Original article

Morphometric analysis of the foramen magnum in human skulls of brazilian individuals: its relation to gender

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Abstract

Introdution: The morphological characteristics obtained by craniometry may be the key to sex determination and enable us to identify unknown individuals in anywhere in the world. Aims: The purpose of this study was to evaluate the effectiveness of the linear morphometry of foramen magnum to verify the morphological characteristics for gender determination in human skulls of Brazilian individuals. Methods: With a digital caliper, were made three non-consecutive measurements of the foramen magnum in 215 human skulls (139 male and 76 female), from the collection of the Department of Morphology and Descriptive Topography – UNIFESP/SP with registered data on nationality, gender, and age. The craniometric measurements were made in accordance with the protocol defined by Günay and Altinkök (2000). The data were submitted to intraclass correlation coefficient (ICC) and Student *t*-test with significance level of 5%. Results: There were no statistically significant differences (chi-square, $p > 0.05$) between the ethnic groups within each gender. The ANOVA and Tukey tests showed that the gender influenced the width of the foramen magnum. The FM is higher in males (30.3 ± 0.20) than in females (29.4 ± 0.23), but not in length ($p < 0.05$). Conclusion: The morphometric linear method of the foramen magnum (width) was able to determine the morphological differences between sexes and can be used in conjunction with other anthropological techniques to gender determination of unknown individuals.

Keywords: foramen magnum, morphometric, skull, human identification, sex.

1 Introduction

The morphological differences between skulls of different genders are mainly determined by genetic factors rather than nutrition, hormones, or muscles (GÜNAY, 2000). Thus, the determination of gender in human skulls is based on morphological differences, mainly on the size and strength of certain structures (ROSING, 2007), which may be characteristics of each population that are influenced by genetic, environmental, and socioeconomic factors (SAUNDERS and YANG, 1999).

The measurements of the skeleton bones, mainly the neurocranium (brain case) and viscerocranium, suffer influences of various factors; however, they are often used for human population morphological studies of age estimation, stature, ethnicity, which are relevant aspects of forensics investigation and anthropological examinations of unknown individuals (ISCAN, 2001; HARVATI and WEAVER, 2006).

For Adams, Rohlf and Slice (2004), the morphometric techniques used in the scientific literature has shown a strong interest in monitoring changes through the evaluation of the skulls among different human populations. According to these authors, various factors that are capable of causing morphological changes in the human skeleton have attracted the interest of the scientific community. The use of accurate methods to identify the differences between genders to understand their changes properly are the current challenges faced by researchers.

Recent studies report that morphometry is a fast and efficient method for the evaluation of morphological characteristics, such as ethnicity, gender, age, genetic factors, dietary habits, and regional variations which can alter the shape and size of bone structures. These aspects are significantly important in determining the anthropometric changes between different populations and genders (HUMPHREY, DEAN and STRINGER, 1999; PRADO and CARIA, 2007).

Gapert, Black and Last (2008) stated that the skull base is covered by a large mass of tissues that preserves the region of the foramen magnum, especially in standing position. For these authors, the foramen magnum has been studied morphometrically to assist in determining the gender when there is the involvement of other parts of the skeleton caused by trauma, fire, explosion, or severe destruction. It is a useful study, since the dimorphism of gender is almost always present.

Many craniofacial skeletal structures are damaged after air accidents, mass disasters, fire, explosion, or injuries resulting from violence making it difficult to determine the gender and the consequent identification. Thus, the skull base and the occipital bone are protected by a large amount of soft tissue, and the anatomical position is useful in such cases (GRAW, 2001).

Herrera (1987), Günay and Altinkök (2000), and Muthukumar, Swaminathan, Venkatesh et al. (2005) used linear morphometric measurements of the foramen magnum as a criterion for gender determination, which is higher in men than women.

Gapert, Black and Last (2008) also evaluated the foramen magnum of nineteenth century British adult skulls morphometrically showing significant differences between men and women classifying 70% of the male skulls and 69.7% of the female skulls by the discriminant function and 76% of men and 70% of women by linear regression. This study confirmed the importance of this region to identify the gender.

In view of the great racial miscegenation of the Brazilian population, the purpose of this study was to evaluate whether the linear morphometric method applied to verify the morphological characteristics of the foramen magnum of Brazilian adult human skulls would be enough to differentiate the genders.

2 Material and methods

215 skulls (76 females and 139 males), 92 white and 123 black between 20 and 80 years old, from the collection of the Department of Descriptive Morphology and Topography of the Federal University of Sao Paulo were evaluated.

From a total of 510 skulls, only 215 were used due to the exclusion criteria used in this study. Only good condition Brazilian adults skulls with gender, age, and ethnic group fully identified in the book record were examined for this purpose. The skulls of children, damaged, with pathological conditions, incomplete, without identification, or different ethnic group were excluded.

Craniometrical measurements (length and width) of the foramen magnum of the occipital bone were performed by means of a digital caliper (JOMARCA®) of 0.1 mm, and were repeated three times by the same examiner at intervals of two weeks between each measurement using the protocol described by Günay and Altinkök (2000):

1) Length of the foramen magnum (WFM) - distance in a straight line from the end of the anterior border (basion) through the center of the foramen magnum until the end of the posterior border (opístio), toward the median sagittal plane (Figure 1).
2) Width of foramen magnum (WFM) - distance in a straight line from the end of the border right side, with the concavity stronger through the center of the foramen magnum to the opposite end of the lateral border of concavity more pronounced, with transverse direction (Figure 1).

2.1 *Statistical analysis*

The data were submitted to statistical analysis (mean ± standard error), the Intra-class correlation test (ICC) to determine the reliability of measurements, the Chi-square tests, the Mann-Whitney and Student t test, with significance level of 5%. The logistic regression analysis and odss Ratio (OR) for the length (LFM) and width (WFM) of the foramen magnum by means of the Bioestat 5.0 software (Mamiramuá Foundation, Bethlehem, PA) were also used.

3 Results

The test of intraclass correlation (ICC) for the measurements of the foramen magnum showed excellent replicability ($ICC > 0.9$, $p < 0.0001$), which means that the measurements taken showed reliable reproducibility.

As it can be observed in Figure 2, there was a prevalence (chi-square, $p < 0.05$) of males (64.7%) on the female skulls. However, no statistically significant differences were observed (chi-square, $p > 0.05$) between the ethnic groups for each gender.

The distribution of the skulls based on gender showed statistically significant differences (Mann-Whitney, $p = 0.0233$) between male skulls (41.8 ± 12.6 years) and female skulls (39.7 ± 18.1 years); the former were older than the latter.

The statistical analysis (multivariate ANOVA and Tukey test) showed that gender influenced the width of the foramen magnum but not ($p < 0.05$) the length. More statistical differences in the measurements were found in male than in female skulls. Considering all skulls analyzed of both gender; it can be said that no measurement was influenced ($p > 0.05$) by gender or teeth.

To determine the dependence of the variables WFM and LFM, in relation to gender, ethnicity, and teeth, the

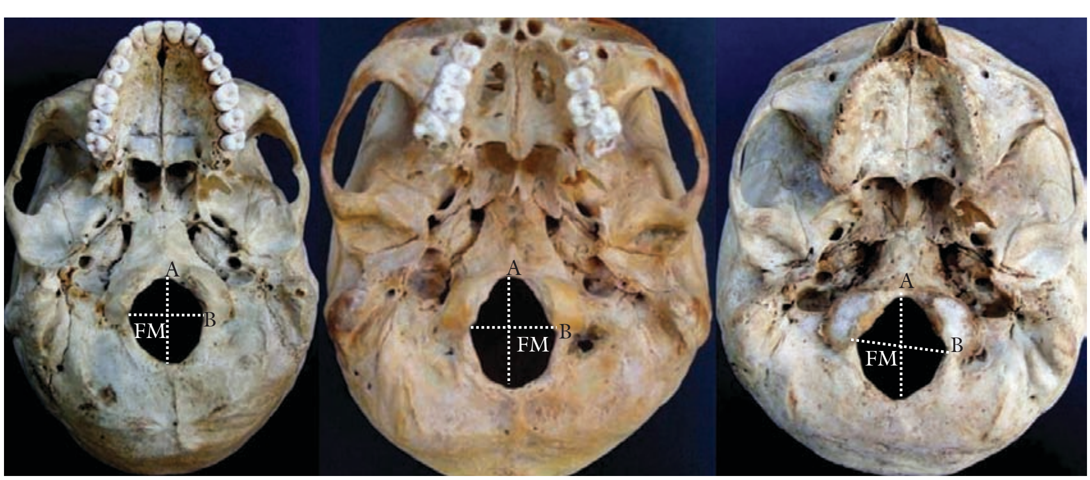

Figure 1. Lower view of Brazilians human adult skulls. Representative images of the measures undertaken in the foramen magnum; the dashed lines represent the anteroposterior and laterolateral measurements from points A and B, respectively.

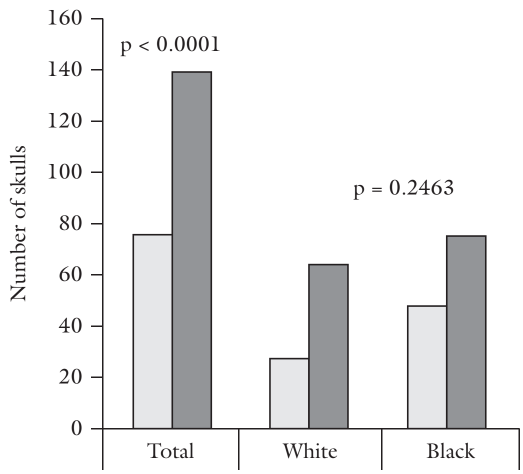

Figure 2. Shows the distribution of the 215 skulls with the size of the foramen magnum correlated with ethnicity and teeth.

Table 1. Mean ± standard error of the linear measurements (mm) Length - LFM (CFM) and Width - WFM according to various factors.

Factor	Length - LFM	Width - WFM
Gender		
Female (n = 76)	35,1 (±0,33)	29,4 (±0,23)
Male (n = 139)	35,7 (±0,29)	30,3 (±0,20)
P value	0,261	0,008
Ethnic group		
White (n = 92)	35,7 (±0,37)	30,2 (±0,24)
Black (n = 123)	35,3 (±0,27)	29,8 (±0,20)
P value	0,279	0,399

*Differences between gender and race.

Table 2. Multiple Logistic Regression considering the LFM and WFM variables in relation to gender, ethnicity, and age.

Variable	Factor	p-value	Odds ratio	IC 95%
LFM	Gender	0,2539	1,4078	0,78 a 2,53
	Ethnicity	0,0825	1,7859	0,93 a 3,44
	Age	0,1095	1,0784	0,98 a 1,18
WFM	Gender	0,3056	1,3649	0,75 a 2,48
	Ethnicity	0,1045	1,7255	0,89 a 3,33
	Age	0,0066	1,204	1,05 a 1,38

multiple logistic regression analysis was used and the results are presented in Table 2.

The results shown in Table 1, overall, indicate that the variables were not influenced by gender, ethnicity, and condition of teeth ($p > 0.05$). Age had an influence on the variables ($p < 0.05$); however, the relationship was very small (odds ratio < 2.0).

3.1 Discussion

The determination of the morphological differences between genders and ethnic groups requires practice and precision. The use of human skull fragments is employed with a certain parsimony due to the great fragility of the viscerocranium which are more susceptible to fractures or accidents Graw (2001). For this reason, the foramen magnum was used since it is a regular structure and less likely to major morphological changes.

Focusing on forensic dentistry and medicine, the morphometric analysis can be used as part of an investigative process prior to more sophisticated and expensive analyses such as the DNA examination (TEIXEIRA, 1982; PÖTSCH, ENDRIS and SCHMIDT, 1985). The morphometry of the skull and jaw are methods for the assessment of sexual dimorphism that can assist in the determination of gender, as already demonstrated the trusted results of (GÜNAY, 2000; WESTCOTT and MOORE-JANSEN, 2001; MURSHED, CICEKCIBASI and TUNCER, 2003).

The analysis of foramen magnum to determine gender has been limitedly used in Brazilian populations (TEIXEIRA, 1982); however, it has shown favorable results in Turkish (MURSHED, CICEKCIBASI and TUNCER, 2003), Spanish (HERRERA, 1987), Indian (ROUTAL, PAL and BHAGWAT, 1984) and English populations (GAPERT, BLACK and LAST, 2008). Therefore, it is necessary to check if the criteria used to determine the gender in other populations with less racial miscegenation is reliable for the Brazilian population.

The comparison of the morphometric analysis obtained in this study with the results of other studies had the following results: the length of the foramen magnum of Brazilian male skulls (35.7 ± 0.29) was lower than the Turkish (37.2 ± 3.43) Murshed, Cicekcibasi and Tuncer (2003), Spanish (36.2 ± 0.3) Herrera (1987), and English populations (35.91 ± 2.41) Gapert, Black and Last (2008), but it was higher than the Indian population (35.5 ± 2.8) Routal, Pal, Bhagwat et al. (1984). The same measure for the female skulls of the Brazilian population (35.1 ± 0.33) was higher than those of the Turkish (34.6 ± 3.16) Murshed, Cicekcibasi and Tuncer (2003), Spanish (34.30 ± 0) Herrera (1987), Indian (32.0 ± 2.8) Routal, Pal, Bhagwat et al. (1984), and English populations (34.71 ± 1.91) Gapert, Black and Last (2008).

Regarding the width of the foramen magnum, the values of the Brazilian male skulls (30.3 ± 0.20) were higher than those of the Indians (29.6 ± 1.9) Routal, Pal, Bhagwat et al. (1984) only and lower than the Turkish (31.6 ± 2.99) Murshed, Cicekcibasi and Tuncer (2003), Spanish (31.1 ± 0.3) (HERRERA, 1987), and English populations (30.51 ± 1.77) Gapert, Black and Last (2008). The same measure for the female skulls of the Brazilian population was higher than the Indian (27.1 ± 1.6) Routal, Pal, Bhagwat et al. (1984) and Turkish populations (29.3 ± 2.19) Murshed, Cicekcibasi and Tuncer (2003) and lower than Spanish (29.6 ± 0.3) Herrera (1987) and English populations (29.36 ± 1.96) Gapert, Black and Last (2008). These aspects can be attributed to the racial mixing, which is common in Brazil and less frequent in other populations (PRADO and CARIA, 2007).

Most of the skulls evaluated in this study were of the Caucasian Brazilians, people from the southeastern region which was strongly influenced by Europeans in the beginning of the nineteenth century, since there was large-scale racial miscegenation between Europeans (Portuguese, German, Italian, etc.), native Indians, and black Africans brought as slaves, which may explain the heterogeneity correlation between people compared with Brazil (PRADO and CARIA, 2007).

Measurements of the foramen magnum performed by Teixeira (1982) in a smaller number of elements (40 skulls - 20 men and 20 women) and small number of specimens limited the conclusions and correlations, especially in relation to a miscegenation population such as the Brazilian population. Therefore, we believe that the data obtained in this study provide more faithful and reality data.

The results of this study indicated that the foramen magnum of male skulls were older and larger than those of women (Mann-Whitney, $p = 0.0233$). The morphology and development should be considered in the analyses. When analyzing the spinal cord for example, the diameter of the foramen magnum should not be influenced because it is known that the central nervous system is developed and matured prior to the skeletal system with a complete fusion of different parts of the occipital bone between 5-7 years of age Scheuer (2002). Another aspect is the weight of the head which is transmitted through the atlanto-occipital region of the foramen magnum, and a male brain is heavier than a female brain. In addition, with age, we lose muscle mass and bone structure, and consequently it justifies the larger diameter and the differences between genders.

According to Woo (1931), an asymmetric craniofacial growth can occur with a predominance of the right side over the left one. Vig and Hewitt (1975); Shah and Joshi (1978), stated that the craniofacial asymmetry is common in most individuals although there is no consensus on the side of asymmetry not pathological. In fact, the human body frequent asymmetry is considered normal because the parts are developed independently, in general due to a local adaptation to functional demands, and not as a uniform pattern of asymmetric growth (BISHARA, TREDER and JAKOBSEN, 1994; HUGGARE and HOUGHTON, 1995; SPERBER, 2001).

The results of Olivier (1975) and Durić, Rakočević and Donić (2005) showed larger of the foramen magnum, especially the anteroposterior and laterolateral. According to the authors, the absence of craniofacial symmetry can occur regardless of age, gender, or ethnicity. However, the results of this study do not confirm these findings, since there was a statistically significant difference in the laterolateral distance between the two genders and evaluated in older skulls.

The present asymmetry ranging from a minimal to severe, in some cases due to genetic factors, is due to the fact that the head consists of soft and rigid structures susceptible to external masticatory forces or of any nature, which are subjected to laterolateral variations becoming more asymmetrical. These characteristics, according to Prado and Caria (2007) can be attributed to different factors such as: food, climatic factors, climatic influences and racial miscegenation.

The craniofacial development and growth are factors that may influence the differences of the skull base; it gives passage to the main vascular bundle-encephalic nerve (ENLOW and HAS, 2006). The morphological differences between skulls of different genders are determined primarily by factors related to size. The width of the foramen magnum of Brazilian skulls showed significant results with the predominance of males over females. According to Enlow and Has (2006), this difference is related to the fact that the main neurovascular bundle such as the cervical spinal cord, vertebral arteries before and after, nerves and meninges pass through the skull base. Thus, the area of foramen magnum is larger in males due to larger structure of skeletal muscle in men.

In the process of refurbishing the skull base, there are changes in the stability of the spaces filled by cranial nerves and vessels with the expansion of the encephalic hemispheres as the skull base sutures increase. Moreover, the foramen magnum is subjected to the process of remodeling to maintain its proper position, which moves with bone deposition and bone resorption following the corresponding movement of the nerves and blood vessels of the skull base such as brain expanding. This movement of relocation is different in magnitude and direction from the movement in the remodeling of the side walls of the posterior fossa of the occipital skull. That remains the position proportional remodeling of the spinal cord, even if the floor of the posterior fossa of the skull that borders expand the cord is considerably more than the circumference of the foramen magnum. Moreover, the increments are much larger growth of hemispheres and occipital scale in contrast to the much smaller increments than the growth of the cord and the foramen magnum. The growth of soft tissue is also necessary in any way by the conditions that produce evidence of regional control, local development, in response to those circumstances architectural (ENLOW and HAS, 1998).

4 Conclusion

There was morphometric difference but no morphological difference of the foramen magnum between genders and ethnic groups (Caucasian and Negroid) evaluated. The linear morphometric measurements method applied in the width of the foramen magnum was effective in determining the gender of the skulls of Brazilian individuals. Together with other anthropological techniques, this linear morphometric method of foramen magnum can be effective to obtain reliable results for the determination of gender in Brazilian human skulls.

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