomputed tomography. Segmentation consisted of selecting the pixels of the bone structure in each tomographic section. Such 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. 3D reconstruction was performed to enable visualization of these components and each three-dimensional surface was exported in virtual stereolithography (STL) to perform surface evaluation.

Morphometric analysis in microcomputed tomography of dry skulls

The 3D reconstructions of the microtomography were imported into the Rhinoceros 5.0 software (McNeel & Associates, Seattle, USA). Linear measurements (mm) were obtained for analysis and morphological characterization of the zygomatic arch on both sides (right and left).

The values obtained by the software were tabulated for statistical analysis.

Classification of the zygomatic arch

The measurements were obtained, in millimeters, regarding the maximum and minimum diameter of the zygomatic arch using the Mimics 18.0 software (Materialise, NV, Belgium) and regarding the distance from the zygomatic arch using the Rhinoceros 5.0 software (McNeel & Associates, Seattle, USA).

To obtain measurements of the maximum and minimum diameter of the zygomatic arch, it was necessary to define the transversal area for its measurement (Figure 1). It was defined by choosing the midpoint between the most superior and the most inferior point of the zygomaticotemporal suture.

The maximum diameter of the zygomatic arch was defined as the maximum diameter that passes through the central point of the chosen transversal area and the minimum diameter as the minimum diameter orthogonal to the maximum diameter obtained.

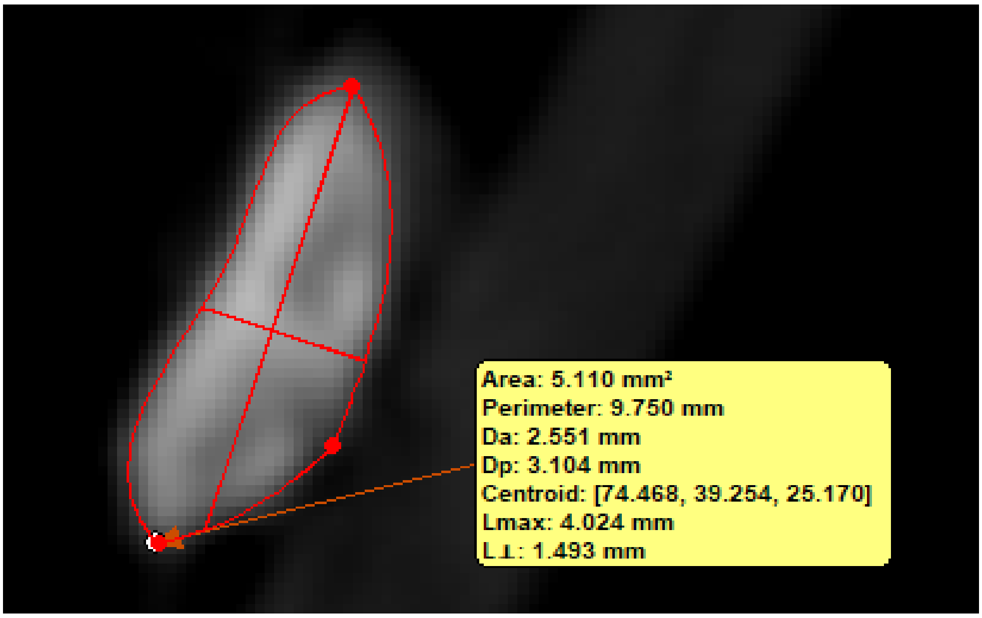

Figure 1. Measurements of the cross-sectional area of the zygomatic arch provided by the Mimics 18.0 software (Materialise, NV, Belgium) in microcomputed tomography. Lmax: maximum diameter (maximum diameter that passes through the central point of the chosen transversal area), L⊥: minimum diameter (minimum diameter orthogonal to Lmax).

The distance of the zygomatic arch consists of the length from its anterior end to its posterior end in an inferior view of the skull, with 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, which is the region of increased volume in the lower and posterior part of the zygomatic arch (Figure 2).

Figure 2. Inferior view of the skull. The black line shows the measurement acquisition of the distance from the zygomatic arch in the Rhinoceros 5.0 software (McNeel & Associates, Seattle, USA).

The measurements of the maximum and minimum diameter of the zygomatic arch were used to classify the zygomatic arches according to the study by Smith and Grosse (2016), in which they characterized three types of zygomatic arch: cylindrical (C), elliptical (E) and blade-like (Bl) with proportions being 1:1; 2:1 and 3.5:1 of the maximum and minimum radii of the cross-sectional area of the zygomatic arch, respectively (Figure 3).

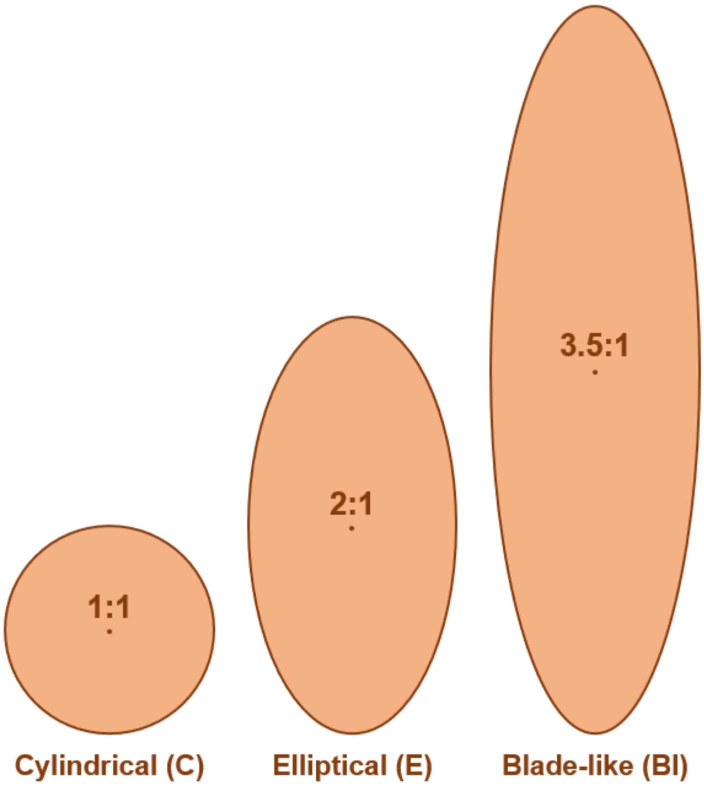

Figure 3. Classification of the zygomatic arch in transverse section by Smith and Grosse (2016). The shapes represent the types defined in their study with their respective proportions: cylindrical (1:1), elliptical (2:1) and blade-like (3.5:1). To classify the sample in the present study, it was necessary to calculate the proportion between the maximum diameter that passes through the central point of the chosen transversal area and the minimum diameter orthogonal to it. Image adapted from Smith and Grosse (2016).

To classify the zygomatic arches in the sample, the proportion between the maximum diameter and the minimum diameter was calculated and, then, the classification was made according to the closest proximity to the value obtained in relation 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.

Statistical analysis

The data were tabulated in the Microsoft Office Excel® package. An analysis of the incidence of morphological types of the zygomatic arches was carried out using percentages (%). Statistical analysis was performed using GraphPAD Prism v.8 software (San Diego, CA, USA). Descriptive statistics were performed for each measurement in each sex and type. 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 sides. In all analyses, a significance level of 5% was considered.

RESULTS

Incidence of types from the classification of zygomatic arch cross-sectional area

Of the 26 zygomatic arches (right and left sides) from the 13 capuchin monkey skulls (6 male and 7 female), 11 (42%) are type E and 15 (58%) are of the Bl type. 12 (46%) are male and 14 (54%) are female.

The incidences of types were obtained according to the classification of Smith and Grosse (2016) according to side (Figure 4) and according to sex and side (Figure 5).

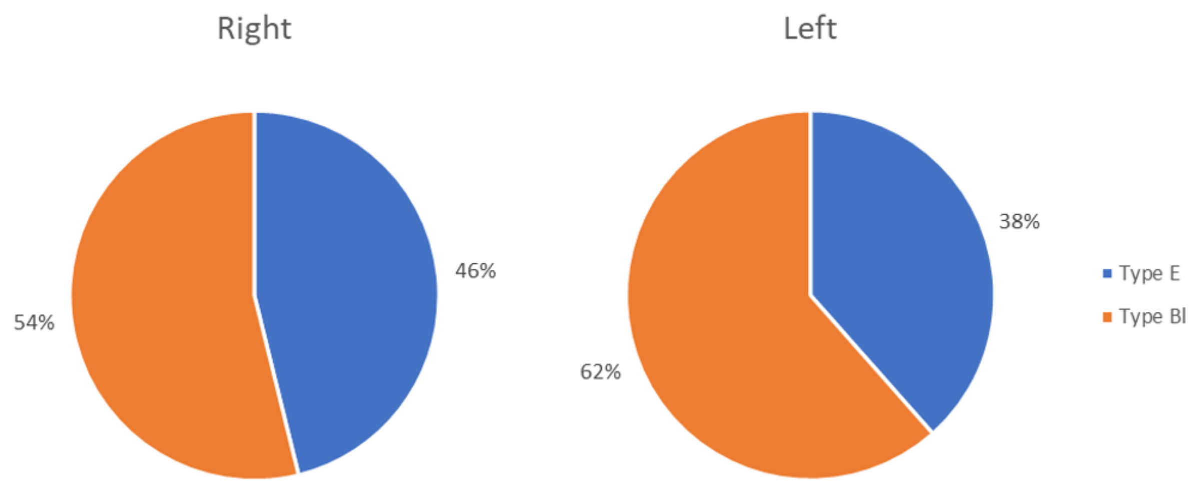

Figure 4. Incidence of types of cross-sectional area of the zygomatic arch on each side, according to the study by Smith and Grosse (2016). Type E: elliptical type, Type Bl: blade-like type.

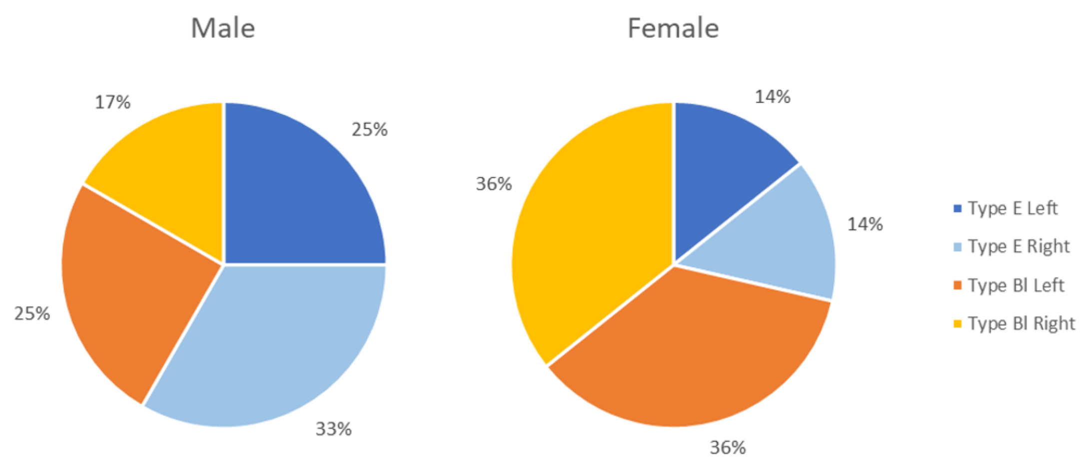

Figure 5. Incidence of types of cross-sectional area of the zygomatic arch according to sex and according to side, based on a study by Smith and Grosse (2016). Type E: elliptical type, Type Bl: laminar type.

Zygomatic Arch Distance

The table 1 showed the descriptive statistical about the zygomatic arch distance in each sex and side. It's possible to note that there was a tendency for the ZA distance to be greater in males than in females (Figure 6).

In general, the two-way ANOVA test showed that, when considering the interaction sex (male and female) and sides (right and left), significant differences were found for the sex (P= 0.0019). No significant differences were found to side (P=0.5372).

The multiple comparisons by Sidak's test performed between the means of each sex on each side detected significant differences on left side of the male sex vs. right side of the female sex (P= 0.0451). For the other comparisons, there were no significant differences (right side of male sex vs. left side of male sex: P=0.9982; right side of male sex vs. right side of female sex: P=0.1256; right side of male sex vs. left side of female sex: P=0,2769; left side of male sex vs. left side of female sex: P=0.1109; right side of female sex vs. left side of female sex: P=0.9987).

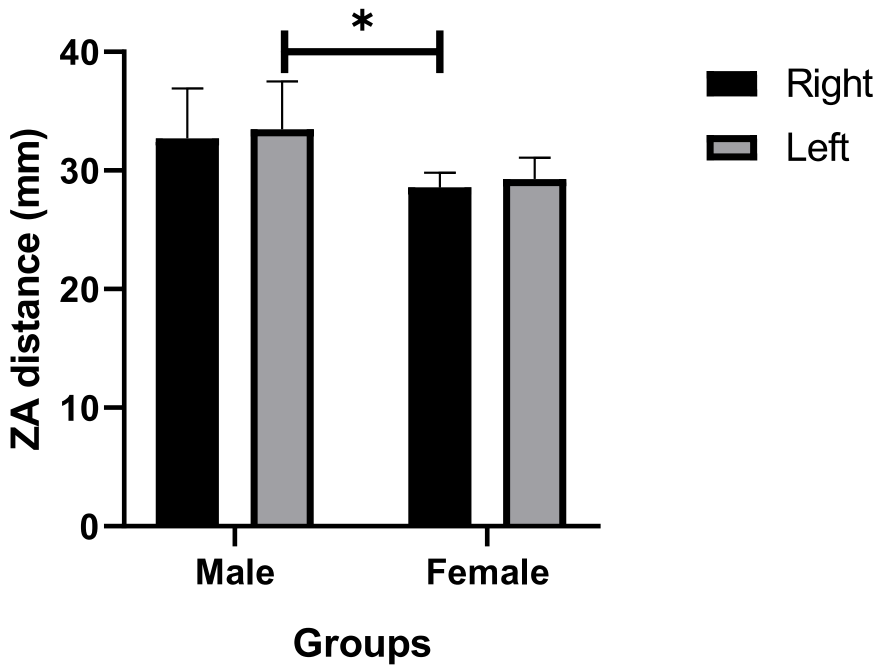

Figure 6. Mean ZA distance (mm) by sex in each side. *Statistical difference.

Table 1. Mean, standard deviation (SD), median, percentiles of measurements obtained (mm) for each sex and side (R = right; L = left).

Measurement	*Mean R side (SD)*	*Mean L side (SD)*	*Median R side*	*Median L side*	*Percentil (25%) R side*	*Percentil (25%) L side*	*Percentil (75%) R side*	*Percentil (75%) L side*
ZA Distance								
Female	28.59 (1.213)	29.28 (1.797)	28.39	28.48	27.66	27.70	29.88	30.74
Male	32.70 (4.204)	33.49 (4.037)	32.23	33.54	28.68	29.11	36.53	37.44
ZA Maximum Diameter								
Female	3.737 (0.7971)	3.387 (0.7704)	3.690	3.060	3.160	2.850	4.150	4.200
Male	4.135 (0.9428)	4.135 (0.8188)	4.105	3.785	3.298	3.508	5.133	5.133

Maximum Diameter of the Zygomatic Arch

The table 1 showed the descriptive statistical about the maximum diameter of the zygomatic arch in each sex and side (Figure 7).

In general, the two-way ANOVA test not detected significant differences in the interaction sex (male and female) (P= 0.0933) and sides (right and left) (P=0.5975).

The multiple comparisons by Sidak's test performed between the means of each sex on each side and not detected significant differences (right side of male sex vs. left side of male sex: P>0.9999; right side of male sex vs. right side of female sex: P=0.9525; right side of male sex vs. left side of female sex: P=0.5346; left side of male sex vs. left side of female sex: P=0.9525; left side of male sex vs. left side of female sex: P=0.5346; right side of female sex vs. left side of female sex: P=0.9688).

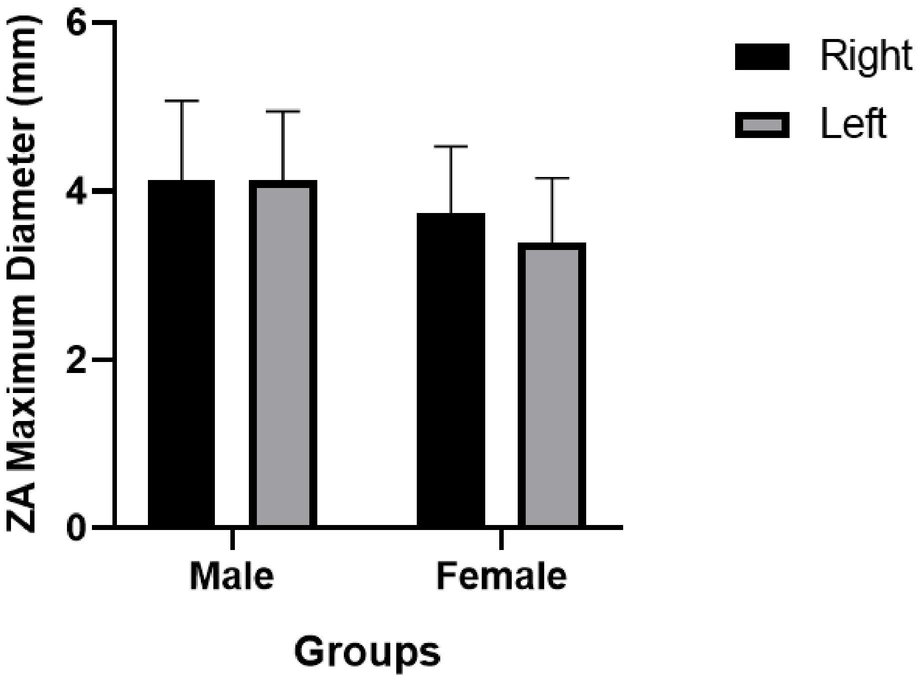

Figure 7. Mean ZA maximum diameter (mm) by sex in each side.

DISCUSSION

The feeding and chewing behavior of Cebus and bone morphology has been extensively studied for years to better understand the craniofacial biomechanics of this genus (Madeira et al., 1977; Wright, 2005; Prado et al., 2016).

The zygomatic arch of monkeys of the genus Cebus is a relevant subject of study because it is an anatomical structure that participates in the zygomatic pillar. Prado et al. (2016) published new data on the microarchitecture of pillars and facial buttresses in *Cebus apella* using microcomputed tomography. According to the authors, this structure is biomechanically optimized to resist the associated forces. The authors evaluated seven microtomography scans of adult *Cebus apella* skulls. They quantified the three-dimensional structure of the bone in the facial pillars and buttress regions. The authors found that the pillars and buttresses have a larger volume than the areas without pillars. However, in non-pillars/buttress areas, the bone represents a greater percentage of the volume of interest than in pillar and buttress areas. As stated in previous studies, the zygomatic arch may appear to be a simple pillar, but it does not adapt to simple pillar mechanics (Rafferty et al., 2000).

It is believed that the different shapes of the zygomatic arch occur due to extrinsic mechanical factors in each species, mainly due to the type of food available in the environment (hard or soft diets) and the way they eat and chew, which would probably explain these variations. Capuchin monkeys have variations of names, including the way they feed. Alfaro et al. (2012) proposed a division of capuchin monkeys into two genera Cebus including the gracile capuchin monkeys and Sapajus including the robust capuchin monkeys. The genus Cebus contains several taxa that feed primarily on soft fruit, known as the “untufted” or gracile capuchins, C. olivaceus, C. albifrons, and C. capuchinus, and several “tufted” or “apeloid” taxa, including C. apella s.s., C. libidinosus and C. nigritus, classified as hard object feeders. Alfaro et al. (2012) suggested that the robust and gracile capuchin monkeys represent two distinct adaptive radiations (the first group originating in the Atlantic Forest, while the last group originating in the Amazon) that diverged from a last common ancestor, which lived approximately 6.2 million years ago.

The shape of the mammalian zygomatic arch is remarkably variable, ranging from nearly cylindrical to blade-like in cross-section. Based on the geometry, it can be assumed that the arch is a substructural pillar whose ability to resist deformation is related to the cross-sectional shape (Smith and Grosse, 2016).

Smith and Grosse (2016) found that modifications in the cross-sectional shape of the chimpanzee zygomatic arch had local effects on the magnitude of tension in the zygomatic arch but had few consistent global effects on craniofacial tension patterns, which were evaluated by the finite element analysis. The modification of material properties of the zygomatic arch also had local effects, but no consistent global patterns emerged. Furthermore, they found that the zygomatic arch does not function as an isolated structure, loaded unidirectionally. The results of Smith and Grosse (2016) imply that the shape (or composition) of the zygomatic arch alone does not have a profound effect on feeding mechanics. Instead, it is likely to be the entirety of craniofacial features that affect the transmission of masticatory forces and resistance to bending in the mammalian skull.

Watanabe et al. (2024) developed a study on human skulls from a Brazilian population in which they also applied the classification of cross-sectional area of the zygomatic arch by Smith and Grosse (2016). Like the present study, there was no incidence of the cylindrical type in human skulls. Furthermore, they found a higher incidence of the elliptical type in males and the blade-like type in females, and, additionally, they took measurements of the distance from the zygomatic arch and made a comparison between the sexes. This distance was longer in males and shorter in females. According to the authors, this may be related to sexual differences in the skulls, involving differences in musculature and bone volume and density. In the monkey skulls studied in the present research, there was a statistically significant difference between the distance of arches of different sexes on opposite sides, which may also be related to the sexual differences in monkey skulls. However, more studies are needed to be able to observe and verify such relationships.

CONCLUSION

Variations in the shape of the zygomatic arch of *Cebus apella* monkeys probably occur in response to the feeding and chewing behavior of these monkeys, since the zygomatic arch is an anatomical structure that is affected by chewing forces.

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3. CONCLUSÃO

As variações na forma do arco zigomático dos macacos *Cebus apella* provavelmente ocorrem em resposta ao comportamento alimentar e mastigatório desses macacos, uma vez que o arco zigomático é uma estrutura anatômica que é afetada pelas forças mastigatórias.

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A Comissão de Ética no Uso de Animais da UNICAMP – CEUA/UNICAMP – esclarece que não há necessidade de submeter o projeto de pesquisa **"Morfologia tridimensional do arco zigomático de macacos do gênero Cebus"**, de responsabilidade da Prof. Dr. Alexandre Rodrigues Freire, e executores: Jadir Donizetti da Silva, Beatriz Carmona Ferreira-Pileggi, Luciane Naomi Oguma Watanabe, Ana Cláudia Rossi, para análise desta comissão.

Referido projeto utilizará microtomografias computadorizadas de crânio de macaco Cebus oriundas da Faculdade de Odontologia de Araçatuba - UNESP. Não haverá qualquer manipulação *in* vivo dentro dos laboratórios credenciados pela CEUA/UNICAMP.

Campinas, 25 de julho de 2023.

Profa. Dra. Cinthia Baú Betim Cazarin
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