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# A Single-center Study Comparing Volumetric and Morphometric Measurements of Chiari Malformation in the Turkish Population

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## Abstract

**Objective:** This study aimed to determine the values of volumetric and morphological parameters in Chiari malformation type 1 (CM1) patients in the Turkish population.

**Methods:** This retrospective study was conducted at a single center and included patients diagnosed with CM1 between 2013 and 2023. The patients were separated into two groups: the group CM1 and the control group comprising healthy individuals (group control). The morphometric measurements were clivus length, supraocciput length, foramen magnum diameters, distance between the midbrain-pons junction and midbrain-medullospinal junction, cerebellar hemisphere height, tentorium angle, clivus angle, clivus-tentorium angle, posterior fossa volume (PFV), and cerebellar tonsillar morphology.

**Results:** The cerebellar tonsillar herniation was 11.43±2.09 mm in group CM1 and -2.64±2.37 mm in the control group. The mean clivus and supraocciput length were 34.26±4.76 mm and 41.26±4.33 mm in group CM1 and 36.85±3.23 mm and 42.21±2.86 mm in the control group, respectively. The mean foramen magnum diameters were 31.41±3.28 mm in group CM1 and 35.64±2.32 mm in the control group ($p<0.05$). The mean PFV was 153.91±5.02 mL in group CM1 and 180.70±11.62 mL in the control group ($p<0.05$).

**Conclusion:** Two parameters were statistically significantly decreased in CM1 patients (PFV and foramen magnum diameters), indicating the main morphometric change that guides diagnosis and treatment in CM1 patients. All other parameters examined in this study were deemed unnecessary because there was no significant difference between CM1 and the average population.

**Keywords:** Chiari malformation, morphometric, volumetric, Turkish population

## INTRODUCTION

Chiari malformation type 1 (CM1) is a congenital disorder described by Chiari (1) in the late 19$^{th}$ century that can disrupt the circulation of cerebrospinal fluid (CSF) at the level of the foramen magnum by displacing the cerebellar tonsils from the foramen magnum into the spinal canal.

The exact reason for the caudal location of the cerebellar tonsils remains unknown; however, a smaller posterior fossa than usual and geometric mismatches relative to the healthy population are believed to contribute. Despite the uncertain etiology, the migration of cerebellar tonsils into the spinal canal in CM1 results in compression of the tracts at this level, disrupting CSF circulation and leading to neurological symptoms and complications. Several theories have been developed in the literature, including caudal traction theory, hydrodynamic theory, overgrowth theory, small posterior fossa theory, dysraphic theory, and developmental arrest theory. These theories explain various phenomena and have been extensively studied in academic research. It is important to consider each theory impartially and objectively before drawing conclusions (2).

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Studies analyzing radiological measurements of anatomical variances in these patients relative to the healthy population are still inadequate (3). Magnetic resonance imaging (MRI) examinations in current radiological analyses of the posterior cranial fossa (PCF) offer highly detailed anatomical data (4). MRI is an exceptional radiological diagnostic instrument for visualizing the craniovertebral junction and describing associated pathologies of the cerebellum, brainstem, and spinal cord (5).

Many parameters are used for radiological measurements in CM1 (6). These radiographic measurement parameters include clivus length, supraoccipital length, foramen magnum diameter, distance between the midbrain-pons junction and midbrain-medullospinal junction, height of the cerebellar hemisphere, tentorium angle, clivus angle, clivus-tentorium angle, volume of posterior fossa, cerebellar tonsillar morphology (pegged, intermediate, rounded), and other parameters related to the posterior fossa and craniovertebral junction (7,8). This study aimed to determine the values of volumetric and morphological parameters in CM1 patients in the Turkish population. This single-center, retrospective, observational study comprehensively included and compared different anatomical parameters that were previously considered significant (3-8). The statistical significance of the data obtained for the parameters studied helps to reveal important anatomical features in the pathophysiology of CM1. These clinical studies may advance decision making for CM1 by improving our understanding of its pathophysiology.

# METHODS

## Study Design

This retrospective study was conducted at a single center and included individuals diagnosed with CM1 and cerebellar tonsillar ectopia of at least 5 mm on cranial MRI between 2013 and 2023, as well as healthy individuals without neurological pathology on cranial MRI. Cranial and cervical MRI exams conducted during the last preoperative period standardized the examination protocol for neurosurgical patients with CM1. Inclusion and exclusion criteria limited the study to individuals 18 years or older, without consideration for gender differences. All cases of CM1 were included in the study, irrespective of the presence of a syrinx. Patients with syrinx in the control group, including healthy individuals, were excluded from the study. Informed consent of the patients was obtained from all cases. Morphometric measurements were conducted using MRI examinations of the craniovertebral junction on subjects separated into two groups: the group CM1 and the control group comprising healthy individuals (group C) (see Table 1 and Table 2). Morphometric measurements compared among the groups were restricted to clivus length, supraocciput length,

**Table 1. Descriptive analysis of group CM1 and group control**

| | Group CM1 | Group control |
|---|---|---|
| **NoC** | 78 | 75 |
| **Gender (F/M)** | 49/29 | 45/30 |
| **Age** | 36.8±11.3 | 37.8±11.6 |
| **Mean tonsillar herniation (mm)** | 11.43±2.09 | -2.64±2.37 |
| **Tonsillar morphology** | | |
| Pegged | 22/78 (28%) | |
| Intermediate | 43/78 (55%) | |
| Rounded | 13/78 (17%) | |
| Syringomyelia | 26/78 (33%) | |
| **Myelomalacia** | 7/78 (9%) | |
| **Platybasia** | 1/78 (1%) | |
| **4th ventricule enlargement** | 1/78 (1%) | |

CM1: Chiari malformation type 1, NoC: Number of cases, F/M: Female/Male, mm: Millimeters

**Table 2. Comparison of the radiological measurements of the two groups**

| Parameters | Group CM1 | Group control | p-value |
|---|---|---|---|
| Mean length of the clivus | 34.26±4.76 | 36.85±3.23 | >0.05 |
| Mean length of the supraocciput | 41.26±4.33 | 42.21±2.86 | >0.05 |
| Mean foramen magnum diameters | 31.41±3.28 | 35.64±2.32 | <0.05 |
| Mean distance between the midbrain-pons junction and midbrain-medullospinal junction | 48.01±3.14 | 45.08±3.02 | >0.05 |
| Mean cerebellar hemisphere height | 52.96±4.03 | 54.11±2.24 | >0.05 |
| Mean angle of the tentorium | 89.21°±8.79 | 92.85°±6.83 | >0.05 |
| Mean angle of the clivus | 121.55°±7.13 | 122.21°±8.76 | >0.05 |
| Mean clivus-tentorium angle | 8.1°±4.49 | 8.2°±3.95 | >0.05 |
| Mean posterior fossa volume | 153.91±5.02 | 180.70±11.6 | <0.05 |

CM1: Chiari malformation type 1

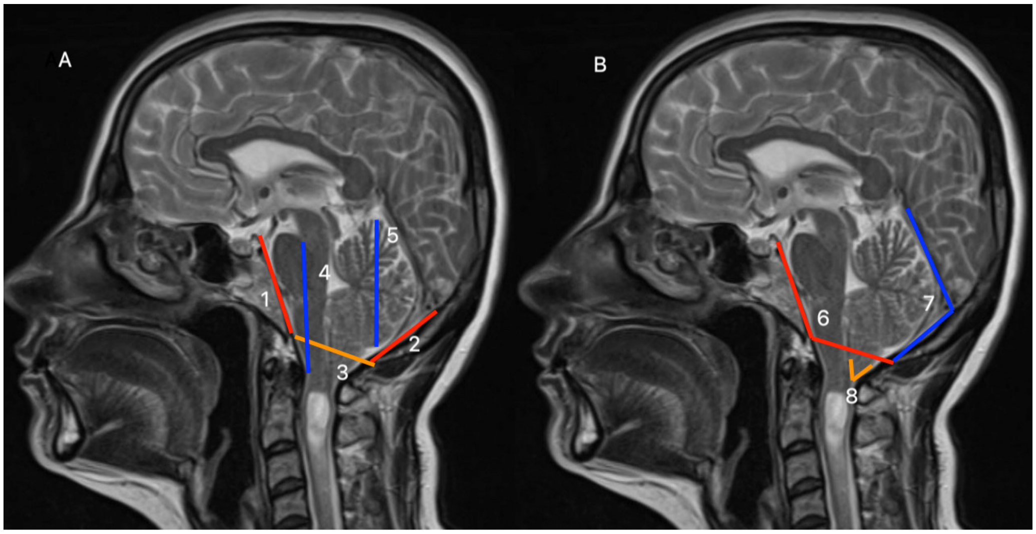


**Figure 1.** Morphometric analyses in T1-weighted sagittal magnetic resonance imaging of a Chiari malformation-type 1 diagnosed patient. A: 1; Length of clivus, 2; Length of supraocciput, 3; Foramen magnum diameters, 4; Distance between midbrain-pons junction and midbrain-medullospinal junction, 5; Cerebellar hemisphere height, B: 6; Angle of clivus, 7; Angle of tentorium, 8; Tonsillar morphology

foramen magnum diameters, distance between the midbrain-pons junction and midbrain-medullospinal junction, cerebellar hemisphere height, tentorium angle, clivus angle, clivus-tentorium angle, posterior fossa volume (PFV), and cerebellar tonsillar morphology (pegged, intermediate, rounded) (3) (see Figure 1 and Figure 2).

### MRI Analysis and Measurement Techniques

MRI was conducted at a single institution using a 1.5-Tesla system (Magnetom Avanto, Siemens Medical Systems, Erlangen, Germany). The imaging comprised sagittal T1 and T2, coronal T2, axial T1, T2, and fluid-attenuated inversion recovery sequences. Examination was performed using sagittal T1-weighted images. Parameters for sagittal T1 sequences were as follows: TR/TE: 346/13, FOV: 270, slice thickness 5 mm, matrix 320x60.

### Volumetric Measurements

The contours of the posterior fossa were manually delineated on each sagittal T1-weighted image by a single radiologist, and the volume was calculated using ExtremePACS software tools (Ekstrem Bir Bilgisayar, Ankara, Turkey) by summation of each voxel in the selected region of interest.

### Clivus Length

The length of the clivus is the length of the line from the apex of the dorsum sella to the basion (Figure 1). Anatomical reference point: the apex of the dorsum sella and the basion (3).

### Supraocciput Length

The measurement of supraocciput length describes the distance between the center of the internal occipital protuberance and the opisthion (Figure 1). The anatomical reference points are from the internal occipital protuberance to the opisthion (3).

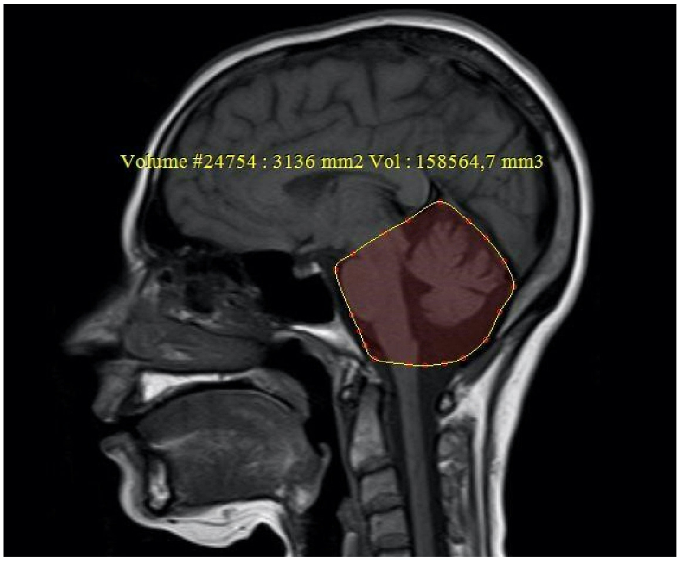


**Figure 2.** Volumetric measurement using the manual delineation method by ExtremePACS software tools

### Diameter of the Foramen Magnum

The length of the line between the basion and the opisthion determines the diameter of the foramen magnum (Figure 1). Basion and opisthion serve as anatomical reference points (3).

### Distance Between the Midbrain Pons and Medullospinal Junctions

This measurement denotes the length of the line between the junction of the midbrain (mesencephalon) and pons and the junction of medullospinal (Figure 1). The anatomical reference points are the midbrain to pons junction and the medullospinal junction (4).

### Cerebellar Hemisphere Height

The length of the line descending from the closest point of the cerebellum to the splenium of the corpus callosum to the closest point to the opisthion in the plane of the foramen magnum is defined as the height of the cerebellar hemisphere (Figure 1). Anatomical reference point: the point closest to the splenium of the corpus callosum and the opisthion in the plane of the foramen magnum of the cerebellum (4).

### Tentorium Angle

The tentorium angle refers to the angle formed by the line between the tentorium and the internal occipital protuberance and opisthion (Figure 1). This anatomical reference point is formed by the line between the tentorium, internal occipital protuberance, and opisthion (5).

### Clivus Angle

The clivus angle is the angle of the clivus relative to the plane of the foramen magnum (Figure 1). Anatomical reference point: the angle at which the clivus line intersects the plane of the foramen magnum (6).

### Clivus-Tentorium Angle

This measurement refers to the angle between the clivus and tentorium (Figure 1). Anatomical reference point: the point where the clivus and tentorium lines meet.

### Posterior Fossa Volume

The PFV refers to the total volume of the space between the tentorium, dorsum sella, basion, opisthion, and internal occipital protuberance (Figure 2). Anatomical reference point: tentorium, dorsum sella, basion, opisthion, and internal occipital protuberance.

### Cerebellar Tonsillar Morphology

This assessment refers to the shape of the cerebellar tonsils descending from the foramen magnum (Figure 1). “Pegged” means pointed. “Intermediate” means moderately prominent. “Rounded” means rounded. Anatomical reference point: cerebellar tonsils and foramen magnum (8).

### Inclusion Criteria

- All adults over 18 years of age

- Without discrimination of the male or female gender

- I have MRI scans of the brain

- Patients with CM1 or no other neurological pathology

### Exclusion Criteria

- Patients with a history of surgery for neurologic pathology

- Patients diagnosed with any neurological pathology other than CM1

### Statistical Analysis

SPSS 15.0 for Windows was used for statistical analysis. Descriptive statistics were reported as number and percentage for categorical variables and mean, standard deviation, minimum, and maximum for numerical variables. Two independent group comparisons of numerical variables were made using Student’s t-test when the normal distribution condition was met and Mann-Whitney U test when it was not. Independent group comparisons of numerical variables were performed with one-way ANOVA when the numerical variables met the normal distribution condition in the groups and with Kruskal-Wallis test when they did not. Subgroup analyses were performed using the Mann-Whitney U test, a nonparametric test, and interpreted with Bonferroni correction. The relationships between numerical variables were analyzed with Pearson correlation analysis when the parametric test condition was met and with Spearman correlation analysis when the condition was not met. Alpha level was set as $p<0.05$ for statistical significance.

In this study, the investigators obtained the necessary approval from the İstanbul Prof. Dr. Cemil Taşcıoğlu City Hospital Clinical Research Ethics Committee (approval number: E-48670771-514.99-208874893, date: 08.02.2023), and the study was conducted in accordance with the Declaration of Helsinki. The article was written in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines.

## RESULTS

One hundred and forty-three participants (94 females, 59 males) had a mean age of 36.3±9.2 years (min: 18, max: 64) (Table 1).

Group control: the study comprised 75 patients, including 45 females and 30 males, aged between 21 and 56 years with a mean age of 37.8±11.6 years. The mean tonsillar herniation was -2.64±2.37 mm, ranging between -7 and 2 mm (Table 1).

Group CM1: comprised 78 patients, including 49 females and 29 males, aged between 18 and 63 years with a mean age of 36.8±11.3 years. The mean tonsillar herniation was 11.43 mm ±2.09 ranging between 9-16 mm. The classification of cerebellar tonsils was pegged in 22 cases, intermediate in 43 cases, and rounded in 13 cases. Apart from tonsillar herniation, syringomyelia was present in 26 patients, focal myelomalacia in 7 patients, platybasia in 1 patient, and fourth ventricular enlargement in 1 patient (Table 1).

The mean clivus and supraocciput length were found to be 34.26±4.76 mm and 41.26±4.33 mm in group CM1 and 36.85±3.23 mm and 42.21±2.86 mm in the control group, respectively. No significant differences were observed in both parameters with $p>0.05$. Additionally, the mean foramen magnum diameters were measured to be 31.41±3.28 mm in group CM1 and 35.64±2.32 mm in group control, with a significant decrease observed in group CM1 ($p<0.05$). The average distance between the midbrain pons and medullospinal junction in the control group was 45.08±3.02 mm, and in group CM1 was 48.01±3.14 mm ($p>0.05$).

The median height of the cerebellar hemisphere was 54.11±2.24 mm in the control group and 52.96±4.03 mm in group CM1 ($p>0.05$).

The average tentorium, clivus, and clivus-tentorium angles were 92.85°±6.83, 122.21°±8.76, and 8.2°±3.95 degrees, respectively, in the control group and 89.21°±8.79, 121.55°±7.13, and 8.1°±4.49 degrees, respectively, in group CM1 ($p>0.05$ in all three parameters).

The mean PFV was 153.91±5.02 mL in group CM1 and 180.70±11.62 mL in group control ($p<0.05$). Statistical analysis indicated that the mean PFV significantly decreased in the CM1 group. Other parameters did not exhibit significant differences between the two groups, except for the mean PFV and foramen magnum diameters (Table 2).

## DISCUSSION

Many parameters are used for radiological measurements in individuals with CM1. However, it is still not fully understood which of these radiological parameters holds more significance. Comparing the radiological measurements with those of a healthy population may prove crucial in determining significant differences, ultimately leading to a better understanding of the pathophysiology of the disease. In this study, we measured and compared various parameters in the posterior fossa and craniovertebral junction of individuals with CM1 and a healthy control group.

CM1 is a congenital malformation characterized by placement of the cerebellar tonsils below the foramen magnum (9). Because clinical progression occurs over time, the disease is not solely a congenital malformation but a dynamic process. Therefore, radiological follow-up is performed in addition to clinical follow-up and evaluation of CM1. MRI is the standard radiological examination used for CM1 because of its ability to clearly display the anatomy at the craniocervical junction. Meadows et al. (10) highlighted the dynamic nature of CM1 and the need for static examinations, such as morphometric measurements obtained through MRI, to fully comprehend this condition. Some measurements obtained on MRI for the posterior fossa and craniocervical junction are important in evaluating the clinical diagnosis, follow-up, and treatment outcome of CM1 (11). These measurements are linked to a reduction in PFV and an augmentation in cerebellar volume. Vurdem et al. (12) used stereological methods to measure posterior fossa and cerebellar volumes and emphasized the potential of these measurements in the evaluation of CM1 cases. Morphometric measurements of CM1 using MRI remain an interesting field of study that warrants further exploration. Notably, Urbizu et al. (13) undertook a morphometric analysis using MRI to examine the oropharynx and oral cavity in CM1 patients, explicitly highlighting the significance of morphometric evaluations in comprehending the anatomical disparities associated with this condition. In their study of surgically treated CM1 cases, Marianayagam et al. (14) analyzed pre- and postoperative morphometric features to evaluate clinical outcomes and emphasized the significance of morphometric measurements in CM1 management.

Thus, volumetric and morphometric measurements constitute a crucial component of the comprehensive evaluation, classification, and management of CM1. These measurements provide important insights into the pathophysiology, clinical outcomes, and dynamic nature of CM1, thus guiding clinical decision-making and treatment strategies.

The study compared various parameters between groups concerning the craniovertebral junction and posterior fossa, including clivus length, supraocciput length, foramen magnum diameters, distance between the midbrain-pons junction and midbrain-medullospinal junction, cerebellar hemisphere height, tentorium angle, clivus angle, clivus-tentorium angle, PFV, and cerebellar tonsillar morphology. It was noted that the PFV and foramen magnum diameter were smaller in the CM1 group than in the control group, exhibiting statistically significant differences among these parameters.

Nishikawa et al. (15) conducted a morphometric study indicating a potential relationship between the overcrowding of the PCF in patients with adult Chiari malformation and their PFV. Roller et al. (16) conducted a study that showed a significant decrease in PFV and posterior fossa linear dimensions in symptomatic pediatric and adult patients with CM1 compared with control subjects.

This finding supports the relationship between Chiari malformation and PFV. Hage et al. (17) presented further evidence on the significance of PFV in the pathogenesis of Chiari malformations, highlighting the correlation between volume reduction in the PCF and CM1. In contrast, Halvorson et al. (18) discovered no variation in PFV between the groups. Given the inconsistent results, further investigation is warranted. In this study, the mean PFV was significantly smaller in the CM1 group than in the control group.

Additionally, the research implies that the foramen magnum diameter in CM1 cases is significantly smaller than that in the control group. While there is no definitive evidence in the literature that indicates a significant variation in the diameter of the foramen magnum between CM1 patients and the healthy population, Furtado et al. (19) highlighted the irregular shape of the foramen magnum in Chiari malformation and demonstrated the potential role of foramen magnum dimensions in the pathophysiology of CM1. Sarvaiya et al. (20) conducted a morphometric analysis of the dimensions of the foramen magnum to comprehend the anatomical variations linked to Chiari malformations. These observations highlight the importance of the foramen magnum diameter in the context of Chiari malformations.

Consistent with the literature, this study demonstrates a substantial connection between reduced PFV and Chiari malformations, suggesting that the role of foramen magnum dimensions is a topic of ongoing investigation and discussion. Additional research is necessary to elucidate the exact morphometric characteristics that contribute to the development of CM1.

Previous studies have used different radiological parameters for morphometric and volumetric examinations of the posterior fossa in CM1 cases, as discussed above. However, this study comprehensively designed the study method and examined multiple radiological parameters together, resulting in findings consistent with those reported in the literature. The study concludes that in cases of CM1, the PFV and the diameter of the foramen magnum are reduced, whereas other radiographic parameters do not show statistical significance. Radiological measurements, especially volumetric measurements, are difficult to obtain and are unlikely to be used in the diagnostic phase. However, they seem to be used to make treatment decisions before surgery and to evaluate treatment effectiveness after surgery. The standard surgical approach for CM1 involves posterior fossa decompression and extensive duraplasty. However, there is currently much discussion in neurosurgery about craniovertebral junction stabilization and fusion surgeries. This study emphasizes the importance of PFV in the pathophysiology of CM1 and suggests that posterior fossa decompression is the main component of CM1 treatment.

### Study Limitations

Although the study relied on prolonged case follow-up, its single-center design can be seen as a limitation.

To enhance generalizability, larger population cohorts with long-term follow-up should be incorporated into multicenter studies.

## CONCLUSION

This morphologic study aimed to rule out unnecessary volumetric measurements in the preoperative planning of CM1 patients. Only two parameters were statistically significantly decreased in CM1 patients (PFV and foramen magnum diameters) and may help us identify actual CM1 patients during outpatient clinics. In contrast, measuring these two parameters may help the surgeon during the preoperative planning period. However, all other parameters examined in this study were found to be unnecessary because there were no significant differences between CM1 and the average population. Because these measurements are generally time-consuming and require trained personnel, unnecessary parameters may be negligible.

### Ethics

**Ethics Committee Approval:** In this study, the investigators obtained the necessary approval from the İstanbul Prof. Dr. Cemil Taşcıoğlu City Hospital Clinical Research Ethics Committee (approval number: E-48670771-514.99-208874893, date: 08.02.2023), and the study was conducted in accordance with the Declaration of Helsinki.

**Informed Consent:** Consent was received from the patients who participated in this study.

### Authorship Contributions

Surgical and Medical Practices: M.A.Ç., Concept: K.Y., Design: M.A.Ç., Data Collection or Processing: K.Y., Analysis or Interpretation: M.A.Ç., K.Y., Literature Search: M.A.Ç., K.Y., Writing: M.A.Ç.

**Conflict of Interest:** No conflict of interest was declared by the authors.

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