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Morphometric aspects of the foramen magnum and the orbit in Brazilian dry skulls

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ABSTRACT

Morphometric analysis of crania structures are of great significance to anatomists, forensic doctors, anthropologists, and surgeons. We performed a morphometric study regarding the foramen magnum and the bony orbit on the right side of the cranium in 77 skulls with the purpose of identifying a correlation between these measures, as they are often employed alone to identify the genre and race of a skeleton with no other remains, since the cranium is a structure that can resist fire, explosions, and mutilations. The foramen magnum receives special attention, as it is located in a region together with many strong muscles and ligaments. The measures were taken with a sliding digital caliper. Our results showed that the foramen magnum had a mean anteroposterior diameter of 34.23±2.54 mm, and the mean transverse diameter was 28.62±2.83 mm. The most common shape for the foramen magnum was oval. The mean right orbital height was 32.89±2.45 mm, and the mean right orbital breadth was 37.15±2.68 mm. There was a weak to moderate correlation between these measures. Furthermore, the foramen magnum and the orbit are regions of surgical and clinical significance, thus requiring knowledge regarding the morphometric aspects of such areas, since they can often suffer morphological changes due to a number of diseases and they undergo surgical procedures in order to treat these conditions.

Keywords: Anatomy, Anthropology, Foramen Magnum, Orbit, Skull

INTRODUCTION

Morphometric analysis of the cranium is often employed with the purpose of identifying the age, stature, ethnicity, sex, and even the species of a damaged skeleton. These measures of the skull are crucial to forensic investigations and anthropologic exams, and they are also relevant to clinical, surgical and anatomical studies [1-3].

The orbit is a cavity shaped like a pyramid with its apex located posteriorly and the base anteriorly located at the viscerocranium. It is formed by the orbital process of the frontal bone, lesser wing of the sphenoid bone, orbital plate and frontal process of the maxilla, zygomatic bone, orbital plate of the palatine bone, lacrimal bone, and the orbital lamina of the ethmoid bone. The orbit contain the eye and associated muscles, the lacrimal glands, the ophthalmic artery and veins, the ophthalmic nerve, the optic (II), oculomotor (III), trochlear (IV), and the abducens (VI) nerves. The orbital characters vary amongst different races and ethnic groups, also, it is known to possess sexual dimorphism, and it is anthropologically relevant in race definition [4-10].

The foramen magnum is an aperture located at the base of the skull. It is formed by the four portions of the occipital bone (two lateral, one squamous, and one basal) and can present different shapes. Furthermore, it is pathway to structures that crosses the head and neck like the cerebellum, medulla oblongata, meninges, vertebral arteries, and the spinal branch of the accessory nerve (XI) [2-4,11-14].

Concerning its site, measures of the occipital region seems to be an alternative to determinate certain characteristics of cadaveric remains in cases where human fragments are greatly damaged by insults (fire, explosions, and multilations), as the basicranium is protected by large and strong tissues, such as muscle, tendons and ligaments [2,15,16].

Other areas of the skull such as nasal aperture, zygomatic extension, malar size, supraorbital ridge, chin, nuchal crest, mastoid process size, nasal size, mandibular symphysis, occipital condyles, forehead shape, and palate size were morphometrically studied in order to increase the number of parameters used to identify the gender, ethnicity, race, and by consequence, the accuracy (when those methods are combined), which could lead to a decrease in the usage of more sophisticated and expensive methods, such as DNA analysis [2,8,15-17]. The orbit is an important factor as well in answering questions regarding the sex and ethnicity of a cadaver, which means that, it is also a region of the skull that possess sexual dimorphism characteristics: orbit pertaining to female skulls are usually rounder, and orbits belonging to male skulls generally have a square format [18,19].

Measures of the foramen magnum are relevant in cases of achondroplasia (as there is a high risk of spinal cord stenosis in the base of the skull), Arnold-Chiari malformation (downward herniation of the cerebellar tonsils), foramen magnum meningioma, plagiocephaly, basilar invagination, and others cranial deformities [3,16,18,20-22].

Morphological knowledge of the orbit is essential, since the orbit is a region exposed to several types of surgical procedures (ophthalmological, maxillary surgeries and reconstructive cosmetic surgeries of face), moreover, the orbit seems to be an important factor during ultrasound evaluation to diagnose diseaseas such as Down syndrome [7,9,10,23-26].

The present study is an attempt to research the foramen magnum and its relation to the craniometric measures of the orbit in Brazilian skulls, with the purpose of verifying any type of morphometric connection between the neurocranium and viscerocranium. Studies about the FM and the orbit morphometry in Brazilians are scarce. Since Brazil has a mixed population, we find that it is necessary to determine a reference value regarding the morphometric aspects of the FM and the bony orbit in order to help anthropologists, forensic doctors, surgeons, physicians, and anatomists identify morphological variants of this structure.

MATERIALS AND METHODS

We performed a morphometric analysis of the foramen magnum and the right side orbit in 77 skulls pertaining to the Morphology Department of the Fluminense Federal University. All skulls were from unknown sex and belonged to adults of age above 18 years. They had great condition overall, skulls with a damaged or broken foramen magnum and orbits were excluded from this study.

The measures were taken using a sliding digital caliper (0.01 mm), each measurement was repeated in order to avoid any errors. The criterion for the antero-posterior diameter (APD) of the foramen magnum was the distance between the basion and opisthion; the transverse diameter (TD) criterion was the distance between the points of maximum curvature of the foramen magnum lateral margins (Fig. 1). The area of the foramen magnum was calculated using the Radinsky's formula (A = ¼ x pi x TD x APD).

The right orbital breadth (ROB) was the distance between the maximum breadth of the orbit from the maxillofrontale to the middle of the lateral orbital border (ectoconchion) and the right orbital height (ROH) was the maximum internal height of the orbit perpendicular to its breadth (Fig. 2). We also calculated the orbital index (OI) of the right orbit and the FM index (FMI): (orbital height/ orbital breadth) x 100; (transverse diameter/ anteroposterior diameter) x 100, respectively.

The foramen magnum shape was classified in 5 categories: oval, round, tetragonal, pentagonal, and hexagonal (Fig. 3).

Statistical analysis was performed using GraphPad Prism 6 software, the collected data were analyzed using the paired, two-tailed student's t-test ($p > 0.05$ was considered significant), the Pearson's correlation method, and D'Agostino& Pearson omnibus normality test. Descriptive statistics (mean, standard deviation, median, minimum and maximum values) were also analyzed. All pictures were taken with a Sony Alpha ILCE-3000K (20.1 Megapixels).

RESULTS

The FM had a mean anteroposterior diameter (MAPD) of 34.23 mm, with a standard deviation (SD) of 2.54 mm, and the mean transverse diameter (MTD) was 28.62 mm, with a SD of 2.83 mm. The APD median was 34.29 mm and the TD median was 28.15 mm, the maximum value (MaxV) for the APD and TD was 39.72 mm and 36.01 mm, respectively, and the minimum value (MinV) was 26.90 mm for the APD and 22.67 mm for the TD (Table 1). The most common shape for the FM was oval (Table 2).

The mean ROH was 32.89 mm, with a SD of 2.45 mm, and the mean ROB was 37.15 mm, with a SD of 2.68 mm, the ROH and ROB median was 32.56 mm and 37.02 mm, respectively. The MinV and MaxV for the ROH were 28.06 mm and 39.15 mm. The MinV and MaxV for the ROB were 29.45 mm and 45.05 mm (Table 3).

The mean area of the foramen magnum was 772.4 mm with a SD of 116.7, and the mean foramen magnum index (FMI) was 83.75 mm with a SD of 7.23 mm. The mean OI was 88.72 mm with a SD of 6.89 (Table 4).

The D'Agostino& Pearson omnibus normality test in all measures taken was considered normal ($p = <1$; alpha = 0.05), meaning that there wasn't a statistically significant discrepancy between measurements. The paired, two-tailed student's t test results showed that the relation between the FMI and OI wasn't statistically significant ($p = 0.0002$), although the Pearson's correlation between the FMI and the OI was moderated ($p = 0.695$), which could indicate at least a weak correlation between these values.

DISCUSSION

The morphometric study of the human skull is a common practice among anatomists, anthropologists, and forensic doctors, as it is a structure of great interest since it possesses sexual dimorphic characters and ethnic differences. The foramen magnum is an anatomic region of vital importance, as it is protected (in most cases) from injuries such as fire, explosions, and mutilations, this is due to the strong muscles and ligaments that are present in this region. Furthermore, the cranium seems to be less affected by factors such as nutrition and they are more genetically driven. The skull alone can provide 90% of accuracy regarding the gender aspect. It is also known that the morphological features of the foramen magnum went through evolutionary changes, thus, conferring this region a special anthropological interest [14,18,27].

The FM is formed by sclerotomes of the first 4 somites that eventually fuse to form the occipital bone and the posterior element of the foramen magnum. The fourth sclerotome (proatlas) contains 3 portions: the hypocentrum, the centrum, and the neural arch, the latter divides into ventro-rostral and dorsal-caudal components. The ventro-rostral portion originates the occipital condyles and the anterior margin of the FM. As such, morphological anomalies and malformations in this process can result in different types and forms of foramen magnum [28]. Its portions suffer distinct process of ossification: the superior part of the squamous portion suffers intramembranous ossification, while the other portions go through endochondral ossification [4].

The formation of the orbit, on the other hand, is set within 2 months of embryogenesis. Cells from the neural crest migrate over the face over 2 different routes: the frontonasal anlage migrates to the prosencephalon, approaching the orbit from above, and the maxillary waves curves around and forms the orbit from below. The frontonasal process originates the lacrimal and ethmoid bones, while the maxillary process forms the floor and lateral walls of the orbit. All bones of the orbit ossify and fuse between the sixth and seventh months of gestation. It is worth mentioning that the development of the eyes is vital to the formation of the bony orbit and its surrounding soft tissue contents. The lesser wing of the sphenoid ossificates through endochondral ossification, and all of the other orbital bones and the greater wing of the sphenoid arises from intramembranous ossification [5].

Studies regarding the morphometric aspects of the foramen magnum in Brazilians are scarce. Manoel et al. (2009) [2] found that the MAPD was 35,7±0,29 mm in males and 35,1±0,33 mm in females, and the MTD was 30,3±0,20 mm in males and 29,4±0,23 mm in females, although our study did not had gender differentiation, there were certain similarities in our results. In another study performed in Brazilian skulls, Suazo et al. (2009) [29] showed that the MAPD was 36.5±2.6 mm and the MTD was 30.6±2.5 mm in males, and in females, the MAPD was 35.6±2.5 mm, and the MTD was 29.5±1.9 mm. Furthermore, they were able to correctly classify the gender in 66.5% of the skulls.

Murshed et al. (2003) [12] described that the MAPD was 37.2±3.43 mm for males and 34.6±3.16 mm for females, and the MTD for males and females was 31.6±2.99 mm and 29.3±2.19 mm, respectively. Gruber et al. (2009) [1] found that the MAPD was 36.6±2.8 mm and the MTD was 31.1±2.7 mm in subjects from central Western Europe, both being higher than our sample. Chethan et al. (2012) [27] reported that the MAPD was 31±2.4 mm and the MTD was 25.2±2.4 mm in Indians, and the most common shape of the FM was round. Osunwoke et al. (2012) [30] reported that the MAPD was 36.11±0.24 mm and the MTD was 26.65±0.24 mm in Nigerians subjects, the MAPD was higher than in our study, although the MTD was lower. Tubbs et al. (2012) [28] found that the MAPD was 31 mm and the MTD was 27 mm, they also reported that there was no significant difference between sexes, in contrast to other authors. Santhosh et al. (2013) [13] reported the MAPD and MTD in a male Indian population were 34.37 mm and 28.98 mm, respectively, and in women 33.80 mm and 27.60 mm, respectively. Natsis et al. (2013) [31] found that the MAPD was 35.53±3.06 mm and the MTD was 30.31±2.79 mm in a Greek population, also, the FM most common shape was "two semi-circles". Mehta et al. (2014) results showed that the MFMI was 82.5 mm±6.780, in an Indian population. Also in Indians, Ganapathy et al. (2014) [3] found that the MAPD was 33.9±2.3 mm and the MTD was 28.7±2.5 mm, although the most common shape of the FM was oval, in accordance to our study. Patel and Mehta (2014) [21] reported that the MAPD was 33.7 mm and the MTD was 28.29 mm in an Indian population from South Gujarat. Other studies of the FM are depicted in Table 5.

Even though studies reported that the FM measures are higher in male subjects than in females [15,33,34], Kamath et al. (2015) [16] stated that the FM measures may overlap and should not be used by itself for the determination of genre, as other authors found that there was no sexual dimorphic characteristics regarding the FM [1,17]. It was reported that the size of the FM in patients with achondroplasia and other neurological problems was reported to be smaller in all ages, and it was stated that the basichondrocranium of fetuses with hindbrain malformations (such as the Arnold-Chiari malformation) is shorter and smaller than the ones in normal fetuses [20,21,35,36], although Furtado et al. (2010) [37] stated that there were no significant relation between the FM measures in pediatric patients with Arnold-Chiari malformation (Type I) and patients without. This brings forth the need to study this morphometric aspect using the same parameters for measurements.

Regarding the morphometric aspects of the orbit, we found relatively few studies that used the same anatomical points that ours did to measure the bony orbit. Ji et al. (2010) [23] observed the orbit measures through a CT-scan in Chinese subjects, and their results revealed that the mean ROH was 33.28±1.58 mm, and the mean ROB was 38±94 mm, also, their research revealed that there wasn't a statistically significant difference of the OH between male and female patients. Ukoha et al. (2011) [38] found that the ROB was 36.03±0.37 mm and the ROH was 31.90±0.70 mm, stating that there were no statistically significance difference between the right and left sides. Fetouh and Mandour (2014) [25] stated that in a male Egyptian population, the mean ROH was 35.83±1.23 mm, the mean ROB was 43.62±1.13 mm, and the mean OI was 82.20±2.97 mm, and in females, the mean ROH was 35.53±0.95 mm, the mean ROB was 42.75±1.35 mm, and the OI was 84.13±3.76 mm. Elzaki et al. (2015) [8] found that the ROB was 34.10±1.76 mm and the ROH was 37.90±2.57 mm, they also found that the OB was slightly higher in man than in woman, but the OH was similar. Many results showed that the males orbit area was significantly larger than in females [23-25], although there is some divergence whether the symmetry of the orbit: some authors agree that there is a significant difference between right orbit and left orbit [23,25], while other authors found no statistically significant difference between them [24,38]. Other morphometric studies regarding the orbit are depicted in Table 6.

Kanchan et al. (2014) [18], in a study similar to ours, compared the FM with the orbit, and they reported (using the Pearson's correlation test) that there was a statistically significant correlation between the OI and FMI, in discordance with our results. They also reported that the FMI in South Indians was 79.70±6.98 mm, and the OI was 84.23±6.64, less than our study showed.

It is important to notice that other relationships with the foramen magnum were observed in other studies, like the carotid foramina [39] (Schaefer 1999), in which it was stated that the correlation was statistically significant, and jugular foramen (Osunwoke et al. 2012) [30] in which they stated that 95% of skulls with a larger FM had a larger jugular foramen. With the comparison between measurements belonging to different ethnicities from other populations of the world, one could verify if there is indeed a correlation to a particular population group, or even, discern the many different types of races that compose a particular population [32].

Study of the shape and size of the FM is crucial to determine pathological changes caused by diseases such as: achondroplasia, occipital vertebra, basilar invagination, condylar hypoplasia, and atlas assimilation, Jeune's asphyxiating, thoracic dystrophy, Marchesani's syndrome, foramen magnum meningioma, Arnold-Chiari malformation, and plagiocephaly [3,16,18,20-22,28]. Those diseases can cause compression of the structures that traverses the FM and produce symptoms like respiratory complications, lower cranial nerve dysfunctions, upper and lower extremity paresis, hypo or hypertonia, hyperreflexia or clonus, and general delay during motor development can appear [28]. Testut and Latarjet (1977) [11] stated that the difficulty of bony resection during surgery is directly proportionate to the size of the FM.

Evaluation of the morphometric aspect of the orbit seems to be relevant in cases of pathological disorders and traumatic injuries, in order to estimate craniofacial asymmetry, the severity of the injury, and to discuss possible complications during preoperative planning, as the orbit is exposed to several types of surgical procedures (optic nerve decompression, vascular ligation, exenteration, excision of the lacrimal gland), requiring anatomical knowledge of the region [9,10,23-26]. It is also stated that tumors confined within the periorbita in the anterior two thirds of the orbit can be approached extracranially, although tumors located in the apical area, medially to the optic nerve, often require a transcranial approach [9,26].

TABLE 1 DESCRIPTIVE STATISTICS OF THE FORAMEN MAGNUM (mm)

	Mean	**SD**	**MinV**	**MaxV**	**Median**
APD	34.23	2.54	26.90	39.72	34.29
TD	28.62	2.83	22.67	36.01	28.15

TABLE 2 - SHAPES OF THE FORAMEN MAGNUM

	N (77)	**%**
Oval	41	53.24%
Round	19	24.67%
Tetragonal	13	16.88%
Egg-Shaped	2	2.36%
Pentagonal	1	1.29%
Hexagonal	1	1.29%

TABLE 3 DESCRIPTIVE STATISTICS OF THE ORBIT (mm)

	Mean	**SD**	**MinV**	**MaxV**	**Median**
OH	32.89	2.45	28.06	39.15	32.65
OB	37.15	2.68	29.45	45.05	37.02

TABLE 4 INDEX AND AREA OF THE FORAMEN MAGNUM AND ORBIT (mm)

	Mean Index	**SD**	**Mean Area**	**SD**
Foramen Magnum	83.75	7.23	772.4	116.7
Orbit	88.72	6.89	-	-

TABLE 5 - Foramen Magnum Studies in Different Populations (mm)

Population/Race	**Author**	**N**	**MAPD**	**MTD**
Indians	Chethan et al., 2012	53	31±2.4	25.2±2.4
Indians	Biswas et al., 2015	53	34.02±1.79	28.10±2.16
Indians	Ganapathy et al., 2014	100	33.9±2.3	28.7±2.5
M Indians	Kamath et al., 2015	41	33.21±3.25	26.92±2.52
F Indians	Kamath et al., 2015	31	30.99±3.49	25.45±2.31
M Indians	Kanchan et al., 2013	69	34.51±2.77	27.36±2.09
F Indians	Kanchan et al., 2013	49	33.60±2.63	26.74±2.36
Indians	Mehta et al., 2014	100	34.32	28.37
Indians	Patel and Mehta, 2014	100	33.70	28.29
M Indians	Santhosh et al., 2013	63	34.37±2.38	28.98±2.22
F Indians	Santhosh et al., 2013	38	33.80±2.56	27.60±2.67
M Indians	Shanthi and Lokanadham, 2013	66	37.1±3.3	32.0±3.1
F Indians	Shanthi and Lokanadham, 2013	34	33.8±3.8	30.4±3.0
M Indians	Shepur et al., 2014	175	33.40±2.60	28.50±2.20
F Indians	Shepur et al., 2014	175	33.10 ±2.70	27.30 ±2.00
M Turkish	Murshed et al., 2013	57	37.2±3.43	31.6±2.99
F Turkish	Murshed et al., 2013	53	34.6±3.16	29.3 ± 2.19
M Iranians	Uthman et al., 2012	43	34.9±2	29.5±2.5
F Iranians	Uthman et al., 2012	45	32.9±2	27.3±2.2
Caucasians	Tubbs et al., 2012	72	31	27
Nigerians	Osunwoke et al., 2012	120	36.11±2.60	29.56±2.60
Greeks	Natsis et al., 2013	143	35.53±3.06	30.31±2.79
Central Western Europe	Gruber et al., 2009	111	36.6±2.8	31.1±2.7
M Brazilians	Manoel et al., 2009	139	35.7±0.29	30.3±0.20
F Brazilians	Manoel et al., 2009	76	35.1±0.33	29.4±0.23
M Brazilians	Suazo et al., 2009	144	36.5±2.6	30.6±2.5
F Brazilians	Suazo et al., 2009	71	35.6±2.5	29.5±1.9

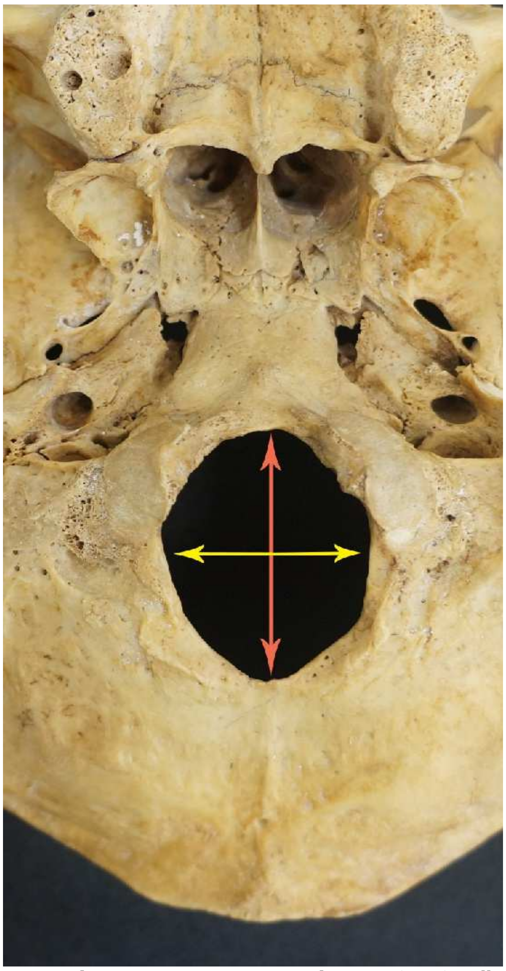
**M = Male, F = Female*

TABLE 6 - Orbit Studies in Different Populations (Right Orbit)

Population/Race	Author	N	MOH	MOB
Indians	Gosavi et al., 2014	128	32.31±2.52	39.46±2.57
Indians	Biswas et al., 2015	53	32.1±2.3	36.6±3.3
Indians	Kumar and Nagar, 2014	68	33.47±1.56	42.06±1.68
Sudanese	Elzaki et al., 2015	110	37.90±2.57	34.10±1.76
M Egyptians	Fetouh and Mandour, 2014	30	35.83±1.23	43.62±1.13
F Egyptians	Fetouh and Mandour, 2014	22	35.53±0.95	42.75±1.35
Chinese	Ji et al., 2015	64	33.45±1.63	39.10±1.83
Nigerians	Ukoha et al., 2011	70	31.90±0.70	36.03±0.37

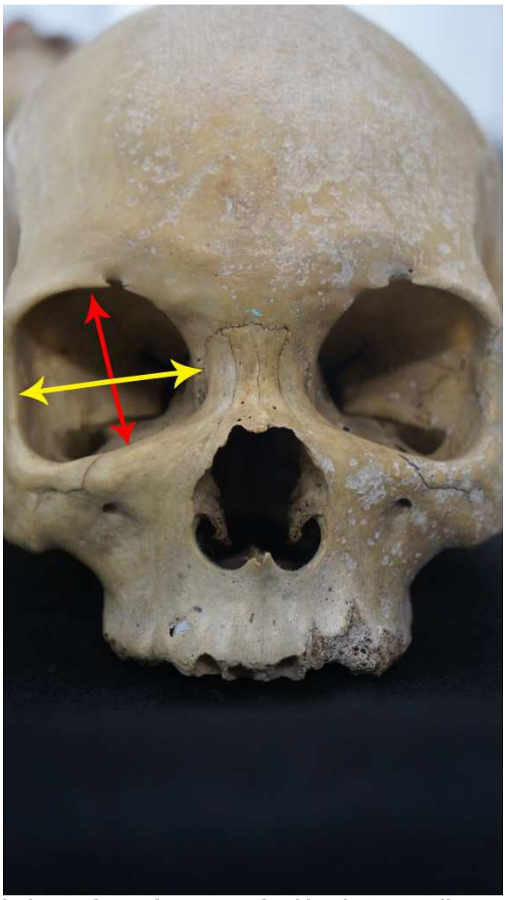
**M = Male, F = Female*

Fig. 1 FORAMEN MAGNUM MEASUREMENTS



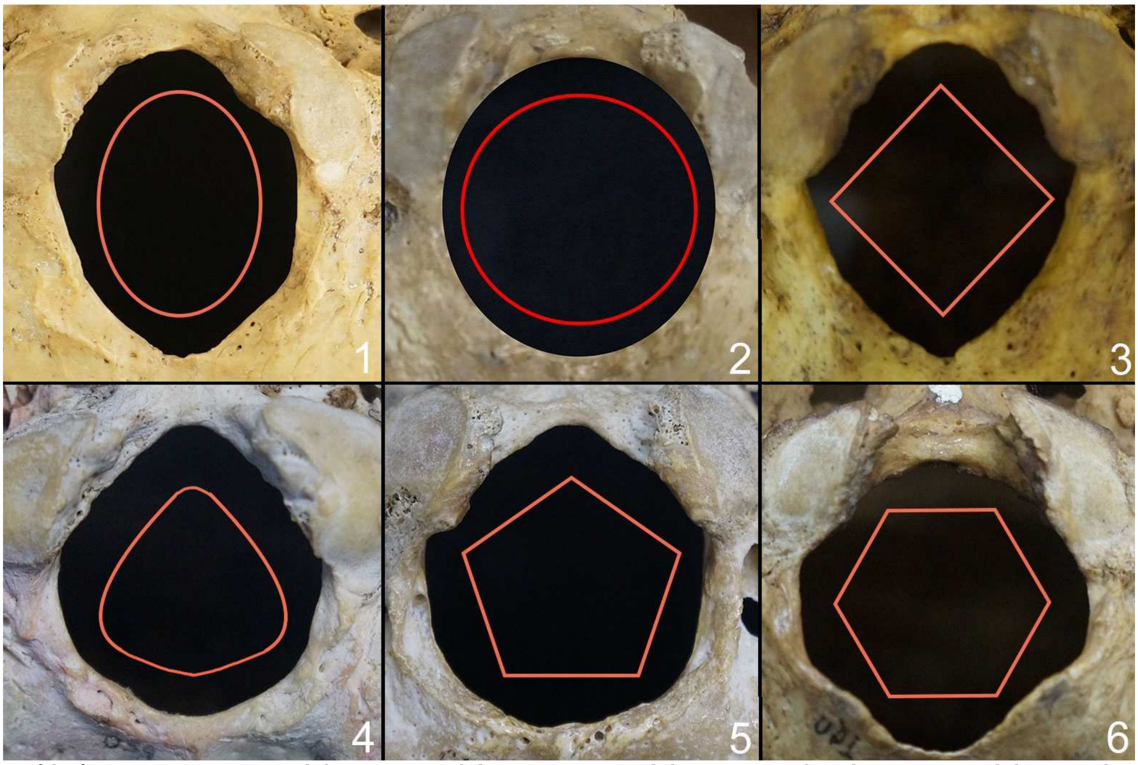
**Foramen magnum measured parameters.Red arrow = antero-posterior diameter (APD), yellow arrow = transverse diameter (TD)*

Fig. 2 ORBIT MEASUREMENTS



**Measured parameters of the bony orbit. Red arrow = orbital height (OH), yellow arrow = orbital breadth (OB)*

Fig. 3 SHAPES OF THE FORAMEN MAGNUM FOUND IN OUR STUDY



**Shapes of the foramen magnum. 1 = oval shape; 2 = round shape; 3 = tetragonal shape; 4 = egg shaped; 5 = pentagonal shape; 6 = hexagonal shape*

CONCLUSION

Even though morphometric studies of the FM and the orbit are relatively frequent, factors such as different classification of the FM shape, different methods of taking the measurements, different methods of statistical analysis, and miscegenation can make the comparison difficult or impossible.

We assessed the clinical and surgical significance of the foramen magnum and the orbit, furthermore, we were able to establish a morphometric parameter for both structures, thus enhancing anatomic and anthropological knowledge regarding Brazilian skulls. Furthermore, our data presented a base in which the investigation of the quantitative morphology of the foramen magnum development in Brazilian skulls.

Our statistical analysis showed a moderate correlation between these structures could indicate a morphometric relation between the neurocranium and the viscerocranium. Since the orbit is an anatomic area used to determine the sex and the ethnicity, its correlation with the foramen magnum can be an important factor for forensic medicine.

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