The far-lateral approach for foramen magnum meningiomas

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Foramen magnum meningiomas (FMMs) are slow growing, most often intradural and extramedullary tumors that pose significant challenges to the skull base neurosurgeon. The indolent clinical course of FMMs and their insidious onset of symptoms are important factors that contribute to delayed diagnosis and relative large size at the time of presentation. Symptoms are often produced by compression of surrounding structures (such as the medulla oblongata, upper cervical spinal cord, lower cranial nerves, and vertebral artery) within a critically confined space. Since the initial pathological description of a FMM in 1872, various surgical approaches have been described with the aim of achieving radical tumor resection. The surgical treatment of FMMs has evolved considerably over the last 4 decades due to the progress in microsurgical techniques and development of a multitude of skull base approaches. Posterior and posterolateral FMMs can be safely resected via a standard midline suboccipital approach. However, controversy still exits regarding the optimal management of anterior or anterolateral lesions. Independently of technical variations and the degree of bone removal, all modern surgical approaches to the lower clivus and anterior foramen magnum derive from the posterolateral (or far-lateral) craniotomy originally described by Roberto Heros and Bernard George. This paper is a review of the surgical management of FMMs, with emphasis on the far-lateral approach and its variations. Clinical presentation, imaging findings, important neuroanatomical correlations, recurrence rates, and outcomes are discussed.

Key Words • far-lateral approach • foramen magnum meningioma • surgical management • surgical technique

Abbreviations used in this paper: BA = basilar artery; FMM = foramen magnum meningioma; GTR = gross-total resection; PICA = posterior inferior cerebellar artery; STR = subtotal resection; VA = vertebral artery.

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treatment options for FMMs, with an emphasis on the far-lateral approach. We describe our institutional experience treating those lesions over the last decade.

**Clinical Presentation**

Meningiomas that involve the foramen magnum have a notoriously insidious clinical course. The mean age of the patients with these lesions at the time of diagnosis is approximately 55 years old, and they often mimic degenerative or demyelinating diseases such as cervical spondylosis, multiple sclerosis, and amyotrophic lateral sclerosis. Such a prolonged—and often relentless—presentation explains the 30.8-month mean length of symptoms prior to diagnosis, even in the era of advanced neuroimaging. Suboccipital headache and upper cervical pain are the most common early complaints, with the pain frequently exacerbated by coughing, straining, or Valsalva maneuvers. The classic foramen magnum syndrome is defined by development of unilateral arm sensory and motor deficits, which progress to the ipsilateral leg, then the contralateral leg, and then the contralateral upper extremity. Long tract findings and spastic quadriparesis present later on in the patient’s clinical course. Untreated cases may progress to quadriplegia and respiratory arrest. Lower cranial nerves are infrequently involved. Cranial nerve XI is the most commonly affected, resulting in atrophy of sternocleidomastoids and trapezius muscles.

Detailed history and physical examination will often disclose signs often ignored or downplayed by the patient. Careful assessment of cranial nerve function should be obtained, with emphasis on detecting dysfunction in the lower cranial nerves (IX–XII). Preoperative assessment of the gag reflex is vital and can reveal compensatory mechanisms developed over the course of the disease. It may alert the neurosurgeon to involvement of lower cranial nerves that increases the likelihood of new/worsening neurological deficit in the postoperative period. Endoscopic assessment of laryngeal and vocal cord function should be obtained in all patients with a history of dysphagia, dysphonia, frequent choking during meals, recurrent pulmonary infections, or abnormal gag reflex on physical examination. Hypoglossal nerve dysfunction is rarely associated with FMMs. Cases that present with ipsilateral tongue deviation and atrophy are often associated with irreversible cranial nerve XII palsy.

**Imaging Features**

Magnetic resonance is the imaging method of choice for FMMs and should be obtained during the initial workup of all patients with suspected foramen magnum lesions. Foramen magnum meningiomas are usually isointense or mildly hypointense on T1-weighted and T2-weighted MR images. Gadolinium-enhanced contrast imaging is helpful in delineating the tumor mass and presence and extension of dural attachment, as well as the tumor-brainstem interface. Foramen magnum meningiomas are homogeneously enhancing, smooth surfaced, and dural based, with characteristic adjacent dural thickening and enhancement (dural tail). Associated parenchymal FLAIR signal and corresponding vasogenic edema is rarely observed, even in cases with marked brainstem distortion; if present, it may represent an indirect indicator of pial involvement and poor pial-tumor plane during resection. The ability to adequately visualize the vertebrobasilar system and vessels adjacent to the tumor represents another great advantage of MR images on preoperative planning for FMMs. In our experience, the degree of involvement or displacement of the vertebral artery (VA), basilar artery (BA), and posterior inferior cerebellar artery (PICA) can be adequately visualized with the use of high-resolution, thin-slice T2-weighted imaging. Routine dedicated MR or CT angiography is not obtained unless specific concerns for vascular occlusion or anatomical variants are identified.

Optimal surgical planning for resection of FMMs should include dedicated high-resolution, thin-slice CT of the craniovertebral junction. Delineating bone margins and estimating the size of the surgical corridor based solely on MRI is deceiving and often inaccurate. Furthermore, a preoperative CT scan is helpful in identifying intratumoral calcifications, evidence of hyperostotic or osteolytic changes of surrounding bone, and the degree of bone resection necessary for adequate tumor exposure.

Historically an essential preoperative study, catheter cerebral angiography is currently reserved only for complex cases that require additional preoperative vertebrobasilar anatomical details. Some authors advocate the need for preoperative embolization of arterial feeders to minimize intraoperative bleeding and operative time; complete 6-vessel angiography would be mandatory in those situations, because the majority of those lesions have arterial feeders derived from external carotid circulation or extracranial VA. However, this has not been the practice at our institution. We believe preoperative embolization has potential peri procedural complications (such as a risk of transient neurological complications as high as 2.6%7) that far outweigh the theoretical benefits realized during resection.

**Neuroanatomical Correlations**

The surgical anatomy of the foramen magnum has been extensively and brilliantly described by Rhoton et al. in multiple previous studies, and a comprehensive analysis of this topic is beyond the scope of the current study. As described by George et al., the foramen magnum corresponds to a zone delineated anteriorly by the lower third of the clivus to the upper edge of the body of C-2, laterally by the jugular tubercles to the upper aspect of the C-2 lamina, and posteriorly from the anterior edge of the squamous occipital bone to the C-2 spinous process. The foramen magnum contains the caudal portion of the medulla, cerebellar tonsils, inferior vermis, fourth ventricle, rostral part of the spinal cord, and lower cranial and upper cervical nerves. The first cervical nerve usually has a diminutive motor component and varies in consistency of its dorsal rootlets. Cranial nerve XII originates from the anterior medulla in the preolivary sulcus and courses posterior to the VA to reach the hypoglossal canal on
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the superior and anterior aspect of the occipital condyles. The relationship of this neuroanatomical structure with the condyle is an important landmark for extreme lateral approaches, where transcondylar extension and generous occipital condyle drilling is necessary.\textsuperscript{16,42} Cranial nerves IX–XI arise as a series of rootlets from the retro-olivary sulcus and exit the skull through the jugular foramen. The spinal component of cranial nerve XI ascends intracranially through the foramen magnum before joining the cranial rootlets. The nerve is easily identified at its origin as a series of rootlets midway between the ventral and dorsal rootlets of the upper cervical cord.\textsuperscript{3,31,36,46}

The dentate ligaments represent lateral extensions of pia mater that form a continuous linear attachment between dorsal and ventral rootlets of the spinal cord and are anchored to the dura by small fibrous triangular processes.\textsuperscript{37} The most rostral of those ligaments lies at the level of the foramen magnum and is a useful indicator of the transition point between the extradural and intradural segments of the VAs. At the level of the most superior dentate ligament, the VA is surrounded by a periosteal sheath that invaginates into the foramen magnum lateral dura and forms a fibrous ring.\textsuperscript{8} The origin of the ipsilateral posterior spinal artery and the distal portion of the first cervical nerve can sometimes be found inside this sheath.\textsuperscript{31,36,37}

The PICA can have an extracranial extradural origin in 5%–20% of the cases.\textsuperscript{3,36}

The third and fourth segments of the VA are important vascular structures to identify when treating foramen magnum lesions. The V\textsubscript{3} segment of the VA (also called the suboccipital segment) extends from the C-2 transverse process to the dura of the foramen magnum. It is divided into 3 portions: vertical (between the transverse process of C-2 and C-1), horizontal (in the groove of the posterior arch of the atlas), and oblique (from this groove up to the dura mater).\textsuperscript{8} Anatomical variants are not infrequent and could be seen, for example, as a V\textsubscript{3} segment terminating in the PICA or occipital artery. A calcified occipitoatlantal membrane can transform the sulcus arteriosus on the posterior arch of C-1 into a tunnel, making the exposure of the horizontal segment technically challenging.\textsuperscript{8} Two important anatomical regions for localization of the V\textsubscript{3} segment are the suboccipital triangles, described by Arnaudovic et al. in their study of the suboccipital cavernous sinus.\textsuperscript{3} The V\textsubscript{3} segment is covered by 3 muscle layers, with a rich venous plexus localized between the intermediate and deep ones. At the occipitoatlantal interspace, 3 muscles from this deep layer form the superior suboccipital triangle (bounded medially by the rectus capitis posterior major muscle, inferiorly by the inferior oblique muscle, and superolaterally by the superior oblique muscle).\textsuperscript{3,31}

The floor of this triangle is formed by the posterior arch of the atlas and the posterior atlantooccipital membrane. The dorsal ramus of the C-1 nerve root and the horizontal segment of V\textsubscript{3} are buried in an abundant areolar tissue, lying deep in this triangle.\textsuperscript{3,31} In the atlantoaxial region, the vertical segment of V\textsubscript{3} and the C-2 nerve are located in the inferior suboccipital triangle, delineated by the obliquis capitis inferior, semispinalis, and splenius cervicis muscles.

The V\textsubscript{3} segment corresponds to the intradural portion of the vessel extending to the verteobasilar confluence. The VA lies posterior and medial to the occipital con-
gins of the tumor and inadequate proximal control of the VAs often make complete resection difficult.\textsuperscript{1,2,8,15,16,37,42} 

Posterior and posterolateral FMMs can be safely resected via a standard midline suboccipital approach. Controversy still exists, however, regarding the optimal management of ventral or ventrolateral lesions. In those cases, surgery could result in undue brainstem retraction, higher rates of subtotal resection (STR), and postoperative morbidity, due to inadequate exposure.\textsuperscript{5,13,18} It has been suggested that patients operated on via conventional suboccipital approaches have worse clinical outcomes than patients operated on via the transcondylar route.\textsuperscript{2,4,42} Those findings were contested by Goel et al., who reported gross-total resection (GTR) of 14 anterior or anterolateral FMMs through a conventional posterior suboccipital approach, similar to the results obtained by other authors.\textsuperscript{5,19,22} 

The endoscopic extended endonasal approach has recently gained attention for treatment of anteriorly located FMMs. Despite their theoretical potential to minimize surgical morbidity, its actual clinical indications remain unclear.\textsuperscript{3,48} The surgical technique described below is the far-lateral approach and its variants for the resection of anterior and anterolateral FMMs.

The Far-Lateral Approach to the Craniocervical Junction

Patient Positioning

Several different patient positions have been successfully applied by different authors, such as modified park bench,\textsuperscript{27,47} true lateral,\textsuperscript{5,21,42} supine with 45° body rotation,\textsuperscript{1,2} prone, and sitting.\textsuperscript{4,3,15} The latter provides a wider angle of view, gravity retraction of posterior fossa structures, and improves venous return, but is associated with a higher risk of air embolism.\textsuperscript{18} In our practice, the true lateral position is most frequently used. The patient is brought to the operating room and, after general endotracheal anesthesia induction, transferred to the operating table and placed in the lateral decubitus position with the lesion side up and the ipsilateral shoulder rotated slightly anterior and inferiorly (Fig. 1A). The head is secured to the operating table using a 3-pin Mayfield skull clamp, and all pressure points are adequately padded. At our institution, we do not routinely use preoperative lumbar drains due to the theoretical risk of brainstem caudal herniation after lumbar drain placement. Neurophysiological monitoring of cranial nerves VII–XI as well as somatosensory evoked potentials and motor evoked potentials are obtained in all cases.

Skin Incision

Various skin incisions have been described.\textsuperscript{18} The most widely accepted incision is an inverted hockey-stick incision. It begins at the level of the mastoid tip and extends superiorly to the superior nuchal line, curving toward the inion and then inferiorly through the midline to the level of the C-2 spinous process.\textsuperscript{4,27} Dissection is carried down to the fascial plane of the superficial muscle layer, and the skin flap is mobilized inferiorly and laterally.

Dissection and Exposure of the Deep Layers

The superficial and intermediate muscular layers are disconnected from their occipital and mastoid insertions and reflected laterally, after careful preservation of a muscular cuff attached to the nuchal line to aid in wound closure (Fig. 1B). The muscles are also detached in the midline from the spinous processes for exposure of the posterior arch of the atlas and the C-2 lamina, if required.

After identification of the spinous process of C-2 and the posterior tubercle of C-1, subperiosteal dissection is carried laterally over the posterior arch of C-1 to identify the sulcus arteriosus and the horizontal segment of the VA. A prominent venous plexus surrounds this segment of the vessel and can be the source of profuse bleeding. Careful dissection over the posterior arch of C-1 is performed in a subperiosteal manner from medial to lateral, inferior to superior, to protect the VA and venous plexus from injury and avoid unnecessary bleeding.\textsuperscript{3,26} Once exposed, the VA is displaced superiorly to review the lateral mass of C-1, the lateral margin of the laminectomy at that level. Skeletonization and transposition of the VA is rarely required and only helpful in rare cases, such as small lesions anterior to the cervicomedullary junction or when proximal control of the VA in its extradural portion is mandatory.\textsuperscript{5,16,26,27} In those cases, the posterior aspect of the transverse foramen is removed and the vessel mobilized caudally and medially. Resection of the ipsilateral posterior arch of C-1 with a contralateral partial hemilaminectomy is then completed using a high-speed drill or rongeurs.

Craniectomy

As described by Heros,\textsuperscript{21} a posterolateral, retrocondylar suboccipital craniectomy is performed (Fig. 1C). This procedure includes the posterolateral rim of the foramen magnum, extends laterally to expose the medial edge of the sigmoid sinus, and is usually completed with the footplate of a high-speed drill. If partial mastoidectomy is necessary, it is imperative to adequately seal the exposed mastoid cells with bone wax to prevent postoperative CSF leak and infection. The lateral rim of the foramen magnum and the condylar fossa are drilled flush under high-power magnification. Invariably, profuse venous bleeding will be encountered at the condylar canal containing the condylar emissary vein. This important landmark is a useful marker for the posterior aspect of the occipital condyle. Bleeding can be controlled with Gelfoam or bone wax.

Transcondylar Extension

Occipital condyle drilling is a controversial technical advantage when performing a far-lateral approach. It theoretically provides a more direct approach to the anterior clivus and anterolateral lesions, increasing the visibility from a standard posterolateral retrocondylar craniectomy by 15.9°.\textsuperscript{31} However, it should be emphasized that those measurements were obtained from cadaveric studies that did not take into consideration the presence of space-occupying lesions, such as FMMs, that naturally enlarge the surgical corridor in vivo.\textsuperscript{5,17,28} 

An important technical concept for the management of FMMs is the definition of surgical corridor. It involves
the space between the lateral margin of the cervicomedullary junction and the medial aspect of the occipital condyle. This corridor can be enlarged naturally by a growing tumor that displaces the brainstem or by bone removal and drilling. Most tumors, once symptomatic, have created a surgical corridor that is wide enough for safe resection without extensive condyle drilling. Although drilling of the occipital condyle permits direct visualization of the ventral aspect of the thecal sac and lower clivus, no studies have demonstrated the superiority of this approach over the lateral suboccipital approach. Nanda et al. affirmed that the resectability of an FMM is influenced by the nature, location, and extension of the tumor and not by the extent of bone removal. They emphasized, however, that occipital condyle drilling is necessary to treat anteriorly located lesions without sufficient lateral extension, as well as large meningiomas associated with bone invasion or VA encasement. Thus, resection of the occipital con-

Fig. 1. Images demonstrating aspects of the far-lateral approach to FMMs. A: Positioning. The patient is placed in the true lateral decubitus position, with the lesion side up and ipsilateral shoulder rotated slightly anteriorly and inferiorly. The marked inverted hockey stick-shaped incision (dashed line) begins at the mastoid tip and curves medially toward the inion, then caudally at the midline down to the midcervical region. The hatched area underlying the skin incision indicates the site where the initial posterolateral craniectomy will occur. B: Exposure. The skin and superficial/intermediate musculature layers are reflected laterally. A small musculoponeurotic cuff is left attached to the nuchal line to aid in wound closure. Note the horizontal segment of V3 exposed deep in the suboccipital triangle. C: Craniectomy. A posterolateral, retrocondylar suboccipital craniectomy is performed with the footplate of a high-speed drill. It includes the rim of the foramen magnum and extends laterally to expose the medial edge of the sigmoid sinus. The lateral rim of the foramen magnum, the condylar fossa, the posteromedial aspect of the occipital condyle, and the posterior arch of C-1 (hatched areas) will complete the bone exposure. Note the V3 segment and its association with the sulcus arteriosus of C-1 as it courses superiorly and medially to penetrate the posterior fossa dura. D: Dural opening. A curvilinear incision is created, extending medially from the transverse-sigmoid junction and then caudally at the midline. The dura is reflected laterally and held in place with nylon sutures. The proximal V3 segment is exposed intradurally. Note the spinal component of the accessory nerve (cranial nerve XI) coursing posteriorly and medially to V4 on its way to the jugular foramen (not shown). CN = cranial nerve; m. = muscle. Copyright Suzanne Truex. Published with permission.
The drilling of the occipital condyle begins with removal of the cortical bone from its posteromedial aspect; soft cancellous bone is found and drilled until a second layer of cortical bone (posterior wall of hypoglossal canal) is encountered, which represents the anterior limit of the condyle drilling. The intracranial opening of the hypoglossal canal is usually located just above the occipital condyle, at the junction of its middle and posterior thirds. It extends anterolaterally with the extracranial foramen located at the junction of the anterior and middle thirds of the condyle. There is general consensus that, in the cases where it is indicated, drilling of the posterior third of the occipital condyle provides access to the majority of anterior or anterolateral FMMs without overt cranio cervical instability.

Dural Opening

A curvilinear incision is fashioned in the dura, extending medially from the transverse-sigmoid junction and then just paramedian to the occipital sinus and caudally at the midline. The amount of cervical dural opening is dictated by the portion of the tumor that extends below the cranio cervical junction. The dura is reflected laterally and held in place by nylon sutures (Fig. 1D). If further lateral mobilization of the dura is necessary for adequate exposure, the dural opening can be modified and centered on the dural ring involving this artery. A large cuff is left surrounding the VA sheath to aid in watertight closure at the end of the resection. The posterior meningeal artery arising from the horizontal suboccipital VA can be coagulated and divided for better exposure. This also represents the first step of the tumor devascularization.

Microdissection

After the dura is opened, lateral FMMs are usually immediately visible and their dural attachment directly accessible. Anterior or anterolateral FMMs, however, may be completely or partially hidden by the neural elements. As described by Bruneau and George, the first step of the intradural stage is to identify important structures and open the surgical corridor. The VA can be easily identified by following the course of the V3 segment where it pierces the dura mater. As previously described, the rostral dentate ligament lies at the level of the foramen magnum and is a consistent indicator of that transitional point. The upper 2 or 3 dentate ligaments may be sectioned to reduce traction on the spinal cord during dissection. The first cervical nerve root may be divided to mobilize the upper cervical cord with negligible clinical consequences. Every effort should be made for early detachment of the tumor from its dural insertion and consequently from its vascular supply; this maneuver makes tumor resection through the small corridor between the cranial nerves and brainstem much easier. From this point on, the microdissection should be guided by the relationship between tumor and the VA (Fig. 2). Foramen magnum meningiomas that arise below the VA push the lower cranial nerves superiority and posteriorly and the resection should begin at the inferior pole of the lesion. After the capsule is opened, internal debulking is carefully achieved with suction technique, CO2 laser, or ultrasonic aspirator, depending on surgeon’s preference and tumor consistency. The predictability of the course of the lower cranial nerves is lost with FMMs that arise above the VA. In those cases, a helpful technique would be to identify their distal segment just proximal to the jugular foramen and dissect them free from the tumor proximally. As noted by Arnautovic et al., an arachnoidal plane frequently exists between the tumor and the lower cranial nerves (IX–XI). Some FMMs will have a more invasive growth pattern and tend to encase the VA and its branches; in those cases, preoperative evaluation of the intracranial course of the VA and the PICA is mandatory. An arachnoidal plane at the tumor-vascular interface can generally be established. In some cases, however, a small tumor cuff will need to be left around the intracranial VA. Once the tumor has been removed, careful inspection of the dural base is completed; it should be scraped free of tumor debris with the use of microdissectors or curettes and thoroughly coagulated. It is not our practice to resect the dural attachment, a technique described by some authors.

Dural Closure

A watertight dural closure, with or without duraplasty, is completed and significantly reduces the incidence of CSF fistulas and the formation of pseudomeningocele. It is frequently reinforced with collagen matrix and fibrin glue. A lumbar drain may be placed postoperatively for CSF diversion on the first few postoperative days to assist with wound healing and reduce the risk of pseudomeningocele. The craniotomy flap is replaced and secured with titanium miniplates. If a craniectomy was performed, cranioplasty

Fig. 2. Intraoperative microscope view of a right-sided ventrolateral FMM. The dura was reflected laterally and held in place by nylon sutures. Note the spinal component of the accessory nerve crossing the posterior aspect of the meningioma. Large ventrolateral lesions tend to displace the neural elements posteromedially; in those cases, the lesion creates an adequate surgical corridor. Tumor resection should begin with internal tumor debulking through a safe entry point identified between the cervical nerve roots or lower cranial nerves. The upper 3 dentate ligaments can be disconnected for mobilization of the neuraxis without countertraction. A clear arachnoidal plane is usually found in the tumor-neural tissue interface and facilitates the microdissection.
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with a multitude of synthetic materials is recommended for better cosmetic results and also to reduce the incidence of postoperative headaches.

Wound Closure

The wound is copiously irrigated with antibiotic-contained saline solution and hemostasis is achieved. The multilayer wound dissected at the beginning of the exposure is then closed using several overlapping layers in a watertight fashion.

Postoperative Care

Airway protection in the postoperative setting is of paramount importance. Not infrequently, the patient is transferred to the intensive care unit intubated and monitored closely for the presence of adequate cough and gag reflexes before extubation. Strict NPO (nothing by mouth) status is maintained until a formal swallow evaluation is completed by a speech therapist; the necessity for a modified barium swallow study or fiberoptic endoscopic evaluation of swallowing is assessed on an individual basis. Cases of suspected true vocal-cord paralysis demand immediate otolaryngological evaluation and fiberoptic endoscopic inspection of vocal cord function to avoid aspiration pneumonia. The early assessment of lower cranial nerve function also guides the treating neurosurgeon on selection of appropriate postoperative actions (total parenteral nutrition or temporary oroantral/nasogastric tube placement, vocal cord injections or medialization, and the need for long-term tracheostomy or gastrostomy tube). Except in the rare cases in which respiratory depression or oropharyngeal/laryngeal musculature paralysis is severe at clinical presentation, preoperative tracheostomy and gastrosyneal/laryngeal musculature paralysis is not routinely placed.

If an intraoperative lumbar drain is placed, it is usually kept in for 3–5 days. Daily CSF studies are costly, labor intensive, and of little clinical or positive predictive values; they are not recommended unless clinical evidence or suspicion of meningitis is raised. The amount of CSF drainage is variable and relies mainly on the indications for CSF diversion (prevention vs treatment of pseudomeningocele, CSF fistula, postoperative infectious meningitis with temporary ICP elevations, and others). The volume and frequency of CSF drainage should also be tailored based on the development of symptoms of intracranial hypotension, such as positional pressure-type headaches, nausea/vomiting, or dysconjugate gaze (usually secondary to stretching of the abducens or trochlear nerves). Cases of painful, enlarging pseudomeningocele or CSF leakage through the surgical incision are successfully treated with temporary CSF diversion in up to 85% of the cases, with few exceptions requiring reexploration of surgical wound for primary repair or—in recurrent cases—ventriculoperitoneal shunt placement.

The average hospital length of stay is 7 days. Uncomplicated cases are usually monitored in the intensive care unit for 1–2 days and are then transferred to the regular neurosurgical ward for the rest of their recovery. Postoperative pain is an important limiting factor and is usually related to posterior cervical musculature dissection; it frequently requires intravenous narcotics and muscle relaxants for adequate control during the initial 72 hours. Physical therapy and occupational therapy evaluations are recommended in all cases and should not be neglected, especially in patients with significant preoperative motor deficits in whom gait, balance, and safety were severely impaired. Arrangements should be made early during the hospital stay for safe and fast progression from the neurosurgical ward to the inpatient rehabilitation unit, when indicated.

Complications

The most frequent surgical complications associated with far-lateral exposure for resection of FMMs are lower cranial nerves deficits, especially cranial nerves IX through XII.2 Talacchi et al., in a recently published series of 64 patients with ventral and ventrolateral FMMs, reported a high incidence of cranial nerve IX–X and XII dysfunctions postoperatively (44% and 33%, respectively).4 At their final outcome assessment, however, 66% of the cranial nerve deficits had improved completely, and all but 2 patients had returned to normal productive life. Samii et al. reported an overall complication rate of 30%, with aspiration pneumonia occurring in 10% of the patients.39 After multiple regression analysis, tumor recurrence, arachnoid scarring, degree of cranial extension, and absence of preoperative cranial nerve dysfunction were all significantly associated with an increased risk of aspiration pneumonia.49 Sekhar et al. showed that tumor size was the most important single variable associated with early postoperative worsening in the surgical management of petroclival meningiomas and FMMs.45 Tumor size and pial invasion were important factors associated with permanent neurological deficits.

Craniovertebral instability is rarely observed but is directly related to the extension of occipital condyle resection. Removal of 50% or more of the condyle has been shown to produce significant hypermobility at the occiptocervical junction, with posterior occipitocervical fusion considered imperative.45 Nonetheless, few authors have reported aggressive drilling of up to the entire occipital condyle without overt postoperative instability.16,40,43

A CSF fistula is one of the most common transient complications, occurring in nearly 16% to 20% of patients.3,33,47 Meticulous dural and wound closure, as well as perioperative use of external lumbar drainage, significantly decreases the incidence of this complication. Air embolism has been reported in patients undergoing the operation in the sitting or semisitting position. George et al. used intraoperative hypervolemia and an antigravity suit (G-suit) as effective measurements to avoid this complication.8,27 Table 1 summarizes some of the temporary and permanent morbidities often noted in the surgical management of FMMs.

Recently reported surgical series have shown a progressive decline in mortality related to the surgical treatment of FMMs. Mortality rates as high as 29% in the early 1980s22 have been replaced by much more favorable outcomes. An overall perioperative mortality rate of 0–3% appears to be a reasonable current estimate.
TABLE 1: Surgical morbidity associated with the far-lateral approach for resection of FMMs

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<td>lower cranial nerve deficits (IX–XII)</td>
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<td>air embolism</td>
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<td>hemiparesis</td>
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<td>postop epidural hematoma</td>
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<td>wound infection</td>
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<td>meningitis</td>
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<td>need for tracheostomy/gastrostomy</td>
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<td>permanent</td>
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Outcome

Excluding cases in which complete cranial nerve palsy was present preoperatively, clinical improvement after resection of an FMM tends to be high. In a meta-analysis of studies of the far-lateral approach that reported individual patient data, Komotar et al. found that 80.6% of patients improved, 6.7% remained stable, and 9% worsened postoperatively.\(^{26}\) Mean preoperative Karnofsky Performance Scale scores improved from 76.4 to 91.2. Frequently, patients with severe quadriparesis at clinical presentation are able to independently perform activities of daily living and regain normal gait and balance during short-term follow-up. Such dramatic improvement has been noted before by several authors.\(^{2,4,6,15,26-44}\)

Surgical series reported over the last 3 decades vary significantly on their degree of FMM tumor resection. In almost 30 studies published up to 2012, only 8 had a 100% complete tumor removal rate.\(^ {26,44}\) The majority of the studies showed a degree of GTR of 70%–96%,\(^ {1,2,4-6,8,15-17,26,31,33,34,39,41,42,44,47}\) Important factors that limit the extent of resection are adequate exposure, tumor recurrence, adherence of lesion to important surrounding structures, VA encasement, and presence of pial invasion with absence of adequate arachnoidal plane. Komotar et al., in a recent literature review that included all studies that reported FMM resection rates (n = 149), concluded that the far-lateral approach and its variations achieved GTR in 93.2%, STR in 5.4%, and partial resection in 1.3% of all cases.\(^ {26}\) The rates were expectedly worse for tumors treated using the extreme lateral approach, with GTR and STR rates of 74.7% and 25.3%, respectively. One explanation for the discrepant results between these 2 different surgical techniques could be the larger tumor size and surgical complexity of the lesions operated on using the latter approach.

Few series have described the histological features of FMMs.\(^ {1,2,4,15}\) Atypical features are rare and observed in less than 6% of the cases. Meningotheliomatous appears to be the most common histological classification (39%),\(^ {2}\) followed distantly by psammomatous, transitional, and fibroblastic subtypes. Bassiouni et al., reporting on their consecutive series of 25 patients with anterior or anterolateral FMMs, found no impact of the histological subtype on extent of tumor resection or clinical outcome.\(^ {4}\)

Available data on recurrence rates are sporadically reported, and their clinical application is limited. Most of the data are derived from single institution case series, sometimes without long-term clinical follow-up. Studies that focused on the far-lateral approach for resection of FMMs have reported no recurrences.\(^ {26}\) Higher recurrence rates were observed in cases in which the extreme lateral approach was used (5.6%); however, even in those series, the rates were drastically lower within GTR FMMs (0%). Similar results were noted at our institution, in which a 0% recurrence rate was noted among patients with 5 years of follow-up or longer, with GTR rates of 82.75%.

In the past decade, the use of SRS for FMMs has evolved, but very few authors have reported their experience. In some of those cases, SRS was not an adjuvant therapy, but was the only treatment modality used. Initial reports in 1999 showed no clinical deterioration and stable tumor size in 4 of 5 elderly patients treated using Gamma Knife radiosurgery.\(^ {30}\) A follow-up study from the same institution published in 2012 showed tumor regression (defined as volume reduction > 25%) in 10 of 21 patients at a median follow-up of 47 months.\(^ {30}\) These investigators concluded that Gamma Knife radiosurgery was a safe strategy for treatment of small, minimally symptomatic primary or residual FMMs. Unfortunately, published data on this topic lack an adequate number of cases and length of follow-up and preclude any meaningful clinical validation. Adjuvant stereotactic radiosurgery should be considered, however, in cases of STR with evidence of growing residual tumor or when reoperation would be associated with prohibitive morbidity rates.

Institutional Experience

Between 2000 and 2011, 30 patients with FMMs were treated at UT Southwestern Medical Center at Dallas. The mean age at the time of surgery was 55.6 years and the majority of patients were female (71.4%). Headaches (42.6%) and hemibody sensory deficits (39.3%) were the most common presenting symptoms, followed by hemiparesis (28.6%), neck pain (21.4%), and gait disturbances (21.4%). The incidence of symptomatic cranial nerve deficits was low (14.3%). The elapsed time between onset of symptoms and initial diagnosis tended to be long (mean 10.3 months). The majority of the FMMs were ventral or ventrolateral to the cervicomedullary junction.

All 30 patients underwent a far-lateral approach for FMMs. The transcondylar extension was used in 89.3% of the cases, with resection of no more than one-third of the ipsilateral occipital condyle. Transposition of the VA was completed in 10 patients; however, 9 of those cases happened early on in our series (before 2005). As our understanding and experience managing FMMs improved, we have abandoned this technical variant. Gross-total resection was achieved in 85.7% of the patients. One pa
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tient underwent adjuvant fractionated stereotactic radiosurgery (CyberKnife) to a small residual tumor adherent to the VA. There were no recurrences, and none of the 4 patients with STR have demonstrated tumor growth on serial imaging follow-up. Histologically, 90% of the FMMs were WHO Grade I, with meningothelial being the most common subtype. Atypical (n = 2) and chordoid (n = 1) meningiomas completed the case series. No WHO Grade III lesions were identified.

At the time of last clinical follow-up evaluation, 1 patient had persistent low postoperative Karnofsky Performance Scale scores and was dependent for activities of daily living (a 54-year-old man with severe spastic quadripareisis at presentation who underwent GTR of a large ventrolateral FMM). His postoperative course was complicated by lower cranial nerve deficits, aspiration pneumonia, and sepsis. He required long-term tracheostomy and gastrostomy tube placement. In 22 patients, the preoperative and postoperative symptoms improved completely within the initial 8 postoperative weeks. No patients experienced deterioration of neurological function postoperatively. Cerebrospinal fluid leakage occurred in 3 patients and resolved with temporary lumbar CSF drainage. Including the above-mentioned case, tracheostomy and gastrostomy tube placement was necessary in 2 (6.6%) and 3 patients (10%), respectively. There were no postoperative deaths at last follow-up.

Conclusions
Foramen magnum meningiomas are relatively rare, but one of the most challenging lesions treated by the skull base neurosurgeon. The far-lateral approach is a versatile technique that provides excellent exposure to lesions located at the lower clivus, brainstem, cervicomedullary junction, and upper cervical cord. Advancement in microsurgical techniques and application of modern skull base surgery principles have positively influenced the outcome while providing acceptable and exceptionally low rates of morbidity and mortality.

Acknowledgment
We would like to thank Suzanne “Jorlam” Truex, medical illustrator, for her invaluable assistance in the creation of this manuscript, transforming a difficult topic into a colorful piece of art.

Disclosure
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Flores, Boudreaux, Mickey, Barnett. Acquisition of data: Flores. Analysis and interpretation of data: Flores, Klinger. Drafting the article: Flores, Boudreaux, Klinger, Barnett. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Flores. Administrative/technical/material support: Flores, Mickey, Barnett. Study supervision: Flores, Barnett.

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