Ovoid Foramen Magnum Shape is Associated with Increased Complications and Decreased Extent of Resection for Anterolateral Foramen Magnum Meningiomas

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J Neurol Surg B Skull Base 2021;82:682–688.

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Abstract

Background Antero-laterally located meningiomas of the foramen magnum (FM) pose significant surgical resection challenges. The effect of FM shape on surgical resection of FM meningiomas has not been previously studied. The present study investigates how FM shape effects the extent of tumor resection and complication rates in antero-lateral FM meningiomas.

Materials and Methods This retrospective study included 16 consecutive patients with antero-lateral FM meningiomas operated on by a single surgeon. FMs were classified as ovoid ($n = 8$) and nonovoid ($n = 8$) using radiographic evaluation.

Results Sixteen patients were examined: seven males and nine females (mean age of 58.5, and range of 29 to 81 years). Gross total resection was achieved in 81% of patients, with tumor encased vertebral arteries in 44%. Patient characteristics were similar including age, sex, preoperative tumor volume, relationship of vertebral artery with tumor, preoperative Karnofsky performance score (KPS), symptom duration, and presence of lower cranial nerve symptoms. The ovoid FM group had lower volumetric extents of resection without statistical significance (93 ± 10 vs. $100 \pm 0\%$, $p = 0.069$), more intraoperative blood loss (319 ± 75 vs. 219 ± 75 mL, $p = 0.019$), more complications per patient (1.9 ± 1.8 vs. 0.3 ± 0.4 , $p = 0.039$), and poorer postoperative KPS (80 ± 21 vs. 96 ± 5 , $p = 0.007$). Hypoglossal nerve palsy was more frequent in the ovoid FM group (38 vs. 13%).

Conclusion This is the first study demonstrating that ovoid FMs may pose surgical challenges, poorer operative outcomes, and lower rates of extent of resection. Preoperative radiological investigation including morphometric FM measurement to determine if FMs are ovoid or nonovoid can improve surgical planning and complication avoidance.

Keywords

- foramen magnum
- foramen magnum shape
- meningioma
- anterolateral
- far lateral approach
- complication
- lower cranial nerves
- extent of resection

Introduction

Surgical intervention of meningiomas of the foramen magnum (FM) have always been challenging due to the complex

anatomy of the FM region and the vicinity of the brain stem, lower cranial nerves, vertebral artery (VA), and other osseous and neurovascular structures. Numerous approaches have been developed for the treatment of FM tumors since this

received
December 9, 2019
accepted
June 11, 2020
published online
October 5, 2020

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Georg Thieme Verlag KG,
Rüdigerstraße 14,
70469 Stuttgart, Germany

DOI <https://doi.org/10.1055/s-0040-1715559>.
ISSN 2193-6331.

region does not allow retraction or manipulation due to the vicinity of vital structures, but as yet there is no consensus on a standard approach.^{1–12}

Meningiomas localized in the FM region are classified into numerous different types based on the compartment they are localized in, the region where they adhere to the dura, and their relationship with the VA.^{13–16} The dentate ligament is another important marker for the classification of these tumors. FM meningiomas are classified as: (1) posterior when localized posterior to the dentate ligament, (2) anterior when anterior to the dentate ligament, or (3) they can be anterior to the dentate ligament with extension over the midline.¹⁴ Anterolateral meningiomas constitute the most common type (68–98%), followed by posterolateral, posterior, and anterior meningiomas.⁸ Anterior or anterolateral FM meningiomas are more difficult to access than posterior or posterolateral FM meningiomas. Resection of these tumors can jeopardize critical structures such as the brain stem, lower cranial nerves, and vertebral arteries.

FM shape has not been previously considered to be a factor that can influence surgical accessibility. These have been described as horizontal (oval-like), longitudinal, round, egg-like, triangular, rectangular, pentagonal, and hexagonal.^{17,18} A recent report based on 30 dry skulls and 10 formalin fixed cadaveric heads simplified these into just two: oval and non-oval.¹⁹ Oval was defined as having a FM index ≥ 1.2 , where the index was calculated as the anteroposterior length divided by the transverse diameter (► Fig. 1). Ovoid FMs were reported in 58% of the population.¹⁹

Since surgical access to posterior or posterolateral FM meningiomas is straightforward via midline suboccipital or far lateral approaches, it is intuitive to believe that FM shape has no effect on these tumor subgroups. However, anterolateral FM meningiomas do pose a significant surgical challenge in accessing their base and their vascular supply due to their deep position relative to critical neurovascular structures. We therefore hypothesize that FM geometry impacts the surgical accessibility of anterolateral FM meningiomas. Thus, the aim of this study is to investigate the effect of FM

shape on tumor resection and complication rates for anterolateral FM meningiomas. To the best of our knowledge, no prior studies have evaluated the clinical outcomes of purely anterolateral FM meningiomas based on FM shape.

Materials and Methods

Patients

This retrospective study included 16 consecutive patients with anterolateral FM meningiomas operated on by a single surgeon (author initials blinded for review) at a tertiary academic center between September 2006 and June 2019. This study received institutional review board approval. Excluded from the study were patients with tumors other than FM meningiomas, with only-anterior or only-posterior FM meningiomas, and patients with a history of prior surgical treatment. Tumors were defined as anterolateral FM meningiomas if there was a dural tumor connection between the anterior midline and the dentate ligament, in preoperative magnetic resonance images (MRI).

Neuroradiological Imaging

Volumetric contrast-enhanced cranial MRI and computed tomography (CT) were performed for each patient prior to surgery. The connection between the VA and the tumor was evaluated by CT angiography, as needed. Tumor volume (TV) was calculated using OsiriX software (version 10.0, Pixmeo, Bernex, Switzerland). The extent of resection (EOR) was volumetrically quantified and calculated as percent resection using the formula: $1 - (\text{residual TV} / \text{preoperative TV})$. The relationship between the tumor and the VA, and whether the VA was encased by the tumor were noted. On CT examination, the antero-posterior length and the transverse diameter of the FM were recorded and the FM index was calculated. The FM with an index ≥ 1.2 was considered ovoid. Patients FMs were categorized as ovoid ($n = 8$) and nonovoid ($n = 8$). Tumor resection rates were recorded as total and subtotal based on a contrast-enhanced MRI within 48 hours postoperatively.

Fig. 1 Dry cadaveric skulls demonstrating (A) ovoid foramen magnum and (B) nonovoid foramen magnum. Arrows show transverse (t) and anteroposterior length (l) measurements. FMI: Foramen magnum index.

Surgical Procedure

The far lateral transcondylar approach was used for all patients. Lower cranial nerve monitoring was performed using electromyography (EMG), and neuronavigation was used to determine posterior fossa landmarks and tumor margins. The patient was placed in the lateral park-bench position with the tumor side facing upward. A hockey-stick-type incision was made, extending from the mastoid tip upward to the superior nuchal line, descending downwards to theinion, and continuing along the midline until reaching the level of C5. The paravertebral muscles were dissected to expose the deep suboccipital triangle. The V3 segment of the VA was exposed. The posterior condylar emissary vein was reached and cauterized. A tear-shaped craniotomy and C1 hemilaminectomy were performed. The extent of condylectomy varied from patient to patient, but in no cases was the EOR greater than one-quarter. The dura was opened in a C-shaped fashion. The dentate ligament was cut to increase the surgical corridor. The tumor was then removed using microsurgical techniques. After tumor resection, the dura was closed in a watertight fashion primarily, or with pericranial dural flap.

Operative Outcomes and Follow-Up

Each patient underwent contrast-enhanced cranial MRI within 24 to 48 hours following surgery and received a daily neurological examination until discharge. The EOR was determined from postoperative MRI images as: gross total resection (GTR) = Simpson grade II; subtotal resection (STR) = Simpson grade III or IV with 95 to 99% excision; partial resection = Simpson grade IV with <95% excision of the lesion.

The patients underwent follow-up examinations with MRIs at postoperative months 3, 12, and thereafter. Karnofsky Performance Scale (KPS) scores and neurological status were noted during the final examination prior to hospital discharge. Progression was defined as an increase in TV during follow-up periods, for patients that underwent subtotal resection. Neurological deficits that developed postoperatively, but were not detected in the last clinic follow-up, were accepted as temporary deficits.

Statistical Analysis

Statistical analyses used IBM SPSS version 24.0 (IBM Corp., Armonk, New York City, United States). Data were presented as mean $\pm$ standard deviation for parametric data, median (interquartile range) for nonparametric data, and number (percentage) for categorical variables if otherwise indicated. Quantitative variables were compared using Student's *t*-test (parametric) and Mann-Whitney U test (nonparametric) between two groups. Categorical variables were compared using Fisher's exact test and Chi-square test. A *p*-value of <0.05 was considered significant.

Results

Demographic and Clinical Characteristics

The 16 patients included seven men (44%) and nine women (56%) with a mean age of 58.6 ± 13.9 years (median: 61, range: 29–81). Occipito-cervical headache was the most common presenting symptom ($n = 13$; 81%), followed by lower cranial nerve deficits ($n = 10$; 63%), hyperesthesia ($n = 8$; 50%), motor deficits ($n = 8$; 50%), dysphagia ($n = 7$; 44%), dizziness ($n = 5$; 31%), and speech dysfunction due to lower cranial nerve involvement ($n = 2$; 13%). The median time from the onset of symptoms to surgery was 4 months (range: 1–36). The mean preoperative KPS score was 78 ± 19 (median: 75, range: 40–100; ►Table 1).

Radiological and Histopathological Findings

All tumors were antero-lateral FM meningiomas, with mean TVs of 9.3 ± 8.0 cm³ (median: 6.7, range: 1–28). The tumors were localized in front of the VA in five patients (38%), behind the VA in four (25%), and encased by the tumor in the remaining seven patients (44%). Tumor tissue was localized above the VA in nine patients (56%) and below the VA in seven (44%). GTR was achieved in 13 patients (81%), with subtotal resection in 3 (19%; ►Fig. 2).

Pathological examination showed transitional meningiomas in 10 patients (63%), psammomatous meningiomas in three (19%), and meningothelial meningiomas in three (19%). One patient who underwent GTR developed a recurrence 8 years after surgery, but as there was no growth during the

Table 1 Baseline patient characteristics.

Variable	Ovoid type ($n = 8$)	Nonovoid type ($n = 8$)	All ($n = 16$)	<i>p</i> -Value
Age	58.9 ± 17.4	58.3 ± 10.4	58.6 ± 13.9	0.932
Sex	5 M, 3 F	2 M, 6 F	7 M, 9 F	0.315
Tumor above VA	3 (38%)	6 (75%)	9 (56%)	0.315
VA encased by tumor	5 (63%)	2 (25%)	7 (44%)	0.315
Preoperative tumor volume (cm ³)	8.8 ± 7.3	9.7 ± 9.1	9.3 ± 8.0	0.838
Preoperative KPS	79 ± 21	76 ± 18	78 ± 19	0.804
Duration of symptoms (mo)	5 (1.0–18.5)	3 (0.9–10.5)	4 (1.0–12.0)	0.645
Lower cranial nerve symptoms	6 (75%)	4 (50%)	10 (63%)	0.608

Abbreviations: F, female; KPS, Karnofsky performance score; M, male; VA, vertebral artery.

Fig. 2 Images from patient with nonovoid foramen magnum with antero-lateral foramen magnum meningioma: (A) preoperative axial bone window computed tomography. (B) preoperative T1 postcontrast axial MRI. (C) Preoperative T1 postcontrast coronal MRI. (D) Postoperative T1 postcontrast axial MRI shows gross total resection. (E) Postoperative T1 postcontrast coronal MRI shows gross total resection. MRI, magnetic resonance imaging.

follow-up period, the patient received no treatment. Another patient who underwent subtotal resection received radiotherapy 2.5 years after surgery due to tumor regrowth during the intervening period. This patient was subsequently followed for 40 months without tumor growth after radiotherapy. The other two patients with small residual tumors showed no tumor regrowth during follow-up, without any adjuvant treatment (► **Table 2**).

Postoperative Morbidity, Mortality, and Follow-Up

The mean follow-up period was 87 ± 52 months (median: 86, range: 2–156) and the mean postoperative KPS score was 88 ± 17 (median: 90, range: 30–100). The mean hospital stay was 7.2 ± 4.2 days (median: 6, range: 4–18), and the mean intraoperative blood loss was 269 ± 89 mL (median: 300, range: 100–400; ► **Table 2**). Six patients (38%) had dysphagia postoperatively, four of whom had been admitted with dysphagia preoperatively. Postoperative examinations revealed that dysphagia improved in four patients, hypoglossal nerve palsy was detected in four, persistent monoparesis was detected in one, and persistent hemiparesis was detected in one. Ventriculoperitoneal (VP) shunts were inserted in four patients (25%) due to postoperative hydrocephalus, three of whom had presented with minimal hydrocephalus. Cerebrospinal fluid (CSF) leaks occurred in two patients: one was treated conservatively and the other

patient underwent surgical repair. In the patient that underwent surgical repair, a VP shunt was inserted due to hydrocephalus. Wound infection was observed in one patient who had uncontrolled diabetes mellitus. This patient had a surgical site infection with positive culture for staphylococcus aureus, and was successfully treated with antibiotic therapy and wound care. Two patients developed aspiration pneumonia postoperatively. Postoperative hematomas were not observed in any patient (► **Table 3**).

Impact of Foramen Magnum Shape on Operative Results

The two FM groups did not differ in baseline patient characteristics (► **Table 1**). However, the ovoid FM shape patients experienced greater intraoperative blood loss ($p = 0.019$) and lower postoperative KPS ($p = 0.007$). Although not statistically significant, the EOR was also lower ($p = 0.069$) and hospital stays were longer ($p = 0.062$) for ovoid FM patients (► **Table 2**). The number of complications per patient was also statistically greater for ovoid FM patients ($p = 0.039$) (► **Table 3**).

Discussion

Posterior or posterolateral FM meningiomas are easily accessed via posterior midline, paramedian suboccipital,

Table 2 Surgical and postoperative patient details

Variable	Ovoid type ($n = 8$)	Nonovoid type ($n = 8$)	All ($n = 16$)	p -Value
Extent of resection (% volume)	93 ± 10 (75–100)	100 ± 0 (100–100)	96 ± 8 (75–100)	0.069
Gross total resection	5 (63%)	8 (100%)	13 (81%)	0.200
Blood loss (mL)	319 ± 75 (200–400)	219 ± 75 (100–300)	269 ± 89 (100–400)	0.019
Postoperative KPS	80 ± 21 (30–90)	96 ± 5 (90–100)	88 ± 17 (30–100)	0.007
Length of hospital stay (d)	9.1 ± 5.2 (4–18)	5.2 ± 1.5 (4–8)	7.2 ± 4.2 (4–18)	0.062
Recurrence	1 (13%)	1 (13%)	2 (13%)	n/a

Abbreviation: KPS, Karnofsky performance score.

Note: Categorical variables are provided as n (%). Continuous variables provided as mean $\pm$ standard deviation and (range).

Table 3 Surgical complications for ovoid and nonovoid foramen Magnum patients

Surgical complication	Ovoid type (n = 8)	Nonovoid type (n = 8)	All (n = 16)	p-Value
New onset dysphagia	2 (25%)	0	2 (13%)	n/a
Hypoglossal nerve deficit	3 (38%)	1 (13%)	4 (25%)	n/a
Motor deficit	2 (25%)	0	2 (13%)	n/a
Hydrocephalus	3 (38%)	1 (13%)	4 (25%)	n/a
CSF leak	2 (25%)	0	2 (13%)	n/a
Aspiration pneumonia	2 (25%)	0	2 (13%)	n/a
Wound Infection	1 (13%)	0	1 (6%)	n/a
Overall				
Patients with complications	5 (63%)	2 (25%)	7 (44%)	0.315
Number of complications ^a	15 (27%)	2 (4%)	17 (15%)	0.002
Complications per patient				
Mean ± SD	1.9 ± 1.8	0.3 ± 0.4	1.1 ± 1.5	0.039
median (IQR)	2 (0–3)	0 (0–0.5)	0 (0–2)	

Abbreviations: CSF, cerebrospinal fluid; IQR, interquartile range; SD, standard deviation.

^aPercentages calculated as overall number of complications divided by number of all possible complications (n = 56) per group (eight patients × seven complications per patient).

transcondylar, and extended retrosigmoid approaches. In contrast, anterior and anterolateral FM meningiomas are difficult to access despite the use of approaches such as the far-lateral transcondylar and its modifications. However, posterior approaches can jeopardize critical structures including the brain stem, lower cranial nerves, and vertebral arteries. Moreover, partial or complete resection of the occipital condyle may lead to craniocervical instability. Anterior approaches, such as transoral or endoscopic endonasal approaches, have also been reported, but these may be associated with an increased risk of CSF leak, inadequate tumor excision, and infections.^{12,20–23}

The reported rates for complete resection of FM meningiomas ranges between 70 and 96%.^{24,25} Consistent with this literature, in the present study, complete resection was achieved in 81% of patients with anterolateral tumors. This rate was 67.5% in patients with ovoid FMs as compared with 100% of patients with nonovoid FMs, with volumetric EOR measurements that trended toward a difference between these two groups ($p = 0.069$; **Fig. 3**). This difference may be because the transverse length of ovoid FMs are relatively narrower, thus leaving the larger portion of the tumor tissue in the anterior area. We thus believe that ovoid FMs obstruct the surgeon's view. This increases the difficulty in exposing the anterior aspect of the FM, which may thus result in greater blood loss, higher complication rates, and a lower EOR. Therefore, it appears likely that the higher the FM index, the more difficult complete tumor resection becomes.

Benoit et al evaluated 26 patients with FM meningiomas and reported that the VA was encased by the tumor in 30% of patients with antero-lateral meningiomas.²⁶ In our study, we observed a comparable rate of 44%. In another study, Bruneau and George evaluated 107 patients with FM meningio-

ma and reported that tumors were below the VA in 79% and above the VA in 16% of patients.¹⁵ In contrast, we found that 56% of the tumors were localized above and 44% were localized below the VA. Of course, this discrepancy may be attributed to the smaller number of patients in our study.

Encasement of lower cranial nerves and the VA meningiomas have been reported as the most important factor preventing complete resection.^{11,14,27} We similarly observed that preoperative lower cranial nerve involvement was more common with ovoid FMs, although a greater number of patients will be necessary to substantiate this finding. It has been suggested that achieving a large tumor exposure in such patients may be beneficial for tumor resection.

Sekhar et al suggested that postoperative deterioration is associated with tumor size²⁸ and postoperative complications have been associated with multiple factors including, anterior location, tumor invasion, extradural extension, VA invasion, absence of an arachnoid plane, and adhesions caused by prior operations.^{2,10,11,14,22,29} It has also been reported that preoperative neurological findings remained unchanged in 2.5 to 20% of patients, while postoperative deterioration occurred in 7.5 to 17.4%.^{7,10,30–32} Lower cranial nerve deficits are the most common postoperative complications and have been reported in up to 60% of these patients.^{8,33} In our study, complication rates were consistent with these reports and were significantly higher in patients with ovoid FMs ($p = 0.039$).

A wide variety of postoperative complications have been associated with the surgical treatment of FM meningiomas. Talacchi et al reported that 33% of patients with anterior and antero-lateral meningiomas developed hypoglossal nerve palsy postoperatively.³⁴ In our study, hypoglossal nerve palsy occurred in 25% of all patients, but in 37.5% of patients with an ovoid FM. Samii et al reported that aspiration

Fig. 3 Images from patient with ovoid foramen magnum with anterolateral foramen magnum meningioma: (A) preoperative axial bone window computed tomography. (B) Preoperative T1 postcontrast axial MRI. (C) Preoperative T1 postcontrast coronal MRI. (D) Postoperative T1 postcontrast axial MRI shows gross total resection. (E) Postoperative T1 postcontrast coronal MRI shows gross total resection. MRI, magnetic resonance imaging.

pneumonia developed in 10% of patients.¹¹ We observed this in two patients (12.5%), both of whom had ovoid FMs. CSF fistulas have been reported in 20% of patients.^{2,29,32} In the present study, we only observed CSF fistulas in patients with an ovoid FM (two patients), which constituted 25% of patients with ovoid FM, and 12.5% of all patients in this study. Komotar et al reported that 9% of operated patients worsened postoperatively,²⁰ while we observed postoperative KPS scores decreases in three patients (19%), compared with their preoperative scores, with all of these patients having an ovoid FM. Accordingly, the postoperative KPS were significantly worse in patients having ovoid FMs ($p = 0.007$) despite similar baseline KPS in both the ovoid and nonovoid groups.

The reported mortality rates for patients with FM meningiomas ranges between 6.2 and 13%.¹⁴ However, in our (small) series, there were no operative mortalities. The reported mean hospital stay for FM meningioma patients is 7 days,²⁵ which is the same as the 7.2 ± 4.2 days in our study. However, hospital stay was longer for patients with ovoid FMs (9.1 ± 5.2 days) than with nonovoid FMs (5.2 ± 1.5 days; $p = 0.062$).

The present study has both strengths and limitations. Study strengths include: (1) this is a relatively homogeneous single surgeon case series with only anterolateral FM meningiomas, (2) the two-study arm have equal patient numbers, and (3) patient data are sufficiently complete. Nevertheless, there are limitations, including: (1) this is small retrospective study due to the rarity of the pathology; (2) although the FM index is a continuous variable, it was necessary to dichotomize this to create two study groups; and (3) the small sample size provided limited statistical significance, where absolute numbers suggested trends. Small sample size also prevented multivariate analyses to examine variables such as cranial nerve encasement, and prevented examining correlations between continuous FM indexes with complications and outcomes. In summary, the principal limitations of this study or a rare pathology are due to the small sample size, thus suggesting that additional studies with larger cohorts are warranted.

Conclusion

In this study, we have found that the preoperative characteristic of FM shape appears to influence the outcomes for anterolateral FM meningioma surgery. In particular, we found that ovoid-shaped FMs are associated with higher complication rates, lower EORs, greater operative blood loss, and longer hospital stays. These results appear to be largely due to the more difficult surgical access and maneuverability present with ovoid FMs. We therefore suggest performing preoperative radiographic evaluation of patients with FM tumors to determine FM shape, since this can provide valuable insight into anticipated operative risk, which can thus be communicated with the patient, and be used to better prepare for surgical challenges.

Authors' Contributions

The first two authors contributed equally to this work.

Conflict of Interest

None declared.

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