



Improving results in patients with foramen magnum meningiomas by translating surgical experience into a classification system and complexity score

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Abstract

Foramen magnum meningiomas (FMMs) are challenging lesions and controversy still exists regarding their optimal management. In the present paper, we propose some principles of surgical treatment of FMMs. We analyzed our series of 39 patients: the average maximum diameter was 31.1 mm (sd, 10.7). In two cases, there was extradural extension. We operated all anterior lesions through dorsolateral approach to craniovertebral junction and all posterior lesions through midline suboccipital approach and C1 laminectomy, following the prevalence of side of the tumor. There were no complications except for one case of post-operative hypoglossus paresis. We translated our experience with surgery of foramen magnum meningiomas into a classification system and a complexity score, in order to assign a score to each individual case and plan the surgical strategy. When the complexity score is 5 or more, we propose subtotal removal, in consideration of the benign nature.

Keywords Foramen magnum · Meningioma · Complexity score · Neurosurgery

Introduction

Foramen magnum meningioma (FMM) has first been described in 1872 [22]. Meningiomas located in this area represent challenging lesions because of their close proximity with the brainstem and lower cranial nerves as well as with the adjacent vertebral artery and its branches. The majority of these lesions (90%) are ventral and ventrolateral, but they can be located anywhere in the foramen magnum ring [11, 12, 39–41]; thus, surgical approaches need to be tailored to the location of the mass. However, controversy still exists regarding the optimal management of anterior or anterolateral lesions. In the current analysis, we review our experience over the last

15 years in the surgery of FMMs. In view of the favorable results we have seen in this series, we have translated the decisions made with respect to guidance and treatment of the patients into a classification system and complexity score.

Materials and methods

The 39 patients included in this study were operated by the senior author (H.B.) for FMMs. We summarized clinical presentation in long tract symptoms, cranial nerve symptoms, and other symptoms (Table 1). For the pre-operative and post-operative disability evaluation, we used the modified Rankin Scale. Imaging work-up included contrast-enhanced magnetic resonance imaging (MRI), computed tomography (CT) with bone algorithm, and vertebral angiography.

Surgical approaches were evaluated for complications and mortality. Based on these evaluations, we classified the lesion feature: maximum tumor diameter, compartment of development (intradural, extradural, and intra-extradural), vertebral artery (VA) involvement (partial and total encasement), brainstem (BS) adhesion, and grade of removal.

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Table 1 General data about patient population and clinical symptoms at admission

Male	16 (41%)
Female	23 (59%)
Mean age	54 years old (15–78)
Cranial nerves symptoms	14 (36%)
Long tract symptoms	33 (85%)
Average pre-operative modified Rankin Scale (mRS)	1.46

In addition, we defined parameters for axial and sagittal localization and attachment of the tumor as follows:

- Axial localization and axial dural attachment: the lesions located in front of the dentate ligament were classified as “anterior” and the lesions behind the dentate ligament were considered as “posterior.” We further divided the anterior dura into left and right sides along the midline and every side into three thirds to systematically analyze the characteristics of dural attachment. This way, we classified lesions with symmetrical dural attachment along the midline as “purely anterior” and lesions with asymmetrical dural attachment with prevalence to one side as “anterolateral.” Within the anterolateral lesions, meningiomas with a complete prevalence towards one side and no extension of dural attachment beyond the midline were classified as “type A” and the meningiomas with the dural attachment on both sides along the midline with differing degrees of extension as “type B” (Fig. 1A, B).
- Sagittal localization: the FM region was divided into two regions. Tumors located between the horizontal line passing through the junction middle-inferior third of the clivus and the horizontal line passing through the basion were classified as “high FM” and tumors located between this last line and the horizontal line passing through the superior edge of the C2 vertebral body were considered as “low FM” (Fig. 2).
- Sagittal dural attachment: we evaluated the extension of the sagittal dural attachment and the ratio with maximum craniocaudal diameter of the tumor. Within the anterior lesions, we described as “type 1” the tumor with ratio < 1, and “type 2” with ratio ≥ 1 (Fig. 3)

We then retrospectively analyzed our set of 39 patients according to these features and developed a complexity score (CS) for anterior and anterolateral lesions in order to define the best surgical approach and to predict the prognosis. The score can have from a minimum value of 1 to a maximum of 8 (Table 2). We correlated the value of CS with the grade of removal and clinical follow-up.

All the data were analyzed using commercially available software (IBM SPSS Statistics for Mac, Version 22.0, Armonk, NY: IBM Corp) for descriptive statistics and ANOVA test. Significance was ascribed for $p < 0.05$. Logistic regression analysis was used to assess the predictive value of CS.

Results

Our set included 39 patients, 23 women and 16 men. The average age was 53 ± 14 years, ranging from 15 to 78 years of age. Female patients had an average age of 49.2 years and male patients had an average age of 60.3 years. None of the lesions showed signs of atypia during histological exam.

Thirty-three patients (84.6%) showed long tract symptoms and 14 patients (35.8%) showed cranial nerve deficits. Other symptoms were headache and neck pain (6 and 5 cases respectively) (Table 1). The average pre-operative modified Rankin Scale was 1.46 ± 0.9 .

Surgery and follow-up

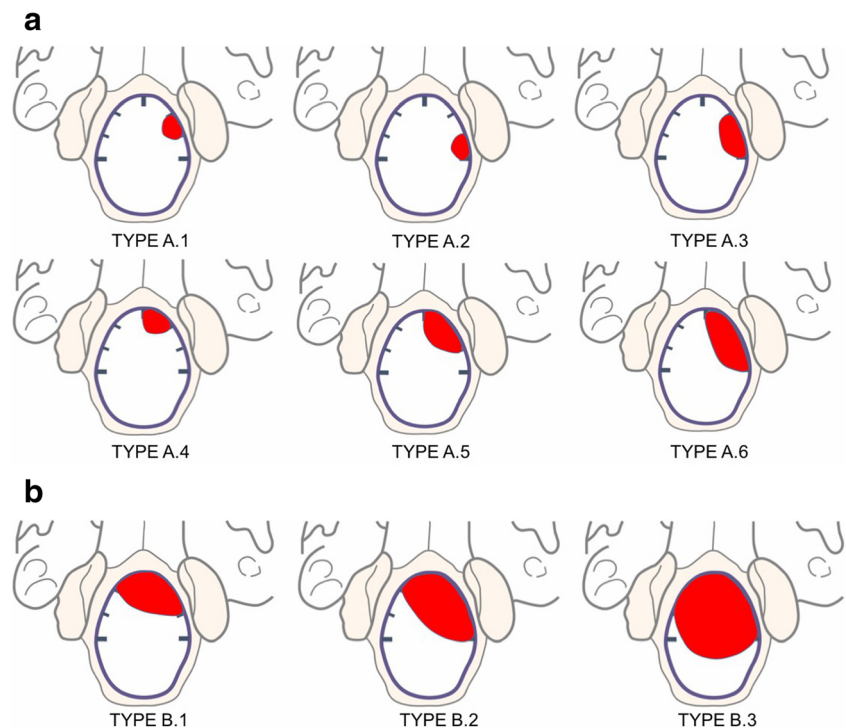
We operated all anterior lesions in a dorsolateral approach to the craniovertebral junction and all posterior lesions in a midline suboccipital approach and C1 laminectomy, according to the side prevalence of the tumor. There were no complications except for one case of post-operative hypoglossus paresis. We did not report any deaths. The average modified Rankin Scale at the discharge is $1.48 (\pm 0.99)$. In two cases, the clinical condition deteriorated at discharge and the CS was 5 and 6. Minimum follow-up was 6 months. During the follow-up period, no remissions or deaths were reported. Total removal was possible in 29 patients (Table 3).

Tumor features and complexity score

Considering the relationship between the axial dural attachment of the tumor and the dentate ligament, 33 patients showed anterior lesions (84.6%) and six patients showed posterior lesions (15.3%). We further differentiated the dural attachment within the anterior lesions into eight purely anterior and 25 anterolateral lesions. The anterolateral tumors were divided into 12 “type A” tumors and 13 “type B” tumors (Table 3).

Of the meningiomas, 10 were located in the “low FM,” 23 in the “high FM,” and six cases showed a symmetrical growth in both regions of the FM. Studying the features of the sagittal dural attachment for the anterior and anterolateral tumors, the “type 1” meningiomas were 22 and the “type 2” were 11 (Table 3).

Fig. 1 (A, B) Various types of anterolateral meningiomas: type A, total prevalence of side and no extension of dural attachment beyond the midline and type B, dural attachment on both sides of the midline with different degrees of extension



The average maximum diameter was 31.1 mm (± 10.7 mm). In two cases (5.1%), there was an extradural extension of the tumor.

We also considered the involvement of neurovascular structures. Brainstem adhesions were present in six cases (18.0%) and a VA encasement was present in 17 cases (51.5%) (Table 3), 12 of the latter being cases of total

encasement (30.7% of patients) and five of partial encasement (12.8% of patients).

We decided to add two additional points to the CS for total VA encasement and BS adhesion as these key conditions influence surgical treatment and prognosis. In fact, the frequency of both these parameters was significantly higher ($p < 0.05$) in the group of patients who underwent partial removal than in the total removal group.

We calculated the CS for each patient with anterior meningioma obtaining the following results: five cases with CS 1, eight cases with CS 2, nine cases with CS 3, five cases with CS 4, three cases with CS 5, two cases with CS 6, and one case with CS 7 (Table 3).

Correlating CS and grade of removal, we obtained that the cases in which a total removal was possible had significantly ($p < 0.05$) lower CS mean value (2.5) than patients who underwent only partial removal (CS 4.9).

A logistic regression was performed to ascertain the value of CS on the likelihood to have partial removal of the lesion. The logistic regression model was statistically significant ($p = 0.001$). The model explained 37% (Nagelkerke R^2) of the variance and correctly classified 85.0% of cases.

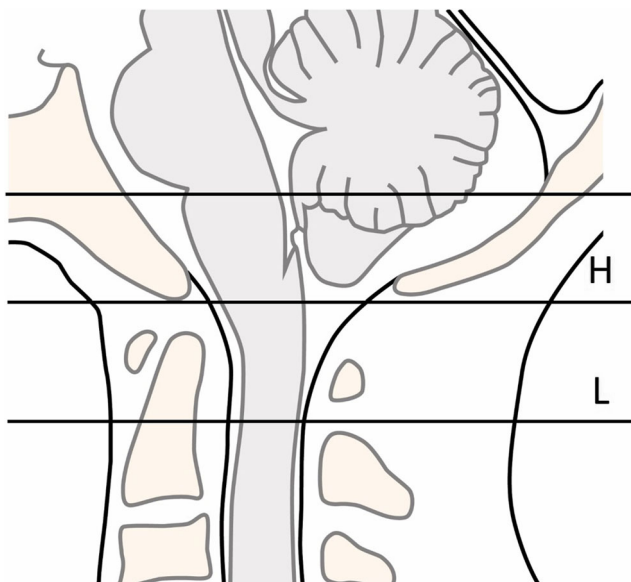
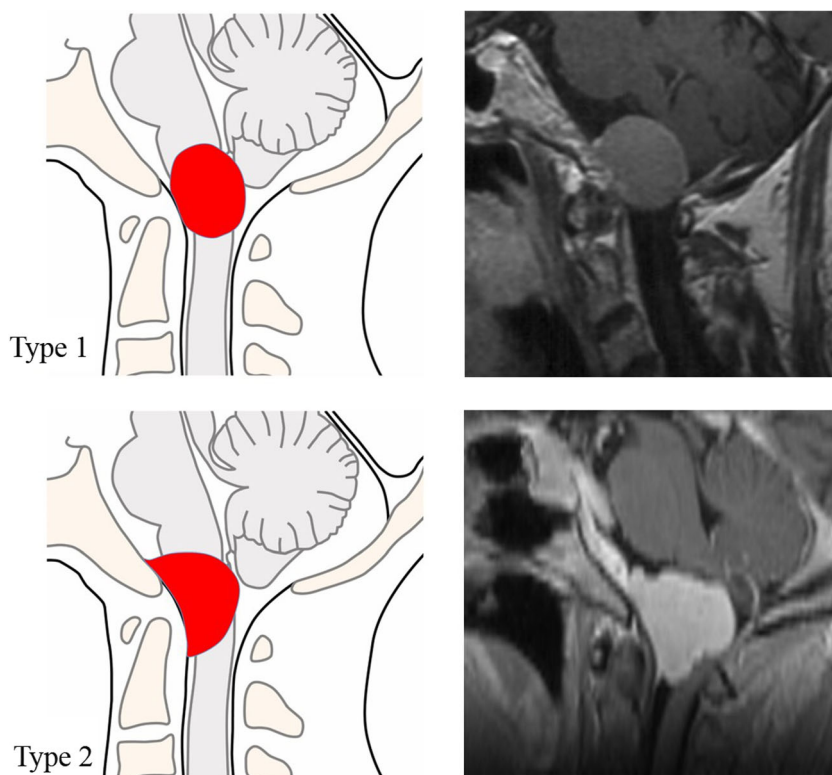


Fig. 2 Graphical illustration of the two regions considered for foramen magnum (FM). High FM (H): between the horizontal line passing through the junction middle-inferior third of the clivus and the horizontal line passing through the basion. Low FM (L): between this last line and the horizontal line passing through the superior edge of C2 vertebral body

Discussion

Meningiomas are the most frequent FM tumors. FMMs account for 2.5% of all intracranial meningiomas and 4.0% of those are found in the posterior fossa [11, 12, 39–41].

Fig. 3 Artist illustration (left) and T1-weighted magnetic resonance images of two treated cases (right) depicting the two types of sagittal dural attachment. We describe as “type 1” the tumor with ratio sagittal dural attachment length/maximum craniocaudal diameter < 1 , and “type 2” with ratio ≥ 1



In 1938, Cushing and Eisenhardt have first proposed a classification system for foramen magnum tumors, by differentiating them into craniospinal and spinocranial lesions [16]. In 1953, Castellano and Ruggiero [15] have then proposed a classification of meningiomas of the posterior cranial fossa according to the site of dural attachment posterior surface of

the petrous bone, tentorium, cerebellar convexity, clivus, and foramen magnum. In the following years, different aspects of these kinds of tumors have been further analyzed in more detail. George et al., in 1997 [18], have classified FMMs into anterior, lateral, or posterior lesions and intradural, extradural, or intra-extradural, and above, below, or both sides of the VA according to the insertion zone along the midline and denticulate ligament, the compartment of growth, and extent along the VA, respectively.

Here, we add an additional, more detailed classification system based on an analysis of the results of our surgical series. We further translate the applied guidance and treatment into a classification system. The key features analyzed by our classification system, in particular those regarding the characteristics of dural attachment, allow to define the surgical approach. By providing a tailored approach, we minimize the surgical trauma and, consequently, the number of potential complications for our patients.

Many surgical strategies have been proposed for the treatment of anterior and anterolateral FMMs including the more recent endoscopic transclival approach that has been preferred by some authors in purely ventral lesions [25]. In our experience, the dorsolateral trans-condylar approach represents a valid and safe surgical route; however, a standardized surgical approach may also include unnecessary surgical steps [6, 7]. Meningiomas located anterior to the brainstem and cervical cord cannot be removed safely without a sufficiently tailored exposure. There is continuing controversy in the literature

Table 2 Complexity score items

Items		Points
Axial dural attachment type	Type A	1
	Type B	2
Sagittal dural attachment type	Type 1	0
	Type 2	1
Vertebral artery encasement	No	0
	Partial	1
	Total	2
Brainstem adhesion	No	0
	Yes	2
Extradural extension	No	0
	Yes	1

Axial dural attachment: “type A,” the meningiomas with a total prevalence of side and no extension of dural attachment beyond the midline, and “type B,” the meningiomas with the dural attachment on both sides of the midline with different degrees of extension

Sagittal dural attachment: ratio sagittal dural attachment length/maximum craniocaudal diameter. We describe as “type 1” the tumors with ratio < 1 and “type 2” with ratio ≥ 1

Table 3 Radiological features, surgery, outcome, and complexity score

General data			Radiological features								Surgery	Post-op mRS	Complexity score
No.	Sex	Age	Axial loc	Axial dural att type	Sag localization	Sag dural att type	Growth	Brainstem att	VA invol	Resection			
1	m	66	AL	b	L	1	Intra	N	N	T	DL	1	2
2	f	61	P		L		Intra	N	Yt	T	SO	3	
3	m	53	A		L	1	Intra	N	Yp	T	DL	2	3
4	m	67	AL	a	H	1	Intra/extra	N	N	T	DL	1	2
5	m	39	AL	b	L/H	2	Intra	N	Yp	T	DL	2	4
6	m	78	AL	b	L	1	Intra	N	Yp	T	DL	2	3
7	f	69	A		L/H	1	Intra	N	N	T	DL	2	2
8	m	73	P		H		Intra	N	Yt	ST	SO	2	
9	f	43	AL	b	L	2	Intra	N	Yt	ST	DL	1	5
10	f	75	AL	a	L/H	1	Intra	Y	N	ST	DL	2	3
11	m	59	AL	b	L/H	1	Intra	N	Yp	T	DL	1	3
12	m	64	AL	b	H	1	Intra	N	Yt	T	DL	2	4
13	m	62	AL	b	L/H	2	Intra	N	N	T	DL	1	3
14	f	62	AL	a	H	1	Intra	N	Yt	T	DL	1	3
15	m	53	A		H	1	Intra	N	Yt	ST	DL	1	3
16	f	72	AL	a	H	2	Intra	N	N	T	DL	1	2
17	m	68	AL	b	H	2	Intra	N	Tt	ST	DL	2	5
18	f	35	AL	a	L	2	Intra	Y	N	ST	DL	2	4
19	f	30	P		H		Intra	Y	N	ST	SO	3	
20	m	57	AL	b	H	1	Intra	N	Yt	T	DL	1	4
21	m	54	AL	b	H	1	Intra	N	Yt	T	DL	1	4
22	f	33	A		H	1	Intra	N	Yp	T	DL	1	3
23	f	46	AL	b	H	2	Intra	N	N	T	DL	0	3
24	f	57	A		L	2	Intra	N	N	T	DL	1	2
25	f	37	AL	a	H	1	Intra	N	N	T	DL	1	1
26	f	54	A		H	1	Intra	N	N	T	DL	1	2
27	f	57	AL	b	H	1	Intra	Y	Yt	ST	DL	1	6
28	m	64	P		L		Intra	N	N	T	SO	2	
29	f	50	A		H	1	Intra	Y	Yt	ST	DL	5	6
30	f	15	AL	a	H	1	Intra	N	N	ST	DL	0	1
31	f	51	AL	a	H	2	Intra/extra	N	Yt	T	DL	1	5
32	f	57	AL	a	L/H	1	Intra	N	N	T	DL	0	1
33	f	67	P		L		Intra	N	N	T	SO	1	
34	f		AL	a	H	2	Intra	N	N	T	DL	1	2
35	f	57	AL	a	H	1	Intra	N	N	T	DL	1	1
36	m	57	AL	a	H	1	Intra	N	N	T	DL	1	1
37	f	46	AL	b	L	2	Intra	Y	Yt	ST	DL	4	7
38	m	45	A		H	1	Intra	N	N	T	DL	2	2
39	f	22	P		H		Intra	N	N	T	SO	1	

AL, anterolateral; P, posterior; L, low; H, high; Yt, total encasement; Yp, partial encasement; T, total; ST, subtotal; DL, dorsolateral; SO, suboccipital; mRS, modified Rankin Scale

concerning the necessity of resecting the occipital condyle [2, 4, 9, 10, 19, 21, 24, 27, 32, 33, 35, 36] but it is our conviction that a wide exposure of the tumor dural attachment is essential. In fact, an early devascularization of meningioma, proved to

be the best strategy, is possible only at the site of tumor insertion to the dura, requiring a so-called extreme lateral exposure. To visualize the tumor from a lateral direction requires resection not only of the medial rim of the FM (medial portion of

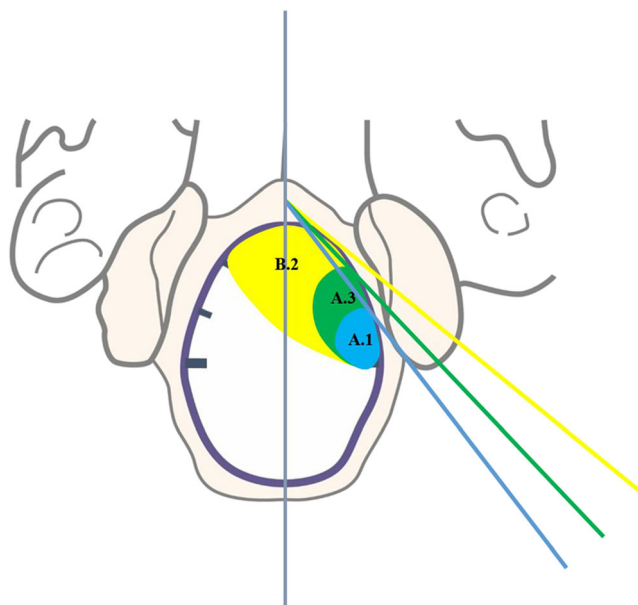


Fig. 4 Artist illustration of the “compass” model showing how the angle of surgical approach must be “open” laterally as much as the dural attachment of the tumor is anterior and extended

the condyle) but also of the jugular tubercle and, depending on the caudal extension of the tumor, of the medial portion of the C1 lateral mass. Based on these concepts, we developed a classification system directly relating to the required surgical exposure. Like with a “compass,” the angle of the surgical approach must be “open” laterally as much as the dural attachment of the tumor is anterior and extended (Fig. 4).

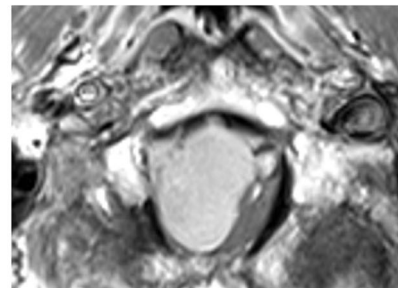
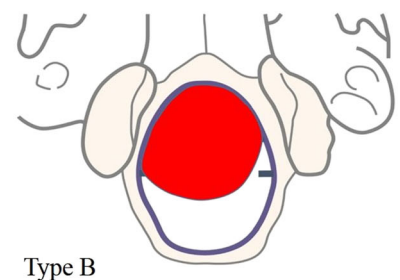
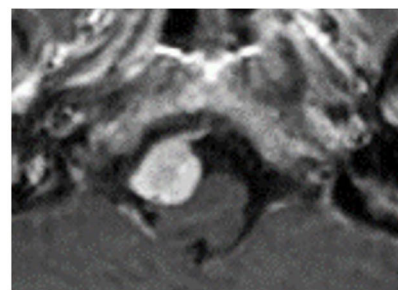
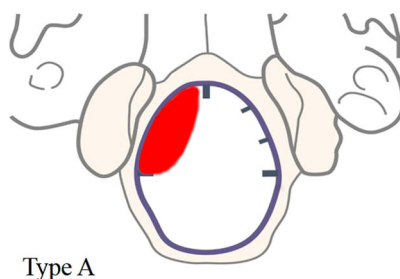
In consequence, meningioma types A.5-2, A.6-2, and B.2 (Figs. 3 and 5), as proposed by our CS, with anterior, extended axial, and sagittal dural attachment, require maximum extreme lateral exposure. Following the same principles, for type A.1-

1, A.2-1, and A.3-1 meningiomas, with a lower axial and sagittal extension of the dural attachment, lateral exposure can be reduced and some surgical steps such as mastoidectomy, exposure of the transverse process of the atlas, extensive resection of the occipital condyle including its articular facet, and complete exposure of the jugular bulb can be avoided.

The location of the tumor on the sagittal plane is an important feature to decide the craniocaudal extension of surgical approach. Using the anatomical limits defined by George and Lot in 1995 [17], we divided the FM region into two parts, high and low FM, by an imaginary line passing through the basion. The larger extension of the meningioma in the superior or inferior part of the FM region determines the superior extent of the craniotomy or the levels of laminotomy [5, 8]. In our series, we did not observe significant differences in relation to the sagittal localization, in terms of surgical resection and outcome, presumably because adherence to neurovascular structures, in particular the encasement of VA, shows almost the same frequency between the two types of localization (high and low FM). We observed VA encasement in 50% of tumors located in low FM and in 43% of tumors located in the high FM.

The complexity score based on our classification system and three additional important tumor features (VA encasement, BS adhesion, and extradural extension), proposed here, could help the intraoperative decision-making. In our hands, in patients with a high complexity score (i.e., $CS \geq 5$), the risk of surgical injury of neurovascular structures is very high and the subtotal removal of the tumor is advised. For the calculation of our score, we decided to assign the highest values to total VA encasement and BS adhesion, as, in our experience, these appear to be two key features contraindicating a safe tumor removal.

Fig. 5 Artist illustration (left) and T1-weighted magnetic resonance images of two treated cases (right) showing example of the two different axial plane positions of the tumor. Totally on one side and no extension beyond the midline (type A) and dural attachment on both sides of the midline (type B)



Over the years, several authors have analyzed the difficulties encountered during the surgical treatment of FMFs. Tumor recurrence, extradural growth, vascular encasement, and arachnoid scarring are important and widely accepted factors in the decision against radical excision of meningiomas of the foramen magnum [1, 18, 33, 34]. We report 51.5% global percentage of VA encasement with total VA encasement in 30.7%. In the literature, this percentage varies considerably, with the mean value of 42.9% of all published surgical series [3, 13, 14, 18–20, 23, 28, 30–33, 38, 39]. During pre-operative planning, it is very important to analyze the course of VA and the presence of VA encasement through MRI imaging, as this artery can be damaged during different steps of surgery: muscular dissection, bone opening, tumor removal [3, 29, 38, 39].

The presence or absence of an arachnoidal plane between the tumor and the BS is another crucial point that determines the extent of removal [1, 38] and post-operative morbidity [19, 33]. In our series, we report six cases of BS adhesion (18%).

The last feature determining our score is the extradural extension of the tumor. In meningiomas, this is a rare condition [13]. The VA sheath and even the arterial adventitia can also be infiltrated. This situation can explain the higher incidence of incomplete removal and higher morbidity as compared to intradural meningiomas [26, 29, 37]. In case of extradural extension of the meningioma, maximum extreme lateral exposure is often required. In our series, we report extradural extension in 5% of cases.

With these considerations in mind, a detailed pre-operative planning is required and, during surgery, an accurate devascularization of the tumor is mandatory for working in a clean surgical field for the proper identification of neurovascular structures. However, for patients with a particularly high CS (CS 4.9), partial removal was the preferred surgical approach. In fact, total removal was usually performed in patients with a significantly lower mean CS value (2.5). For CS ≥ 5 , partial tumor removal may provide the best surgical result considering outcome and prognosis.

Conclusions

Based on our experience with surgery of foramen magnum meningiomas, we developed a classification system and associated complexity score in order to make the right decisions at every turn of the patient's course. Our score includes the following: type of dural attachment, vertebral artery encasement, brainstem adhesion, and extradural extension. In consideration of the benign behavior of the tumor, we propose subtotal removal for a complexity score of 5 or higher.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The clinical study was approved by the ethical commission of the institute.

Informed consent All patients (parents in the case of minors) were fully informed about the surgery and the documentation used for this study and signed informed consent.

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