

Morphometry and spatial correlation of the foramen magnum and spinal cord through the magnetic resonance in normal young adults – anatomical and clinical aspects

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Abstract

Aim: to establish the spatial relationship between the surfaces of foramen magnum (FM) and spinal cord (SC) identifying how much of the FM surface is occupied by the SC. **Material and methods:** 40 normal adults (23 females) with a mean age of 22 yrs (18-25) were evaluated through MRI to evaluate the sagittal and transversal diameter of foramen magnum and spinal cord. The surface area of FM and spinal cord was calculated, in the craniovertebral junction. **Results:** the sagittal diameter was consistently greater than the transversal diameter in the FM with a mean value of 34.78 mm. On the other hand, the transversal diameter was bigger in the spinal cord, with the mean value of 12.18 mm. The spinal cord occupies 82.93% of the FM surface in the craniovertebral junction. There was no difference between sexes. **Conclusions:** The better knowledge of craniovertebral junction anatomy is helpful in the neurosurgical planning and in the diagnosis of diseases that present intracranial hypertension.

Keywords: morphometric, magnum foramen, spinal cord, MRI.

1 Introduction

The *foramen magnum* (FM) varies in shape in children and adults (TESTUT, 1947; GARDNER, GRAY, and O'RAHILLY, 1988; WILLIAMS, WARWICK, DYSON et al., 1995; PETROIANU, 1999). Lang classified the shapes into 5 groups, with the following composition: semicircles; an elongated circle; egg-shaped; rhomboidal and rounded (ZAIDI and DAVAL, 1988; LANG, 1991). Brazilian studies classified the FM in 2 groups: egg shaped and rounded⁶. Configuration and size of the FM play an important role in the pathophysiology of various disorders of the craniovertebral junction. The embryologic development of the craniocervical junction is a complex process involving the notochord as an inducer of neuroectodermal differentiation and the paraxial mesoderm, a precursor to bone and skeletal muscle in the craniocervical region. For the formation of the cranial base, a combination of endochondral ossification and the growth of regional sutures is necessary. Elongation of the clivus and the anterior aspect of the foramen magnum results from growth of the spheno-occipital synchondrosis and sutural growth along the lateral portion of the base (TUBBS, GRIESENNAUER, LOUKAS et al., 2010).

The neural structure located in the region of the FM are the caudal part of the brainstem, cerebellum and fourth ventricle, the rostral part of the spinal cord, and the lower cranial and upper cervical nerves. The accessory nerve is the only cranial nerve that passes through the FM. The major arteries related

to the FM are the vertebral and posteroinferior cerebellar arteries (PICA), and meningeal branches of the vertebral, and external and internal carotid arteries. The venous structures in the region of the FM are divided into three groups: one composed of the extradural veins, another formed by the intradural (neural) veins, and a third constituted by the dural venous sinuses. The three groups anastomose through and emissary veins (PETROIANU, 1999; DI DIO, 2002; MOORE and DALLEY, 2006; RHOTON, 2000a). Other authors proposed vertebral foramen evaluations using X-ray methods but very different results have been observed (MALZAC and BARROS FILHO, 2002; PETROIANU, 1999; MOORE and DALLEY, 2006; AUMÜLLER, AUST and DOLL, 2009; CATALINA-HERRERA, 1987; GÜNAYA and ALTINKÖKB, 2000). At this moment there are no data about spinal cord sectional area and FM area correlations. Fundamental knowledge of normal anatomy and basic craniometric measurements for assessing craniovertebral relations is important to the neurosurgeon who operates on this anatomy (TUBBS, GRIESENNAUER, LOUKAS et al., 2010). The aim of neurosurgical approaches to this FM region is designed to maximize the restoration of CSF (cerebrospinal fluid) circulation across the FM (FURTADO, THAKAR and HEGDE, 2011). Many surgical approaches have been advocated for the surgery in the FM region. The surgical approach depends on the anatomical location of the disease and its extension. Three

main routes to FM are anterior, lateral, and posterior. In general, anteriorly placed lesions may be approached through a transoral route, which is the most frequently used but is usually suitable only for extradural lesions. However, the risk of cerebrospinal fluid leak and infection limits the use of this approach for most intradural disease. Lateral approaches and their variants were developed and used to remove lesions located anteriorly or laterally to the brainstem and FM. The main advantages of these approaches are wide exposure and adequate working space. Many variations have been described for the lateral approach, including: lateral inferior suboccipital approach, transcondylar approach and far lateral approach. Posterior midline approach is used for most lesions. The main advantages of this approach are low risk of damage to vertebral artery, wide exposure, and extension of lower exposure by laminectomy of required vertebrae (TAGHIPOUR, MOIN, ZAMANIZADEH et al., 2004; RHOTON, 2000a, b; KAWASHIMA, TUNRIOVER and RHOTON, 2003) (Figure 1). The aim of our study was to measure the sagittal and transversal diameters of FM and SC, establishing a spatial relationship between them and identifying how much of the FM surface is occupied by the SC in normal adults, through MRI.

2 Material and methods

Forty adults (23 female and 17 male) of both sexes had their MRIs evaluated and measured. The mean age was 22 years (18 to 25 years-old). Exclusion criteria included cervical pain, scoliosis, kyphosis, vertebral canal stenosis, and nervous system disease.

We used MRI acquisition in T1W and T2W sequences (Siemens 1.5 Tesla) in sagittal and transversal modes. Bright calibration was performed to make a precise measure of FM structures. Reference points were determined for measurements: sagittal diameter of FM was measured by a virtual line from basal clivus (anterior part) to posterior border (Figure 2), and for transversal diameter we used extreme lateral points of FM (Figure 3). For spinal cord we directly measured the nervous tissue calculating the area. We used Osirix software to this evaluation; The examiner evaluated the same image three times. The mean data was

used after these three individual values to reduce our error factor. All data was evaluated using t Student statistical method ($P \leq 0.05$).

3 Results

No difference in the sagittal and transversal diameters of FM and SC was seen with regard to the sex of the patient, and all the patients were grouped, independently of the sex, for our analyses. The FM has a greater sagittal diameter (mean 34.78 mm) compared with the transversal diameter (mean of 28.69 mm) (Table 1).

The transversal diameter of the SC was greater (mean of 12.18 mm) than the sagittal (mean of 10.30 mm) (Table 2).

The surface of FM is greater than the surface of the SC. The mean surface of the FM is 95.25 mm², and the SC, 79.00 mm² (Table 3). The SC occupies 82.93% of the FM in the craniovertebral junction.

4 Discussion

Our results show that the sagittal diameter of FM was consistently bigger than the transversal diameter, which is in accordance with studies performed in dried skulls (HENRÍQUEZ PINO, CRICENTI, and DIDIO, 1995).

In a study of 211 dried skulls, the sagittal diameter of FM was 36.5 mm (males) and 35.6 mm (females), while the transversal diameter of FM was 30.6 mm (males) and 29.5 mm (females), but no statistical significance was obtained between the sexes (GALDAMES, PEREZ, ZAVANDO et al., 2009). According to Günaya and Altinkökb (2000) the diameters of FM were smaller in the females due to the accentuated oval shape in women (GÜNAYA and ALTINKÖKB, 2000). In our study, we did not evaluate the shape of the FM.

To our knowledge there is no such data in the medical literature. The foramen magnum is a fundamental component in the complex interaction between bony, ligamentous, and muscular structures composing the craniovertebral junction. In this complex we can find motor myelopathy, sensory abnormalities, brainstem and lower cranial nerve dysfunctions, and signs and symptoms due to vascular pathology, bone disease, congenital anomalies, metastatic and degenerative processes, neurological diseases



Figure 1. Foramen magnum anatomy (a) and its relation with brain structures and possible neurosurgical approaches (b).



Figure 2. Sagittal Section. MRI T1W image. A-B Line (red line): measured diameter of FM. C-D Line (blue line): measured diameter of spinal cord.

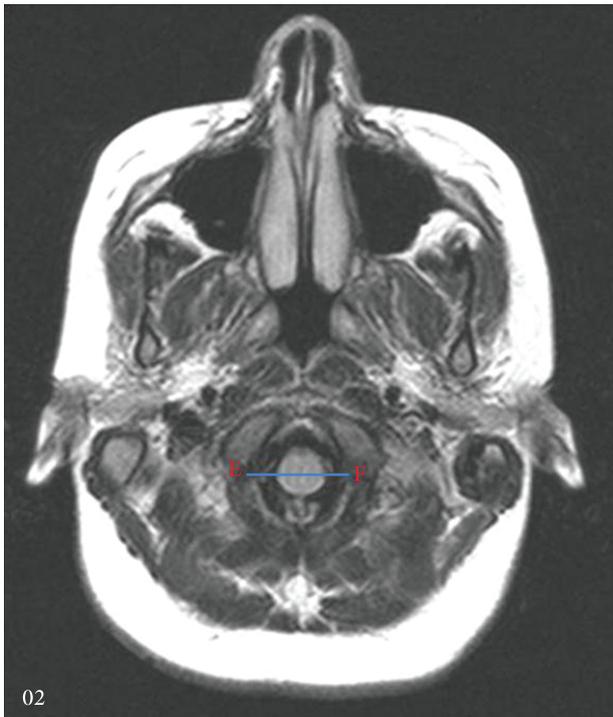


Figure 3. Axial section. MRI T1W. E-F Line shows transversal diameter of FM.

and more rarely inflammatory and infectious diseases (TELLA JUNIOR, PAIVA NETO, AGUIAR et al., 2006; TAGHIPOUR, MOIN, ZAMANIZADEH et al., 2006). The clinical manifestations of FM stenosis include respiratory failure, vomiting, impotence, cranial nerves palsy, cerebellar symptoms/ataxia, central cord syndrome, bulbar symptoms, headache, sensitive and or motor neurological deficits (OJEMANN, 1992; NANDA, VINCENT, VANNENREDDY et al., 2002; BOULTON and CUSIMANO, 2003; TUBBS, GRIESSENNAUER, LOUKAS et al., 2010). Some diseases involving this area

Table 1. Foramen magnum sagittal and transversal diameters (mm).

	Sagittal diameter	Transversal diameter
Mean	34.78	28.69
Minimum	28.44	21.34
Maximum	39.97	34.6
SD	2.19	2.73

SD – Standard Deviation.

Table 2. Spinal cord sagittal and transversal diameters (mm).

	Sagittal diameter	Transversal diameter
Mean	10.30	12.18
Minimum	8.12	10.47
Maximum	12.03	13.35
SD	2.41	2.62

SD – Standard Deviation.

Table 3. Spinal cord and foramen magnum area (mm²).

	FM Area (mm ²)	Spinal cord area (mm ²)
Mean	95.25	79.00
Minimum	63.49	43.82
Maximum	125.41	88.79
SD	13.86	12.51

SD – Standard Deviation.

such as meningiomas, neurofibromas, schwannomas, astrocytomas, chordomas (clivus), ependymoma, Arnold-Chiari type I and II malformations, hydatid cysts, Beare-Stevenson syndrome and Marchesani syndrome have been reported (TELLA JUNIOR, PAIVA NETO, AGUIAR et al., 2006). We believe that our data may be helpful in the neurosurgical evaluation of craniovertebral junction, through MRI.

5 Conclusion

A fundamental knowledge of normal FM neuroanatomy and its structural correlations are very important for clinicians (SIVARAMAKRISHNAN, ALPERIN, SURAPANENI et al., 2004). Our results found a transversal and sagittal FM and spinal cord diameters by MRI and their respective areas. The spatial correlation between spinal cord and FM in the craniovertebral junction were analyzed showing that spinal cord occupied 82.93% of FM total area without statistical difference between sexes. MRI is an important diagnostic method to craniovertebral diseases.

Rereferences

- AUMÜLLER, G., AUST, G. and DOLL, A. *Anatomia*. Rio de Janeiro: Guanabara Koogan, 2009.
- BOULTON, MR. and CUSIMANO, MD. Foramen magnum meningiomas: concepts, classifications and nuances. *Neurosurgical Focus*, 2003, vol. 14, n. 6, p. 1-8. <http://dx.doi.org/10.3171/foc.2003.14.6.10>
- CATALINA-HERRERA, CJ. Study of the anatomic metric values of the foramen magnum and its relation to sex. *Acta Anatomica*, 1987, vol. 130, n. 4, p. 344-7. <http://dx.doi.org/10.1159/000146468>

- DI DIO, JAL. *Tratado de Anatomia Sistemica Aplicada*. São Paulo: Atheneu, 2002.
- FURTADO, SV., THAKAR, S. and HEGDE, AS. Correlation of Functional Outcome and Natural History with Clinicoradiological Factors in Surgically Managed Pediatric Chiari I Malformation. *Neurosurgery*, 2011, vol. 68, p. 319-328. PMID:21135728. <http://dx.doi.org/10.1227/NEU.0b013e31820206e5>
- GALDAMES, S., PEREZ, PR., ZAVANDO, DA. and SMITH, RL. Dimorfismo sexual em lâs dimensiones Del forâmen magno. *International Journal of Morphology*, 2009, vol. 27, n. 1, p. 21-3.
- GARDNER, E., GRAY, DJ. and O'RAHILLY, R. *Anatomia: estudo regional do corpo humano*. 4. ed. Rio de Janeiro: Guanabara Koogan, 1988.
- GÜNAYA, Y. and ALTINKÖKB, M. The value of the size of foramen magnum in sex determination. *Journal of Clinical Forensic Medicine*, 2000, vol. 7, n. 3, p. 147-9. PMID:16083665. <http://dx.doi.org/10.1054/jcfm.2000.0430>
- HENRÍQUEZ PINO, J., CRICENTI, SV. and DIDIO, LJA. Morphometry of the foramen magnum and its relationship to skull types on brazilian individuals. *Revista Chilena de Anatomía*, 1995, vol. 13, n. 2, p. 159-64.
- KAWASHIMA, M., TUNRIOVER, N. and RHOTON, AL. Comparation of the far lateral and extreme lateral variants of the atlanto-occipital transarticular approach to anterior-extradural lesions of the craniovertebral junction. *Neurosurgery*, 2003, vol. 53, p. 662-675. PMID:12943582. <http://dx.doi.org/10.1227/01.NEU.0000080070.16099.BB>
- LANG, J. *Clinical Anatomy of the posterior cranial fossa and its foramina*. Stuttgart: Thieme, 1991.
- MALZAC, A. and BARROS FILHO, TEP. Morfometria do canal vertebral no segmento cervical em militares jovens assintomáticos. *Acta Ortopédica Brasileira*, 2002, vol. 10, n. 4, p. 40-51. <http://dx.doi.org/10.1590/S1413-78522002000400006>
- MOORE, K. and DALLEY, A. *Clinically Oriented Anatomy*. 5th ed. Toronto: Lippincott Williams & Wilkins, 2006.
- NANDA, A., VINCENT, DA., VANNENREDY, PSS. and CHANDA, A. Far-lateral approach to intradural lesions of the foramen magnum without resection of occipital condyle. *Journal of Neurosurgery*, 2002, vol. 98, p. 302-9. PMID:11841072. <http://dx.doi.org/10.3171/jns.2002.96.2.0302>
- OJEMANN, RG. Foramen magnum meningioma. In TATTER, SB. *Clinical neurosurgery*. New York: Saunders, 1992.
- PETROIANU, A. *Anatomia Cirúrgica*. Rio de Janeiro: Guanabara Koogan, 1999.
- RHOTON, AL. The Far-Lateral Approach and Its Transcondylar, Supracondylar, and Paracondylar Extensions. *Neurosurgery*, 2000, vol. 47, n. 3, p. S195-S209.
- RHOTON, AL. The Foramen Magnum. *Neurosurgery*, 2000, vol. 47, n. 3, p. S155-S194. PMID:10983308.
- SIVARAMAKRISHNAN, A., ALPERIN, N., SURAPANENI, S. and LICHTOR, T. Evaluating the Effect of Decompression Surgery on Cerebrospinal Fluid Flow and Intracranial Compliance in Patients with Chiari Malformation with Magnetic Resonance Imaging Flow Studies. *Neurosurgery*, 2004, vol. 55, p. 1344-1351. PMID:15574215. <http://dx.doi.org/10.1227/01.NEU.0000143612.60114.2D>
- TAGHIPOUR, M., MOIN, H., ZAMANIZADEH, B., KAMKARPOUR, A. and ESMAEELI, M. Foramen Magnum Surgery: Experience With 22 Cases. *Neurosurgery Quarterly*, 2006, vol. 16, p. 96-99. <http://dx.doi.org/10.1097/00013414-200606000-00010>
- TELLA JUNIOR, OI., PAIVA NETO, MAP, AGUIAR, PH. and HERCULANO, MA. Meningiomas anteriores e antero-laterais do forame magno. *Arquivos de Neuro-Psiquiatria*, 2006, vol. 64, n. 2b. <http://dx.doi.org/10.1590/S0004-282X2006000300016>
- TESTUT, L. *Tratado de Anatomia Humana*. Barcelona: Salvat, 1947. PMID:20087140.
- TUBBS, RS., GRIESENNAUER, CJ., LOUKAS, M., SHOJA, MM. and COHEN-GADOL, AA. Morphometric Analysis of the Foramen Magnum: An Anatomic Study. *Neurosurgery*, 2010, vol. 66, p. 385-388.
- WILLIAMS, P., WARWICK, R., DYSON, M. and BANNISTER, LH. *Gray Anatomia*. 37th ed. Rio de Janeiro: Guanabara Koogan, 1995. PMID:3223599.
- ZAIDI, SH. and DAVAL, SS. Variations in the shape of foramen magnum in Indian skulls. *Anatomischer Anzeiger*, 1988, vol. 167, n. 4, p. 338-40.

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