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Research Article

Tomographic Morphometry of the Magnum Foramen during Postnatal Development: Preliminary Results

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Abstract

Introduction: The foramen magnum (FM) is an anatomical structure located in the posterior fossa of the skull. This foramen becomes relevant in compressive syndromes of the central nervous system, which compromised the neuronal function and circulatory failure. The purpose of this study is to determine the morphometric values of the foramen magnum in studies by image and its relationship with the sex, ethnicity and pre- and post-natal history, being the first of its kind in our region.

Material and Method: This are an observational, cross-sectional and retrospective study. We analyzed 152 images of computed tomography of individuals (0 - 4 years old) of both sexes that did not present pathologies that affect the morphology of the skull. We analyzed the CT obtained from the year 2013 onwards. These images are part of the files of the Service of Neuroimaging Studies of the Pediatric Hospital S.A.M.I.C.; "Prof. Dr. Juan P. Garrahan", City of Buenos Aires. Methods were used based on morphometry of the linear measurements, angles and distances, obtaining a total of four measures. An AGFA software was used for image processing, getting the length of the foramen magnum, the transverse diameter, its area and shape.

Results: 82 of the subjects were boys and 70 girls. The mean length of the FM increases gradually, being 28,43 mm at birth and 33,95 at age 4, in the same way, the mean transverse diameter increases from 21,06 mm at birth to 28,83 mm at age 4. The FM area grows from 453,63 mm^2 at birth to 718,28 mm^2 at age 4. The predominant shape of the foramen magnum in both sexes was pentagonal.

Conclusion: There are significant differences in longitude and area of the FM between men and women, being higher in males. It was also observed an increase in the results concomitant with age.

Keywords: *Skull; Foramen Magnum; Children; Anthropometry; Variations*

Introduction

The base of the skull is divided into an anterior cranial pit, a middle and a posterior. The middle and posterior cranial pits are separated by the petrous portion of the temporal; and the right rear pit is separated from the left by the clivus and the magnum foramen. The foramen magnum is a large opening at the base of the skull, is oval, wider backwards, and its larger diameter is anteroposterior. Through the magnum hole pass the junction of the spinal bulb with the spinal cord, meninges, vertebral arteries, anterior and posterior spinal arteries, accessory nerves (XI) and veins that communicate with the inner spinal venous plexus.

The occipitalis, of all the bones of the skull, the one whose development has led to more numerous research and more disputed controversies. It forms the floor of the rear pit with three portions: an anterior or basioccipital, two sides or exoccipital and a posterior or supraoccipitals.

In relation to each of the sketches:

1. **Basioccipital:** Develops by a single and middle point that extends along the cartilaginous basil plate that surrounds the occipital hole. Ahead, the basioccipital presents in the course of its development a tape of primitive cartilage that plays the role of conjunction cartilage and separates it from the sphenoids. From behind, similar tapes separate it from the exocytosis.

2. **Exoccipitals:** One right and one left, they develop each by a bone point located on each side of the occipital hole. This point of ossification extends, in the front, in the direction of the basioccipital and from behind towards the supraoccipitals. Locally the occipital condyle develops in each of these two pieces.

3. **Supraoccipitals:** Each is developed by an ossification point. This point sits on the cartilage of the posterior roof of the skull, but in the proximity of the upper boundary of the skull. Each point is quickly welded to the opposite side and hence the formation of a single piece. This, separated primitively from the top of the shell formed by the interparietals, is also quickly soldered to it. In contrast, welding with exocypits occurs at two years.

4. **Interparietals:** Each interparietal is constituted by a unique ossification center located somewhat outside the middle line, in the connective tissue of the skull vault. These two centers are quickly sold in the middle line; in contrast, its lower edge is soldered later to the underlying or supraoccipital portion (two-month embryo).

All these bone pieces appear in the human skull from the seventh to the eighth week. The base parts, the basioccipital and the exoccipital parts, remain for a long time relatively independent. After birth the tapes of the bonding cartilage still persist. They are true fertile conjunction or growth cartilage on both sides. This device plays a key role in the growth of the different diameters of the cranial cavity of this region. Welding is usually done only at the age of four [1].

From a general point of view, this bone represents the cranial assimilation of the cranial part of the primitive spine. It represents in the course of embryonic life two perfectly distinct regions: one, which corresponds to the base, is membranous at the beginning, then becomes cartilaginous and finally bone; while the other, which corresponds to the vault, does not pass through the concurrent state. However, the cartilaginous portion of the base is raised behind the occipital hole to form the synoptic or posterior roof. This cartilaginous portion, which contributes to the development of the squeaky portion of the occipital, is related at the top to the membranous portion of the skull, which will also contribute to the formation of the upper bone [2,3].

Various pathologies including synomical and non-syndromic congenital defects and trauma-related injuries, among others, affect the normal development process of the skull base. Although the clinic and the physical examination guide the diagnosis of the pathologies that settle in this area, the characterization of them hangs from imaging techniques. In addition, the increasing incorporation of microsurgery techniques requires mastering the normal anatomy and craniometric repairs used to study this region, taking into account the peculiarities of each ethnic group or the anatomical variants of the different structures. But, as is well known, two criteria are met in the concept of anatomical "normality"; a statistical criterion (the characteristic observed in the largest percentage of the population) and a physiological criterion (the characteristic that ensures optimal function) [4].

There are similarities between the anatomical values obtained in different cadaveric studies, however, the same is not true of the radiological values obtained in studies carried out with images. As most studies in adults or small samples of postmortem skulls, the change of these structures *in vivo*, throughout growth and development, is largely unknown [5-7].

There are no studies, *in vivo*, of the development of the skull base. There are also no clear normal cut-off values of the size of the different substructures of the cranium in our population, nor that they contemplate ethnic variations. Previous studies on the subject have been conducted on small samples of adult patients [8,9]. A better understanding of the development and growth of the skull, as well as its different measurements, are of fundamental diagnostic importance and when planning a surgical procedure. The dimensions and shape of the magnum foramen can determine changes in surgical behavior in transcondylar approaches, for example for tumor resection in that area. Therefore, the change of these structures *in vivo*, throughout growth and development, is largely unknown.

Materials and Methods

This is an observational, cross-sectional and retrospective study. 152 CT images previously obtained from infant individuals (0 - 4 years of age) of both sexes who do not have pathologies affecting the morphology of the skull were analyzed, from 2013 onwards. The images are part of the archive of the Neuroimaging Service of the Hospital de Pediatría S.A.M.I.C. "Prof. Dr. Juan P. Garrahan", City of Buenos Aires.

To identify clinically, surgically or anthropologically relevant craniometric measures, a bibliographic search was conducted in Pubmed, Scielo, Lilacs, under the terms "skull base", "anatomy", "normal imaging", "computed tomography, "measurements" resulting in 95 publications. From the bibliographic literature review carried out, 4 linear measures, angles and areas were defined:

- Mac Rae Line: Length foramen magnum (FM), from the basion (center of the previous edge of the foramen magnum) to the opisthion (midpoint at the back edge of the magnum foramen) (See figure 1).
- Transverse FM diameter: Maximum distance between the side edges of the foramen (See figure 2).
- FM area: FM contour-delimited area (See figure 3).
- FM shape.

Figure 1: *Mac Rae line (from battery to opisthion).*

The above measurements were made using a 64-track General Electric lightspeed VCT multicut computed tomography (with automatic exposure control), with isotropic volumetric acquisition with cutting thickness of 0.625 mm; Using AGFA image processing software, available at the Hospital. The obtained variables were analyzed using uni and multivariate statistical techniques (ANOVA, regression, analysis of major components, Student t test for paired samples). For the formation of the sample of normal subjects, whether the inclusion and exclusion criteria detailed below have been given.

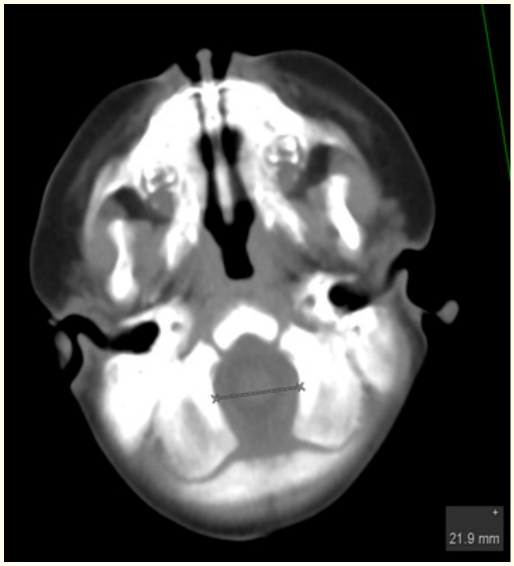

Figure 2: *Fm Transverse Diameter: Maximum distance between the side edges of the foramen*

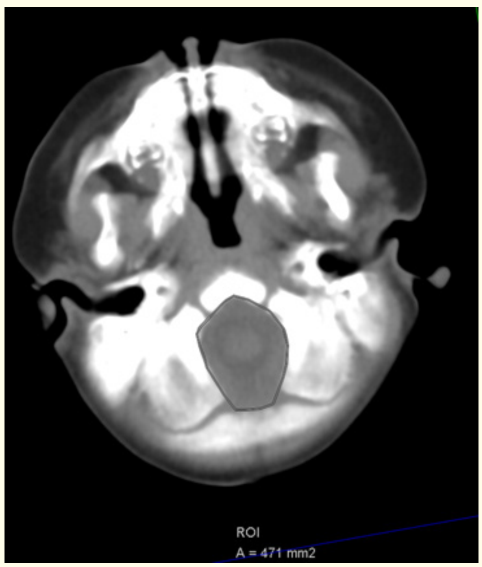

Figure 3: *Area of the magnum foramen, limited by the contour of the same.*

Inclusion

Individuals between 0 and 4 years of age of both sexes who do not have pathologies affecting the morphology of the skull. Patients with neck and head CT are sprayed and if possible those who had more than one CT (at different times).

Exclusion

History of premature, dystonic births, clinical micro or macrocephaly, recent skull-cervical trauma, metabolic diseases associated with bone disturbances (abnormalities of phosphometabolism-calcium, mucopolysaccharidosis, etc.), skeletal dysplasias, tumors or intracranial cysts, hydrocephalus syndrome, genetic syndrome, delay of intrauterine growth.

Since the error in the measurement log can significantly affect the results of statistical analyses, an estimate of their nature and magnitude was made by evaluating the measurement error. Once the sample was selected, three observers with no previous experience in obtaining the measurements to be relieved, made 3 sets of measurements spaced at seven-day intervals. With the measurement values of each individual and each observer, a Variance Analysis (ANOVA) of repeated measurements was carried out using the R statistical software. From this analysis, the measures in which each observer had errors were identified, after which they were repeated by each. A repeating ANOVA was also performed to assess observer error. Based on the results of this analysis, measurements that were significantly error-free were then identified. Then, among observers, an attempt was made to join criteria for measuring the measures that were misleading, in order to minimize it. After re-performing the failed measurements, when repeating the analysis, these errors were found to have been eliminated. With all the images analyzed, and after having eliminated intra and interobserver errors, it continued to develop the tables and graphs in the Microsoft Excel program, discriminating in each of them the sex and age, in order to be able to calculate average values, standard deviations, t-test for paired samples (between males and females),considering as statistically significant values of p-0.05.

Results

So far 152 individuals were studied, 70 female and 82 male individuals.

Length

The average length (Mac Rae line) in children aged 0 - 1 year was 28.43 mm, with a number of 8. In the 1 - 2 year group it was 33.47 mm, with a 20 mm; 2 - 3 years, 34.58 mm, with a no. 24 and 3 - 4 years, 33.95 mm, with a no. 18. The maximum value was 40.7 mm and the minimum was 26 mm; the first in a child aged 3 to 4 years and the other in the younger age group. In women, the maximum value was 39.6mm, in a girl of 3 - 4 years and the minimum of 23.4 mm, in a girl of 1 month of age. The average in girls aged 0 to 1 years was 26.38 mm, with a n-8; 1 - 2 years was 31.89 mm; with a no. 19;33.54 mm of 2 - 3 years, with a 22nd and 33.63 and in girls aged 3 - 4 years, with a no. 11. The difference between males and females was statistically significant (p. 0.0141 for an IC of 95%).

Transverse diameter

The average in males from 0 to 1 year was 21.66 mm; 1 - 2 years was 26.41 mm; 2 - 3 years was 27.54 and 3 - 4 years, 28.83 mm; being the maximum value of 36 mm, observed in a 3 - 4 year old and the minimum of 19 mm, in a child of 0 - 1 year. In girls, the average values were similar to those of the male sex with an average of the first group (0 - 1 year) of 21.06 mm; the second group (1 - 2 years) of 25.55 mm; 27.32 mm in the third group (2 - 3 years) and 28.15 mm in the fourth group (3 - 4 years). The maximum value recorded was 35.3 mm, in a girl aged 3 - 4 years and the minimum of 18.3 mm, in a girl of 0 - 1 year. The difference between males and females was not as significant (p-0.0698 for a 95% CI).

Area

The average in children from 0 to 1 year was 435.63 mm^2; 1 - 2 years was 643.8 mm^2; in children aged 2 - 3 years was 697.65 mm^2 and 3 - 4 years, 718.28 mm^2. The maximum value recorded was 1112 mm^2, in a child aged 3 - 4 years and the minimum, 343 mm^2, in a 1-month-oldchild. In girls, the average of 0 - 1 year was 391.25 mm^2; 1 - 2 years was 566.17 mm^2; 2 - 3 years was 658.05 mm^2 and in the third group, it was 729.09 mm^2. The maximum value in girls was 994 mm^2, in a girl of 3 - 4 years and the minimum, 299 mm^2, in a girl who did not complete the month of age. The difference between males and females was very significant (p-0.009 for an IC of 95%).

Way

Overall, bringing the 150 cases, the prevailing form of the magnum foramen is pentagonal, with a total of 52 cases (43%), following in place the tetragonal with 25 cases (16.55%) and thirdly the irregular shape with 14 cases (12.5%) (See figure 4).

In both boys and girls aged 0 - 1 years, the pentagonal form prevails with a total of 13 on the 16 cases analyzed; in boys 1 - 2 years, the tetragonal form prevails; 2 - 3 years, the pentagonal; and 3 - 4 years, there is a tie between the pentagonal and hexagonal form. When talking about girls, 1 - 2 years of age prevails the pentagonal form; 2 - 3 years, the irregular shape, and 3 - 4 years, the pentagonal again.

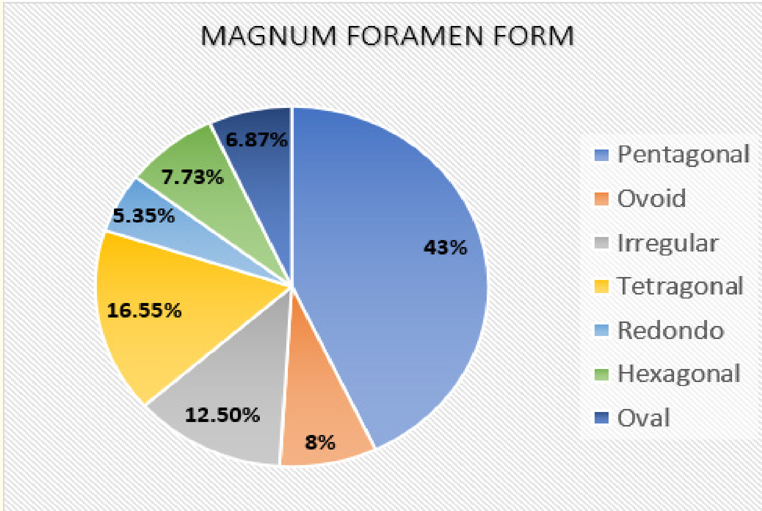

Figure 4: *The graph shows the percentage distribution of the form of the magnum foramen.*

Discussion

As the first study on the morphometry of the magnum foramen in children, discriminating in sex and age, and using CT scans, the results obtained differ significantly and with the rest of the authors (See table 1) [11-13]. In the present and studio, the average length in boys and girls, without age discrimination was 31, 88 mm and 31,36 mm, respectively. However, no staggered increase in length was observed according to age growth in boys, as a higher average was observed for boys aged 3 - 4 years, which was not observed in girls. When compared to previous studies, which measured not only by tomography but also in skulls, the results are significantly minor. In these, the average length according to Shepur, was 38.5 mm and according to Murshed 37.7 mm and 34.6 mm in men and women respectively; both lower than this work. It should be borne in mind that Shepur's work does not discriminate on the basis of sex, and that both were done on adult populations, over the age of 18.

Authors	FM Length	FM transverse diameter	FM Area
Schmeltzer., *et al*. 1971	35 mm	30 mm	-
Catalina - Herrera 1987	35.2 mm	30.3 mm	-
Wanebo and Chicine 2001	36 ± 2 mm	32±2 mm	-
Murshed., *et al*. 2003	35.9mm	30.4mm	863. 35 mm^2
Tubs., *et al*. 2010	32 mm	28 mm	-
Get meat here in 2012	37.06 mm	32.98 mm	877.4 mm^2
Shikha Sharma 2015	38.76 mm	33.44 mm	970, 57 mm^2
Muralidhar P Shepur 2014	36.85 mm	28.35 mm	810 mm^2
Esteban Espinoza G 2011	36.5 mm	31 mm	837.5 mm^2
Present Study 2017	31,5 mm	27,2 mm	604,98 mm^2

Table 1: *Comparison between authors.*

In the case of the transverse diameter, the values in boys exceed in a little significant way the values observed in girls of similar age, obtaining an average generated of 26.78 mm in men and 26, 08 in women; obtaining a value of $p > 0.05$ (0.11). In this measurement, the results have risen continuous growth from 0 to 4 years; situation that was not observed in the length of the foramen magnum. If compared to the works of Shepur and Murshed, the numbers in this study are also smaller. The values reported by Murshed in Turkish population were 31.6 mm in men and 29.6 mm in women; while in Shepur's work it was 29.6 mm in men and 28.6 mm in women, both below the present.

With regard to the area of the magnum foramen and comparing with previous studies, this is where the greatest differences were observed. Without discriminating by age, in this study, the results were 623.83 mm2 in men and 586.14 mm^2 in women, averaging between them 604.98 mm^2, resulting well below studies such as Mur (863 mm^2), Shika Sharma (970 mm^2) or Burdan (877.4 mm^2) (See table 1). Comparison of measures according to the age of children shows increasing results and with a large difference between one age range and another, with a value of r-0.52. What is surprising and different from the rest of the measurements is the highest value observed in girls aged 3 - 4 compared to boys of equal age, being 729, 09 mm^2 in the first group and 718, 28 mm^2 for the second.

In disagreement with previous studies, where the form of the prevailing magnum foramen was rounded and irregular (Sharma-Ashad/Murshed), in our work the pentagonal form is most often observed, except in girls of 2 - 3 years, where the irregular shape prevails. Previous studies have shown that the form of FM relates to ethnicity, something that will be investigated in the final version of this work [13].

The magnum foramen is taken as a safe anatomic mark in occipital condyle resection surgeries [14,15]. This study illustrates the morphometric information and variations in the morphology of foramen magnum, emphasizing its clinical implications. This study can serve even in the field of legal medicine in the recognition of NN (unidentified) individuals. Thanks to the advancement of CT, anatomical research on the foramen magnum became an interesting field of medicine.

Conclusion

Comparing the measurements of length, transverse diameter and area of the foramen magnum, it was seen that the results obtained in men are greater than those achieved in women. When comparing the results obtained by age, an increase in the same according to the age of the sample was observed, with more than 3 to 4 years compared to the rest. In a single case this is not observed; it is the length in children from 2 to 3 years, which is greater than that of the older group. This would mean that the length of the magnum foramen would not be conditioned by the growth of the child's skull. Both the Mac Rae line and the transverse diameter should be taken into consideration during craniovertebral and spinal cord surgical procedures. Morphometric analysis of the magnum foramen can be used as support in research to estimate sex and age in cases of damaged and incomplete skulls being found. Knowledge of the dimensions of the magnum foramen may even help determine the cause of certain syndromes, such as Arnold Chiari's; as well as serve as a reference and establish a transcondylar safety margin in occipital condyle resection surgeries.

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