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Does Foramen Magnum Morphometry Influence the Development of Chiari Malformation?

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ABSTRACT

AIM: To examine foramen magnum morphometry and shape of Chiari malformation in comparison with a control group, and to contribute to the literature on whether Chiari malformation affects foramen magnum morphometry.

MATERIAL and METHODS: In this study, cranial magnetic resonance images of 71 people with Chiari malformation and 61 people as controls were examined. The anteroposterior diameter, transverse diameter, and area of the foramen magnum were measured, and the shape of the foramen magnum was determined.

RESULTS: In the Chiari malformation group, the anteroposterior diameter of the foramen magnum was 39.11 ± 4.29 mm, the transverse diameter was 34.25 ± 3.27 mm, and its area was 969.21 ± 199.57 mm^2. These results were statistically higher in female patients in the Chiari malformation group than in the control group. No significant difference was found between male patients in the Chiari malformation group and those in the control group. Round-shaped foramen magnum was predominant in both groups, but this was not statistically significant.

CONCLUSION: In Chiari malformation, the foramen magnum is affected. This effect can be a factor that influences development of a malformation. As a result of a malformation, the foramen magnum may have expanded due to the pressure effect. More detailed and extensive research is needed to explain this phenomenon.

KEYWORDS: Arnold-chiari malformation, Foramen magnum, Magnetic resonance imaging

ABBREVIATIONS: CM: Chiari malformation, **FM:** Foramen magnum, **MRI:** Magnetic resonance imaging, **CT:** Computed tomography

INTRODUCTION

Chiari malformations (CM) are defined as a spectrum of abnormalities of the posterior brain, including the cerebellum, brainstem, skull base, and cervical cord (16). In 1891, Arnold–Chiari identified posterior brain anomalies in cases of congenital hydrocephalus and divided these malformations into four categories (23). These types (i.e., types I to IV) depend on the degree of herniation of the brain tissue displaced in the spinal canal and the characteristics of the development anomalies of the brain or spine (16). Other

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controversial classifications include Chiari 0, Chiari 1.5, and Chiari V. Chiari type I is the most common and severe CM. It occurs approximately in 1 of every 1000 births and is more common in women (13,16,18,23,25).

Although many theories have tried to explain the etiology of CM, the cause is still unknown, and no single common pathogenesis is established. Morphometric studies related to CM showed that this malformation was caused by a development anomaly of the fossa cranii posterior or underdeveloped bone structures embryologically (13,20).

Magnetic resonance imaging (MRI) (especially MRI of the head and cervical vertebrae) is the most commonly used and most effective imaging method in the evaluation of CM. MRI shows possible disorders in the skull base, cerebellum, and vertebrae. Although MRI provides acceptable results, it may not be as accurate as computed tomography (CT) in terms of bone structures. However, Dagtekin et al. did not find a statistically significant difference when they compared MRI measurements of the dry skull CT and control group, and this provided scientific evidence in the MRI–CT dilemma (8). Thus, in morphometric measurements related to CM, MRI provides detailed anatomical information about the structures at the base of the skull (8,10,13,24,25).

Morphometric measurements of skull base structures are important for clinicians and radiologists during diagnosis and treatment. The skull base has a complex anatomical structure, and during surgical interventions (such as posterior fossa decompression and duraplasty), the radiological and morphological anatomy of this area must be well known to prevent possible fatal complications (7,12,13). Among the structures in the skull base, the foramen magnum (FM) is a transition zone between the spine and cranium, and it is an important point, as it is adjoining to vital structures such as the cerebrum and spinal cord. Detailed morphometric analysis of the FM region is mandatory for surgeons due to the anatomical complexity of the FM and surrounding structures, damage to vital structures passing through it, or occurrence of complications such as craniocervical instability during surgery (7,26). The shape and size of the FM are critical parameters for clinical signs and symptoms in craniocervical pathology (26). This study aimed to contribute to the literature on whether FM morphometry has an effect on CM by examining FM morphometry and CM shape in comparison with the control group. The results of this study would provide clinicians and radiologists reference data on the FM shape and measurement while evaluating patients with CM.

MATERIAL and METHODS

This retrospective clinical study was performed after ethical approval.

The patient group consisted of 71 patients who had cranial MR images taken for any reason and were diagnosed with CM. In this study, 64 of 71 patients were symptomatic and 7 were asymptomatic. The most common symptom was headache (n=51). In addition, symptoms included dysphagia, pain in upper extremities, hypoesthesia, vertigo, tinnitus, neck pain, and spinal neurodeficits. Moreover, 10 patients had CM with syringomyelia. Decompressive craniectomy was performed in 15 patients. The control group consisted of 61 people (aged 18–59 years) whose MR images were taken for headache or for other reasons. In the control group, MR images contained completely normal findings. Since MRI is the best diagnostic tool to detect CM, we used MR images in our measurements.

Individuals aged <18 and >65 years who have a hereditary or acquired systemic disease (especially neurological or neurosurgical), including tumor, cyst, and hematoma, other than CM were not included in the study.

Images were taken using a 1.5-T MRI unit (30 mT/m) (Intera, Philips Medical Systems, Best, Netherlands) with a standard head coil. Sagittal and transverse images with 4 mm of slice thickness were obtained according to the standard cranial MRI protocol.

Measurement Parameters

The measured parameters were as follows: 1) maximum front–back length – anteroposterior (AP) diameter of the FM: maximum front and back length of the FM (basion–opisthion distance); 2) maximum width, which is the widest length of the FM in transverse section; 3) area of the FM; and 4) shape of the FM, including egg-shaped, round, oval, quadrangular, pentagonal, hexagonal, irregular (1,19) (Figure 1, Figure 2). Measurements were made by an experienced radiologist and an anatomist, and their accuracy was checked.

Statistical analysis was performed using SPSS for Windows version 20.0 (SPSS Inc., Chicago, IL, USA). All values were presented as mean ± standard deviation (SD). The normality of data distribution was evaluated by the Kolmogorov-Smirnov test. Nonparametric tests were preferred because the variables did not conform to the normal distribution. The Mann-Whitney U-test was used to determine the difference between the two groups. The results were evaluated as 95% confidence interval and $p<0.05$ as significance.

RESULTS

In this study, 71 patients had CM and 61 individuals were controls, and their MR images were used in the analysis. The control group was composed of 30 male and 31 female individuals, and the mean ages were 36.77 ± 13.58 and 38.87 ± 12.45 years, respectively. The CM group was composed of 53 female and 18 male patients, and the mean age was 39.91 ± 11.50 and 38.33 ± 16.39 years, respectively. No difference was found between the two groups in terms of age and sex ($p>0.05$) (Tables I and II). These features of both groups were well matched.

As regards measurement parameters, the AP diameter, transverse diameter, and FM area were higher in the CM group than in the control group ($p<0.05$) (Table I).

In female individuals, all measurements (AP diameter, transverse diameter, and area the FM) were higher in the CM group than in the control group, and this difference was statistically significant (Table II, $p<0.05$). In male individuals,

Figure 1: Measurement of the anteroposterior diameter of the foramen magnum.

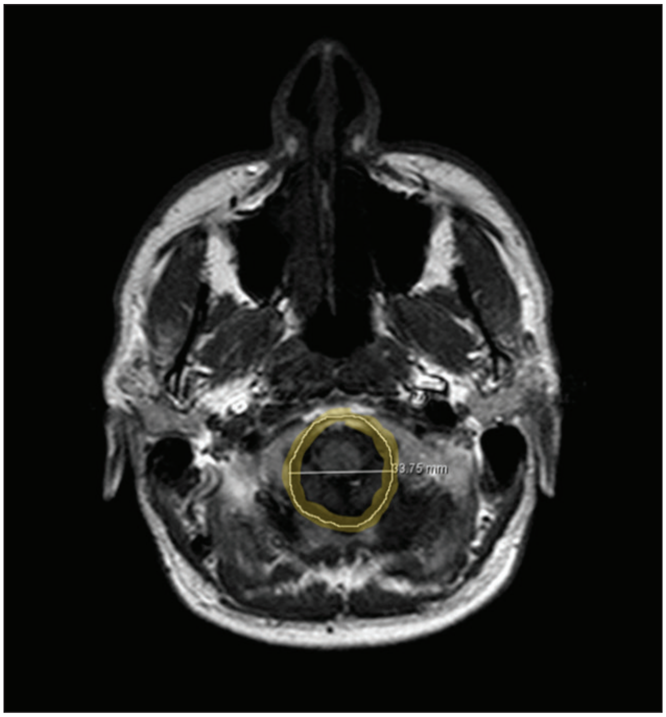

Figure 2: Measurement of transverse diameter and area of the foramen magnum.

Table I: Gender Distribution of the Two Groups and Descriptive Statistics of Measured Parameters of the FM in the Both Groups

	Control Group		CM Group		
Male, n(%)	30 (49.18)		18 (36.36)		
Female, n(%)	31 (50.82)		53 (63.64)		
	Min-Max	**Mean ± SD**	**Min-Max**	**Mean ± SD**	**p**
Age	18.00-63.00	37.84 ± 12.96	18.00-66.00	39.51 ± 12.80	0.465
AP diameter (mm)	26.73-47.50	37.59 ± 4.00	26.60-53.64	39.71 ± 4.44	**0.005***
Transvers Diameter (mm)	21.87-38.75	32.00 ± 4.52	26.81-46.09	34.53 ± 3.30	**0.004***
Area (mm²)	322.66-1308.59	829.79 ± 237.65	606.86-1776.73	966.99 ± 196.60	**0.001***

CM: *Chiari Malformation,* ***AP:*** *Anteroposterior,* ***SD:*** *Standart deviation,* ***mm:*** *Milimetre,* ****:*** *p<0.05.*

no significant difference was found between the CM group and the control group in all measurements (Table II, p>0.05).

The AP diameter, transverse diameter, and FM area were higher in males than in females in the control group (p=0.001). In the CM group, no significant difference was found between both sexes in all measurements (p>0.05) (Table II).

As regards the shape of the FM, no statistically significant difference was found in the comparison between the CM group and the control group and between male and female members of both groups, although the number of round-shaped FMs was high (Table III).

DISCUSSION

In this study, values of FM measurement parameters (i.e., AP diameter, transverse diameter, and area) were higher in individuals with CM. In addition, corresponding values in female patients with CM were higher than those of female controls.

In the literature, a substantial number of studies have investigated the morphometry of the FM in healthy individuals (1,7,28) but the number of studies that have focused on the morphometry of the FM in patients with CM is quite limited to enable comparison of results.

Table II: Gender Comparison of Measurements of the FM Between Groups

	Control Group	CM Group	p
Female	**Mean ± SD**	**Mean ± SD**	
Age	38.87 ± 12.45	39.91 ± 11.50	0.941
AP diameter (mm)	35.89 ± 3.66	39.11 ± 4.29	**<0.001***
Transvers Diameter (mm)	29.96 ± 4.78	34.25 ± 3.27	**<0.001***
Area (mm²)	690.81 ± 206.56	969.21 ± 199.57	**<0.001***
Male	**Mean ± SD**	**Mean ± SD**	**p**
Age	36.77 ± 13.58	38.33 ± 16.39	0.725
AP diameter (mm)	39.35 ± 3.59	41.46 ± 4.56	0.173
Transvers Diameter (mm)	34.11 ± 3.10	35.35 ± 3.35	0.370
Area (mm²)	973.40 ± 175.30	960.45 ± 193.06	0.749

CM: *Chiari malformation,* ***AP:*** *Anteroposterior,* ***SD:*** *Standart deviation,* ***mm:*** *Milimetre,* ****:*** *p<0.05*

Table III: Comparison of Types of the FM Shape Between Groups and Genders

Shape	Control Group		CM Group		Total		p
	n	%	n	%	n	%	
Irregular	21	34.43	19	26.76	40	30.30	0.307
Oval	9	14.75	7	9.86	16	12.12	
Round	24	39.34	29	40.85	53	40.15	
Egg-shaped	7	11.48	16	22.54	23	17.42	
	Female		**Male**		**Total**		**p**
	n	%	n	%	n	%	
Irregular	13	27.08	27	32.14	40	30.30	0.636
Oval	6	12.50	10	11.90	16	12.12	
Round	18	37.50	35	41.67	53	40.15	
Egg-shaped	11	22.92	12	14.29	23	17.42	

CM: *Chiari Malformation.*

Dagtekin et al. compared the FM measurements in 15 adult patients with Chiari type I malformation with the findings of 25 controls and 30 dry skulls, and they measured the AP diameter of the FM in the malformation group, which was 40.1 mm on average, and this value was significantly higher than that in the control group (8). Likewise, according to Aydin et al., the AP diameter of the FM was 31.7 mm in 60 adult patients with Chiari type I malformation, and this value was significantly higher than that of the control group. They concluded that herniation may result in the obstruction of normal anatomical functioning, such as cerebrospinal fluid circulation (4). On the contrary, Noudel et al. reported 37.1 mm in 17 patients with Chiari type 1, but they did not find a significant difference when compared with the control group (21). In the present study, the AP diameter of the FM was 39.71 mm, which was higher in the CM group than in the control group. In addition, the transverse diameter and area of the FM, in comparison with the results of other studies, were higher in the CM group.

Similar to the present study, other studies have performed detailed morphometric analysis of the FM, but this was carried out in pediatric individuals with CM. From these studies, Bliesener and Schmidt measured the transverse diameter of the FM on the X-ray images of 35 children with CM and found that it was significantly higher in children with CM (5). Moreover, Furtado et al. measured the AP diameter, transverse diameter, and area of the FM in 21 pediatric individuals with CM, but they did not find a significant difference between the CM group and the control group (10).

Based on the results of this study, we found a statistically significant increase in all FM measurements in female individuals with CM compared with those in the control group. However, no significant difference was noted in the measurements between male individuals with CM and male subjects in the control group. In literature, we could not find any information that could explain this increase in the number of female patients with CM. These studies have often focused on the frequency of CM between female and male patients (9, 22,29).

The shape and dimensions of the FM have a high degree of accuracy when analyzed by sex (11,27). Many studies have found that FM measurements are higher in healthy male than in healthy female population (6,12,14). In our study, when the measurements of male and female individuals of the control group were compared, the results were significantly higher in male individuals.These results were compatible with literature data.

The shape and morphological variations of the FM are important in surgical approaches (3,12). For example, surgical applications can be difficult in oval-shaped FM (3), while some surgical methods are easier to perform in round-shaped FM than in oval or rhomboid FM (3,20). Despite the varying literature data about the shape of the FM, the FM is generally oval (3,15,17) and round (10) shaped. In our study, round-shaped FM was more common than other FM shapes.

Detailed examination and analysis of the FM and the skull base in CM and in other clinical situations are crucial for medical evaluation, treatment, and surgery (2,8,10,13).

To the best of our knowledge, no study has evaluated the FM of adult individuals with CM in all aspects. Our study performed detailed morphometric analysis of the FM in adult individuals with CM, and this is a strong aspect of our study. We believe that our evaluation results of the FM will contribute to the etiology, pathogenesis, and clinical monitoring of CM, which can also guide clinician in determining patients with poor prognosis, such as those with neurological deficits.

CONCLUSION

In this study, FM measurements in female patients with CM increased significantly compared with that of female controls and no significant difference was observed in male patients with CM. This result suggests that the complex mechanism of CM should be also evaluated on the basis of sex. Moreover, our results reveal a relationship between FM morphometry and CM. However, as regards the cause–effect relationship, these questions need to be answered: Is CM caused by an enlarged FM? Is the FM expanding due to the pressure effect of CM? Further studies with posterior cranial fossa morphometric parameters are needed to show the relationship between CM and FM morphometry.

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