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Journal of Craniovertebral Junction and Spine

Original Article

Classification system of foramen magnum meningiomas

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DOI: 10.4103/0974-8237.65476 J Craniovert Jun Spine 2010, 1:3

Abstract

Background: Foramen magnum meningiomas (FMMs) are challenging tumors. We report a classification system based on our experience of 107 tumors. **Materials and Methods:** The three main algorithm criteria included the compartment of development of the tumor, its dural insertion, and its relation to the vertebral artery. **Results:** The compartment of development was most of the time intradural (101/107, 94.4%) and less frequently extradural (3/107, 2.8%) or both intra-extradural. (3/107, 2.8%). When developed inside the intradural compartment, FMMs were subdivided into posterior (6/104, 5.8%), lateral (57/104, 54.8%), and anterior (41/104, 39.4%), if their insertion was respectively posterior to the dentate ligament, anterior to the dentate ligament without or with extension over the midline. Anterior and lateral intradural lesions grew below (77/98, 78.6%), above (16/98, 16.3%), or on both sides (5/98, 5.1%) of the VA. Only three cases of extraduralFMMs (3/107, 2.8%) were resected by an antero-lateral approach while all the other ones (104/107, 97.2%) were removed successfully by a postero-lateral approach. Lower cranial nerves were displaced superiorly in FMM growing below the VA but their position cannot be anticipated in other situations. **Conclusions:** This classification system helps for defining the best surgical approach but also for anticipating the position of the lower cranial nerves and therefore for reducing the surgical morbidity.

Key words: Classification, foramen magnum, meningioma, surgical approach, tumor - vertebral artery

INTRODUCTION

Foramen magnum meningiomas (FMMs) are undoubtfully challenging lesions due to their location, to their close relation with the neuraxis and lower cranial nerves as well as with the vertebral artery (VA) and branches.[1] Moreover, when discovered, these tumors are often large due to their slow-growing rate, their indolent development, and the difficulty of the diagnosis leading to a long interval since the first symptom as well as the wide subarachnoid space at this level.[2] Several other factors are well known to be associated with a higher morbidity rate such as anterior tumor location,[3,4] tumor invasiveness, extradural extension,[3] VA encasement,[5] absence of arachnoidal sheath,[6-8] and adherences in recurrent lesions.[4,6,9,10]

Meningiomas are in fact the most commonly observed FM tumors. They represent 70% of all benign tumors.[3,4,8,11-13] Most of the time, these are strictly intradural. In the literature, 10% have an extradural extension: most are intra- and extradural and a few may be entirely extradural.[3,11-16]

Basically, two surgical approaches are mainly used for resecting anterior and lateral lesions: the postero-lateral approach, also called the far-lateral approach, and the antero-lateral approach, also named the extreme-lateral approach. A third approach, the midline posterior approach, has also been recommended by Goel to approach anterior and anterolaterally placed tumors.[17]

Based on our experience of 107 FMMs treated surgically, we have developed a classification system aimed at choosing what we consider the adequate approach and at lowering the surgical morbidity.

SURGICAL ANATOMY

First of all, it is important to define the limits of the FM. By definition, a FMM grows from the FM dura mater. It is thus not a lesion developed outside the FM and extending into it. Afterward, some important points on the FM anatomy will be reviewed because perfect anatomy understanding of neurovascular structures is a mandatory prerequisite.

LIMITS OF THE FM

The landmarks we used to define the FM limits are:[3,11,13] anteriorly, the lower third of the clivus and upper edge of the body of C2; laterally, the jugular tubercles and upper aspect of C2 laminas; and posteriorly, the anterior edge of the squamous occipital bone and C2 spinous process.

LOWER CRANIAL NERVES

Four lower cranial nerves pass through the FM. Preserving them intact is crucial for lowering the surgical morbidity.

The glossopharyngeal (CN IX), the vagus (CN X), and the spinal accessory (CN XI) nerves arise from rootlets of the post-olivary sulcus and join the jugular foramen, passing ventral to the choroids plexus protruding from the foramen of Luschka and dorsal to the VA.[18] The hypoglossal nerve (CN XII) arises from rootlets of the pre-olivary sulcus. This nerve runs anterolateral in the subarachnoid space and pass behind the VA to reach the hypoglossal canal. Rarely, the VA separates the CN XII rootlets.[18] Of note, the accessory nerve is composed of rootlets originating from the medulla and the spinal cord. The upper medullary rootlets run directly into the jugular foramen.[18] A main trunk is formed by spinal rootlets which join together; it ascends through the FM running behind the dentate ligament and unites with the upper medullary rootlets. Anastomoses with the dorsal roots of the upper cervical nerves are frequent, that with the C1 nerve root being the most common and largest one.[18]

THE VA V3 AND V4 SEGMENTS

Surgery of FMMs is unseparable from VA surgery. Indeed, the surgical approach is closely related to the VA V3 segment and the resection of the lesion itself is linked with the VA V4 segment.

The VA V3 segment, also called the suboccipital segment, extends from the C2 transverse process toward the dura mater of the FM where it becomes the V4 segment when passing through it.

The VA V3 segment owns three portions. The first one is vertical between the transverse processes of C2 and C1. The second one is horizontal, after the VA turns medially at the level of the C1 transverse foramen and courses along the superior border of the posterior arch of atlas. The third portion is oblique due to a step formed by the bone of the posterior arch of atlas, just before entering the dura mater. It is of crucial importance to remember that the anatomical relations between the vertical and horizontal portions changes according to head position. When the head is in neutral position, both portions run perpendicular. But, when the head turns to one side, the contralateral C1 transverse process moves anteriorly; it implies that the vertical and horizontal portions of the contralateral vertebral artery become stretched and finally run almost parallel, only separated by the bone of the C1 posterior arch. This point must be perfectly understood because head positioning for an antero-lateral approach is directly related to the surgical anatomy.

The VA V3 segment is surrounded by a periosteal sheath constituted by an extension of the transverse foramen periosteum. Inside the periosteal sheath, the artery is encircled by an important venous plexus. The periosteal layer is anatomically in continuity with the outer layer of the dura mater and invaginates into it. At this level, the VA is attached to the periosteal sheath and the adventitia is adherent to the double furrow forming the distal fibrous ring.[19] By this way, despite being the most mobile VA segment, the VA V3 segment is fixed at its upper extremities.

Along its course, this VA V3 segment gives off small collateral branches. In the middle of the posterolateral aspect of the vertical portion starts the C2 radicular artery. There also exists a small muscular branch coursing posteriorly at the upper exit of the C1 transverse foramen and the posterior meningeal artery. Finally, the posterior spinal artery begins most of the time just before the dural penetration and enters the dural foramen where the C1 nerve root exits the spinal canal[20] but it may also arise from the initial intradural part of the VA V4 segment, or from the posteroinferior cerebellar artery (PICA).[20-23] This branch runs medially behind the most rostral attachment of the dentate ligament and divides into ascending and descending branches, when reaching the lower medulla, providing respectively the vascular supply to a part of the medulla oblongata and the spinal cord.[20]

Anatomical variations of the VA V3 segment are crucial to know and identify preoperatively, remembering them participate at lowering the surgical morbidity:

- In 40% of the people, the VAs are of different sizes: one side is dominant and the other one is hypoplastic or atretic.[19]
- The VA V3 segment can end at the PICA or at the occipital artery.[24]
- As frequently as 20% of the cases, the PICA originates extracranially, arising from the VA above C1, between C1 and C2, or even in the V2 segment.[25,26] Ignoring this condition could result in an inadvertent injury and a posterior fossa infarct already during the surgical exposure.
- More anecdotic, the VA V3 segment can be duplicated: one atretic portion follows the normal course but the main portion pierces the dura between C1 and C2.[27-31]
- A proatlantal artery is exceptional and consists of a persistent

congenital anastomosis between the carotid artery and the VA; it is often associated with an atretic proximal VA and an extracranial origin of the PICA.[24,26,32]

Finally, the groove of the arch of atlas can be turned into a tunnel if the occipitoatlantal membrane is calcified or ossified, raising some difficulties to expose the horizontal portion at this level.[33,34]

After passing through the lateral aspect of the occipitoatlantal dura mater, the VA V3 segment becomes the V4 segment. Both VA V4 segments join then together to form the basilar artery.[19] The VA V4 segment ascends from the dura mater up to the anterior aspect of the pontomedullary sulcus where it fuses with the controlateral one. Initially the VA V4 segment courses posteriorly and medially to the occipital condyle, the hypoglossal canal, and the jugular tubercle. Later, it lies on the clivus and runs in front of the hypoglossal and the lower cranial nerves rootlets.

The VA V4 segment is at the origin of several important branches, especially the PICA and the anterior spinal artery. The PICA is the most important VA branch. It can originate at, above, or below the FM level.[35] The anterior spinal artery starts near the vertebrobasilar junction. Most of the time, the anterior spinal arteries of both sides joins together above the FM level near the lower end of the olives, then the artery descends through the FM and runs on the anterior midline.[35] In some cases, one artery is dominant. If no fusion exists between both arteries, only one of these arteries forms.

FM DURA MATER VASCULARIZATION

Dividing meningiomas afferents is a basic principle in meningioma surgery. It allows for resecting the lesion in a dry surgical field. This concept is especially important at the level of the cranial base where the working area is limited and vital structures are numerous.

Four meningeal vessels participate to the vascular supply of the FM dura mater: the anterior and posterior VA meningeal arteries, and meningeal branches of the ascending pharyngeal and occipital arteries.[20,21,36] Infrequently, meningeal branches arise from the PICA, the posterior spinal artery, and the VA V4 segment. The anterior meningeal branch, the most important branch, arises from the VA at the C2-C3 level. The posterior meningeal artery originates from the posterosuperior aspect of the VA when it turns around the lateral mass of the atlas, above the posterior arch of the atlas, just before it penetrates the dura, or just at the beginning of the V4 segment.[19-21] The ascending pharyngeal artery is a branch of the external carotid artery; it gives meningeal branches penetrating into the hypoglossal canal and the jugular foramen. The meningeal branch of the occipital artery is inconstant and passes through the mastoid emissary foramen.[20]

THE DENTATE LIGAMENT

Identification and division of the dentate ligament is the first intradural step. This maneuver allows for enlarging the surgical corridor and for reducing compression of the neuraxis. The ligament is a white fibrous sheet extending from the pia mater, medially, to the dura mater, laterally. It forms arches. The first arch gives passage to the VA and the second arch to the second cervical nerve root.

SURGICAL APPROACHES

Basically, three surgical approaches are commonly used for resecting FMMs: the midline posterior approach, the postero-lateral approach, and the antero-lateral approach.

As detailed by Rhoton,[37] the postero-lateral approach, or far lateral approach, is a lateral suboccipital approach directed behind the sternocleidomastoid muscle and the VA and just medial to the occipital and atlantal condyles and the atlanto-occipital joint. The antero-lateral approach, or extreme lateral approach, is a direct lateral approach deep to the anterior part of the sternocleidomastoid muscle and behind the internal jugular vein along the front of the VA. In fact, both approaches permit drilling of the occipital condyle but provide a different exposure because of the differences in the approach direction.

During the postero-lateral approach, the VA V3 segment is controlled in its horizontal portion, meaning above the C1 posterior arch. VA transposition is not applied. The FMM lateral wall can be drilled in a variable way, in fact directly proportional to the tumor extension to the contralateral side. Recently, Bassiouni[6] classified judiciously postero-lateral approaches in 2 groups: transcondylar or retrocondylar if the occipital condyle is or is not drilled.

The extreme-lateral transcondylar approach in cases of FMMs was first reported by Sen and Sekhar[10] in 1990. It requires VA transposition to reach and drill the occipital condyle.[9,10,38-41] Several variations were described by Salas *et al*.,[41] the most common one being the partial transcondylar approach and more rarely the transfacetal, retrocondylar, and extreme transjugular approaches. With the partial transcondylar approach, the posterior one-third of occipital condyle and superior facet of C1 are resected. Some authors describe condyle drilling ranging approximately from one-third to one-half of the condyle, without causing craniocervical instability.[38]

OUR CLASSIFICATION SYSTEM OF FORAMEN MAGNUM MENINGIOMAS

The classification system that we have developed is based on the lesion characteristics observed on preoperative imaging. It has the objectives to define preoperatively the adequate surgical approach and to help for anticipating the position of vital neurovascular structures thereby decreasing the surgical morbidity.

Three mains criteria are used in the classification system: the compartment of development, the dural insertion, and to the relation to the VA [Figure 1].

According to the compartment of development, FMMs can be subdivided into intradural, extradural, intra- and extradural.

Intradural meningiomas are the most common lesion encountered. In our opinion, all intradural meningiomas can be accessed through a posterior approach. The use of the antero-lateral approach can be restricted to some cases with an extradural extension. Like at any other site, an extradural location or extension of an intradural lesion means that the lesion is very invasive into the bone, the nerves, and soft tissues. The VA sheath and even the arterial adventitia can also be infiltrated. This situation is especially problematic and explains the higher incidence of incomplete removal and higher morbidity as compared to intradural meningiomas.[16,42,43]

According to the dural insertion, FMM can be subdivided depending on their location in the antero-posterior plane into posterior, lateral, or anterior. The lesion is considered posterior if its insertion is posterior to the dentate ligament; lateral, if its insertion is between the midline and the dentate ligament; or anterior, if its insertion is on both sides of the anterior midline.

In posterior FMMs, the neuraxis is always displaced anteriorly. The midline posterior approach is dedicated for removing them whatever their intra- and extra-dural extension.[12,15]

Lateral FMMs push the neuraxis posterolaterally and thus widely open the lateral surgical corridor; therefore, bone resection has never to be extended to the FM lateral wall consisting of the lateral mass of the atlas or the occipital condyle [Figure 2].

These lateral FMMs are in close relation with the VA. Analyzing preoperatively the relation of the lesion with the VA is crucial because it allows in some circumstances for anticipating the position of the lower cranial nerves; this is definitively in direct relation with the surgical morbidity.

In fact, FMMs have the possibility to develop above, below, or on both sides of the VA. More often, meningiomas grow below the VA. In this condition, the lower cranial nerves are always displaced cranially and posteriorly and there is thus no need to look for them until the end of the resection which starts at the lower pole of the lesion. The nerves will come into view on reaching the superior tumoral part. In contrast, if the lesion develops above the VA, the position of the lower cranial nerves cannot be anticipated; indeed the nerves may be displaced separately in any direction. After partial debulking of the tumor, great care must be taken to look for them so as to identify and protect them during the tumor resection. In case of tumoral extension on both sides of the VA, a similar problem is encountered with the position of the lower cranial nerves but an additional problem exists: the dura mater around the VA penetration may be infiltrated by the tumor. As previously mentioned the dura is normally adherent to the adventitia and then complete resection of the tumor at this level can be hazardous. In this rare condition, we advise for safety reasons to leave a cuff of infiltrated dura around the VA and to coagulate only this zone.

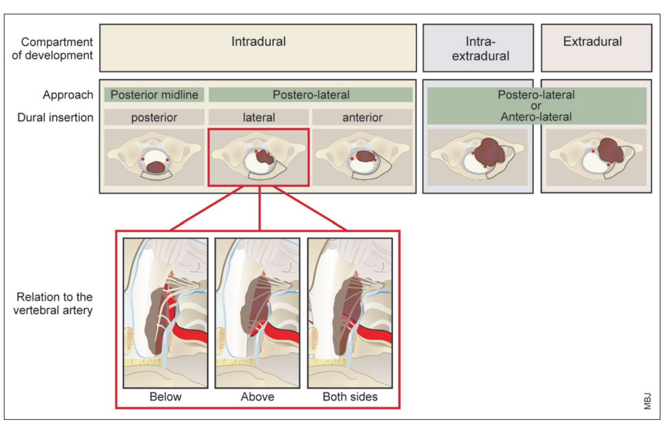

Figure 1: Classification system of foramen magnum meningiomas. Reprinted with permission from Bruneau M and George B. Foramen magnum meningiomas: detailed surgical approaches and technical aspects at Lariboisière Hospital and review of the literature.[1]

Anterior FMMs displace the spinal cord posteriorly. Therefore, the surgical space between the neuraxis and the FM lateral wall to access the lesion is narrow. Two different strategies confront each other in this subtype of tumors. Indeed, for some authors the antero-lateral is the most appropriate. In our opinion, we consider that all these lesions can be resected successfully with minimal morbidity through a postero-lateral approach [Figure 3]. The tumor access implies the resection of the laminae and a suboccipital craniotomy extended to the medial part of the FM lateral wall. Nevertheless, in almost every case no drilling of the lateral mass of atlas and occipital condyle is necessary. Only exceptionally, some anterior FMMs require an extended enlargement by drilling of at maximum the medial fifth of the FM lateral wall; this is encountered with small-sized lesions without anterior compartment enlargement.

Avoid drilling of a significant part of the FM lateral is associated with preservation of the craniovertebral junction stability which participates in the low morbidity rate and the maintenance of a better quality of live by avoiding a debilitating craniovertebral osteoarthrodesis. Moreover, in contrast to the antero-lateral approach, the postero-lateral requires less VA manipulations which finally only need to be controlled but not transposed.

Extradural lesions can be removed either by the posterolateral or anterolateral approach. The extent of bone resection in this case can be more important than for intradural lesion but is in fact only dictated by the tumoral invasion and must be limited to the destroyed or invaded bone. By this way, postoperative instability is only a preoperative concern since the extent of bone resection is determined at that time. As far as less than half of the C0-C1 and C1-C2 joints are resected, we have not encountered craniovertebral instability.[12]

OUR EXPERIENCE

Our present surgical series encompasses 107 cases of FMMs. Intradural meningiomas constitute by far the main group with 101 tumors. Three meningiomas were intra-extradural and three purely extradural. Most of these meningiomas were operated

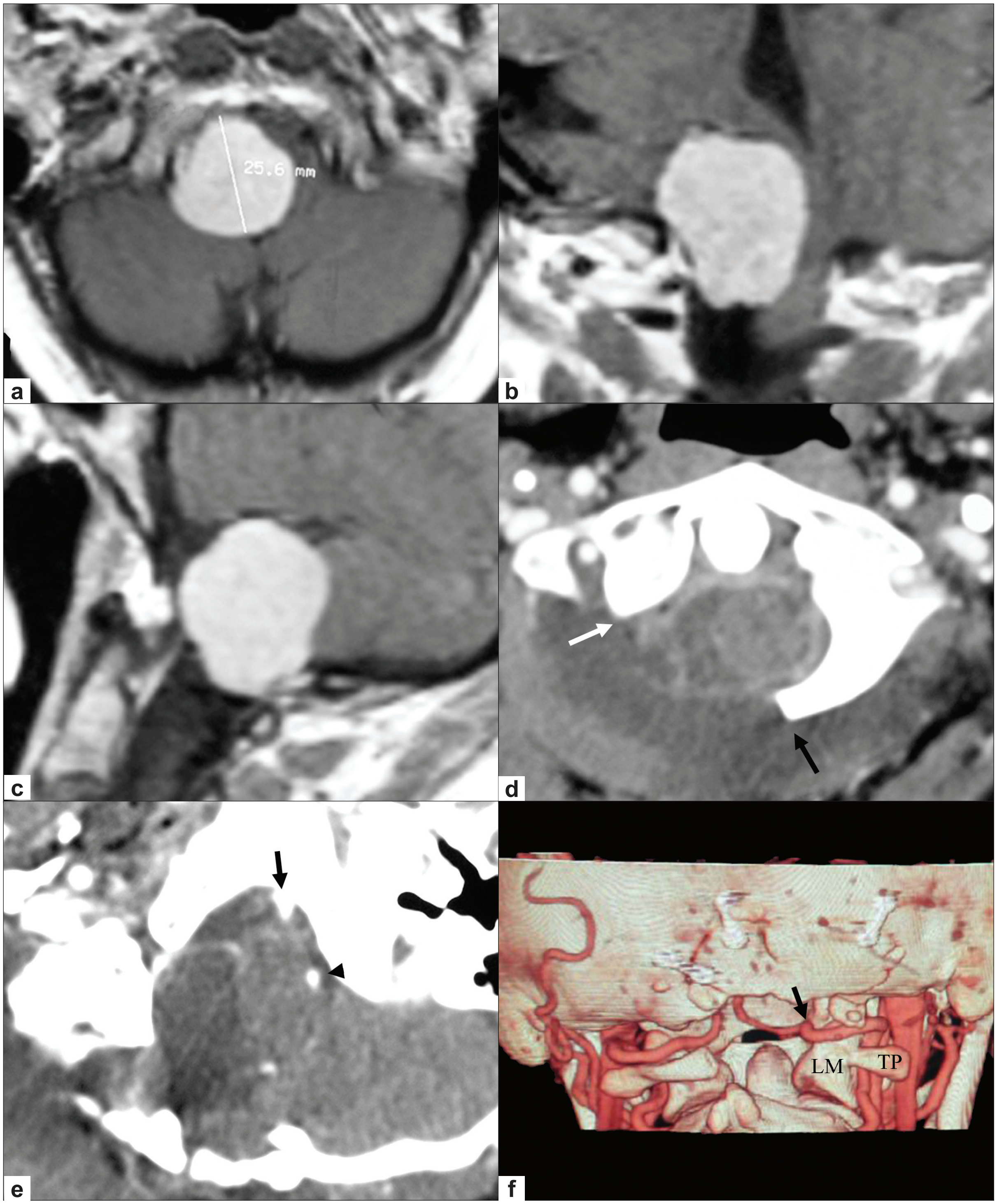

Figure 2: Lateral intradural foramen magnum meningioma. (a-c) Preoperative MRI in axial (a), coronal (b) and sagittal (c) planes. (a) The meningioma inserted on the right side but not across the midline. The tumor displaces the neuraxis antero-laterally and creates a large surgical corridor. (d-f) Postoperative CT-scans, after complete resection of the tumor through a postero-lateral approach. (d) The extension of the C1 laminectomy. The white arrow indicates the lateral limit with a C1 lateral mass left intact. The access is obtained on the base of insertion as demonstrated by the arrow direction. The laminectomy has been extended over the midline (black arrow) for preventing stretching of the neuraxis on the bone edge during the resection. (e) The size of the craniotomy. Black arrow and arrowhead show respectively the right and left vertebral arteries. (f) shows the vertebral artery V3 and V4 segments courses on a 3D reconstruction. The arrow indicates the V3-V4 junction. LM: C1 lateral mass. TP: C1 transverse process. Modified with permission.[1]

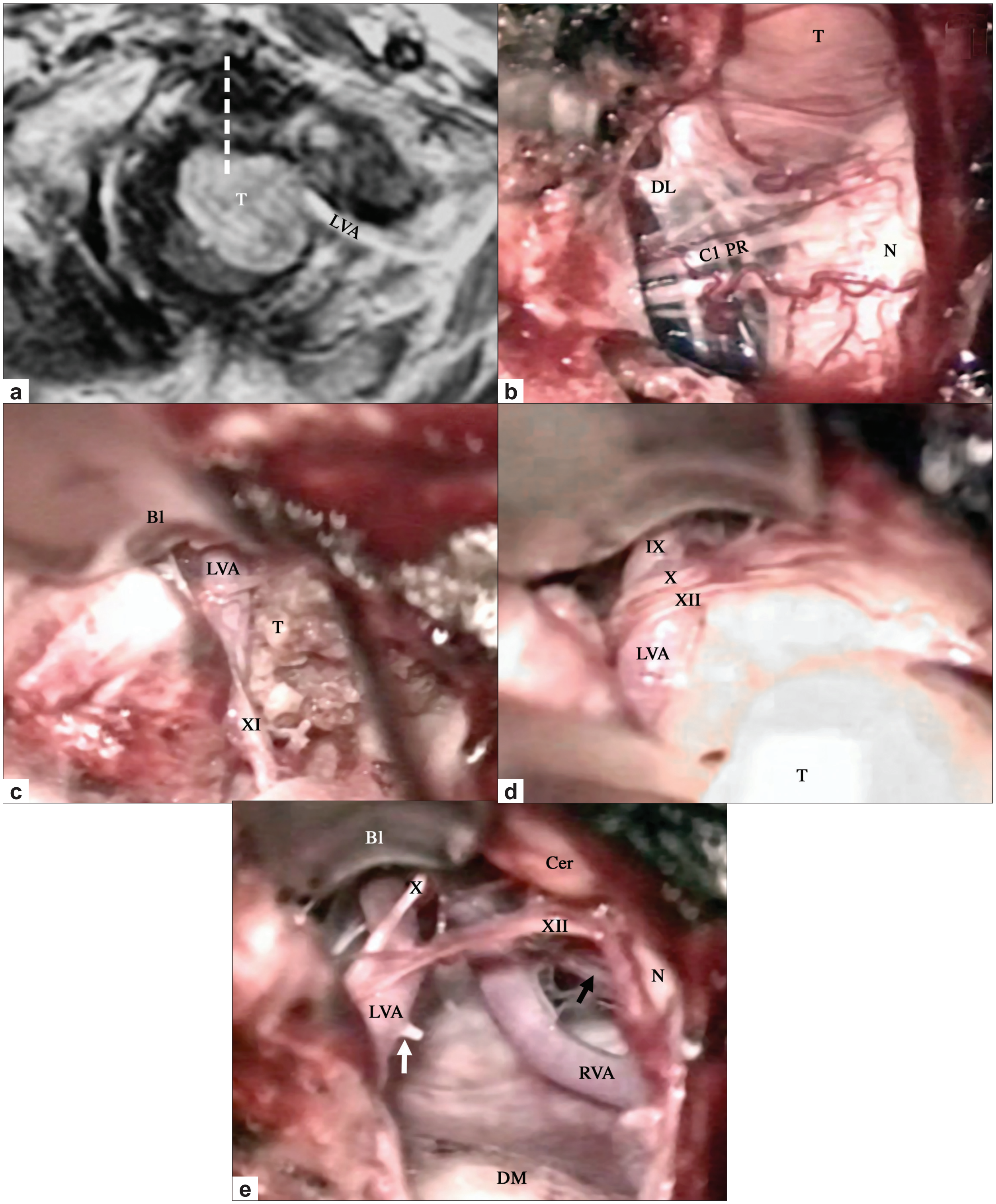

Figure 3: Anterior intradural foramen magnum meningioma developed below the vertebral artery. (a) Preoperative view on axial T1-weighted MRI with gadolimium administration. The tumor (T) inserts on both sides of the midline (dotted line). The left vertebral artery (LVA) passes above the tumor. (B-E Operative views. (b) View just after the dura opening. (c) The tumor is developed below the vertebral artery. (d) The lower cranial nerves are identified at the superior aspect of the tumor. (e) Final view. White arrow indicates a feeding vessel that has been divided. Black arrow shows the right PICA. Bl: blade. C1 PR: C1 posterior rootlets. Cer: cerebellum. DL: dentate ligament. LVA: left vertebral artery. N: neuraxis. T: tumor. IX: glosso-pharyngeal nerve. X: vagal nerve. XI: accessory nerve. XII: hypoglossal nerve. Modified with permission.[1]

on at first presentation but six patients were recurrent cases previously treated elsewhere.

Overall, 97.2% of the patients were operated on through a postero-lateral approach. Only three cases of entirely extradural lesions were operated on through an anterolateral approach with VA transposition. Of intradural lesions, 5.8% (6/104), 54.8% (57/104), and 39.4% (41/104) were respectively classified as posterior, lateral, and anterior according to their dural insertion. Of anterior and lateral intradural lesions, 78.6% (77/98) grew below, 16.3% (16/98) above, and 5.1% (5/98) on both sides of the VA.

Complete removal was achieved in 86% and subtotal removal in 11%. Subtotal removals were due to an extradural extension or to recurrent cases. The rate of complete removal increased up to 94% when selecting only intradural lesions treated at first presentation.

Postoperative deterioration has been noted in three patients, all of them due to swallowing disturbances in tumors located above the VA. We deplore two postoperative deaths in the first years of this series due to pulmonary and air embolisms, respectively.

Most patients were followed up with MRI at 1, 3, 6 and 10 years. We are aware of only one recurrence 9 years after surgery in the group of primary cases. In this case, the meningioma had an usual (muschroom) type at the first surgery and becomes en plaque type at recurrence, involving half of the circumference of the FM dura and bone.

CONCLUSIONS

FMMs are undoubtfully challenging tumors in the vicinity of the brainstem, the VA, and lower cranial nerves. These lesions can be classified according to their compartment of development, their dural insertion, and their relation with the vertebral artery. The first two criteria help for choosing the most appropriate surgical approach. In our experience, only purely extradural FMMs anterior to the VA necessitate to be operated on through an antero-lateral approach; the vast majority of lesions were resected successfully through a postero-lateral approach. In the intradural group, the relation of the tumor with the VA was crucial and allows for anticipating the position of the lower cranial nerves and therefore for reducing the postoperative morbidity. In all cases of tumor growing below the VA, the lower cranial nerves were displaced at the superior pole of the tumor, while in the other cases, their displacement was discovered in all directions.

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Source of Support: Nil, **Conflict of Interest:** None declared.