

George I. Jallo  
Ann Biser-Rohrbaugh  
Diana Freed

## Brainstem gliomas

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G. I. Jallo (✉) · A. Biser-Rohrbaugh ·  
D. Freed  
Division of Pediatric Neurosurgery,  
Johns Hopkins Hospital,  
600 North Wolfe Street, Harvey 811,  
Baltimore, MA 21287, USA  
e-mail: gjallo1@jhmi.edu  
Tel.: +1-410-9557851  
Fax: +1-410-9557862

**Abstract** *Introduction:* Brainstem gliomas have historically been one of the most difficult pediatric cancers to treat. Tumors arising in the brainstem were once uniformly discounted as surgically unresectable lesions. Early neurosurgeons thought this location to be inoperable and fraught with disaster. The advent of computed tomography (CT), magnetic resonance imaging (MRI), and sophisticated neurophysiological monitoring techniques have significantly advanced the surgical treatment of these precarious lesions. *Review:* Brainstem gliomas are now recognized as a heterogenous group of tumors. They have been broadly classified into

several categories depending upon the classification scheme. All these classification systems provide a framework to predict growth patterns, surgical resectability, and overall prognosis of these tumors. These systems allow the surgeon to obtain a better understanding of the distinction between low-grade tumors and diffuse inoperable tumor types. The authors review the current literature and management of brainstem tumors.

**Keywords** Brainstem glioma · Cervicomedullary · Midbrain tumors · Pontine glioma · Surgery

### Introduction

The brainstem, or mesencephalon, is defined as the midbrain, pons, and medulla. Gliomas within the brainstem constitute 10–20% of all pediatric CNS tumors. In the United States, there are approximately 150–300 annual cases [8, 63]. Brainstem gliomas can occur at any age, although they generally present in childhood, with the mean age of diagnosis of 7–9 years [15, 46]. There is no gender predilection.

In the era before modern imaging, all brainstem gliomas were regarded as a single pathological entity, and the prognosis was considered uniformly poor. In 1969, Matson summarized that “regardless of specific histology, brainstem gliomas must be classified as malignant tumors since their location in itself renders them inoperable” [50]. Pool was one of the first neurosurgeons to advocate surgery for certain brainstem tumors. He operated upon several children and reported a survival of 10–25 years

(reported in [36]). In the early 1980s, several neurosurgeons began reporting favorable surgical outcomes for certain types of brainstem gliomas [10, 28, 30, 38, 62]. Classification systems were then introduced, which attempted to identify those tumors that benefited from surgery. These morphological systems evolved further with the advent of magnetic resonance imaging, thus helping to predict tumor behavior and determine the best management algorithm for these tumors.

This article reviews the current literature and provides treatment options for brainstem gliomas.

### Imaging and classification

Magnetic resonance imaging (MRI) has emerged as the primary diagnostic modality for brainstem gliomas. MRI multiplanar images assist in the establishment of the tumor diagnosis, identification of tumor epicenter, and

**Table 1** Classification systems for brainstem tumors

Author	Classification system	System based on
[27]	Intrinsic Diffuse Focal Cervicomedullary Exophytic Anterolateral into cerebellopontine angle Posterolateral into brachium pontis Posterior into fourth ventricle Disseminated Positive cytology Positive myelography	Computed tomography
[28]	Diffuse Focal Circumscribed mass less than 2 cm, no edema Cervicomedullary	Computed tomography, magnetic resonance imaging and surgical observation
[62]	Group I—dorsal exophytic glioma Group IIa—intrinsic brainstem tumors Hypodense, no enhancement Group IIb—intrinsic brainstem tumors Hyperdense, contrast enhancing, exophytic Group III—focal cystic tumor with contrast enhancement Group IV—focal intrinsic isodense, contrast enhancing	Computed tomography
[12]	Location Midbrain, pons, medulla Focality Diffuse or focal Direction and extent of tumor growth Degree of brainstem enlargement Exophytic growth Hemorrhage or necrosis Evidence of hydrocephalus	Magnetic resonance imaging
[5]	Focal Midbrain, pons (dorsal exophytic pontine glioma), medulla Diffuse	Magnetic resonance imaging
[33]	Midbrain Diffuse, focal, tectal Pons Diffuse, focal Medulla Diffuse, focal, dorsal exophytic	Magnetic resonance imaging
[23]	Type I—intrinsic tumor, diffuse, hypodense on CT, low intensity in T1-weighted images, with no significant enhancement Type II—intrinsic and focal tumor, which may be solid or cystic Type III—exophytic tumor, either dorsally or laterally Type IV—cervicomedullary tumor	Computed tomography and magnetic resonance imaging

prediction of its biological behavior. Astrocytomas are the most common intrinsic tumor of the brainstem. Histologically, these tumors are fibrillary, in contrast to cerebellar astrocytomas, which are predominantly pilocytic. Other tumors that may arise in the brainstem include PNET (primitive neuroectodermal tumors), lymphomas, gangliogliomas, and oligodendrogliomas [23]. Lymphomas are distinguished by their uniform enhancement after gadolinium administration. Although ependymomas are extra-axial, they can resemble an intrinsic tumor of the brainstem since they may cause brainstem compression

or appear to insinuate into the brainstem by their lateral extension out the foramen of Luschka. Ependymomas can also originate as cervicomedullary lesions. Non-neoplastic lesions such as hemangioblastomas, cavernous malformations, tuberculomas, and epidermoids have also been reported to arise within the brainstem. Additional imaging studies such as angiography, MRI spectroscopy or diffusion-weighted MRI sequences may be required if the diagnosis is uncertain [25, 51]. These imaging sequences have supplanted the need for stereotactic biopsy for certain brainstem gliomas [7].

Many classification schemes have been devised for brainstem tumors (Table 1). The earliest categorizations relied on computed tomography (CT) and surgical observations; however, the more recent schemes include MRI sequences. All these systems categorize the tumor by epicenter (diffuse or focal) or imaging characteristics. The simplest classification divides these tumors into two groups, either focal or diffuse regardless of tumor epicenter. The more complex schemes subdivide these tumors by location, focality, presence of hydrocephalus or hemorrhage, and growth pattern.

### Diffuse brainstem gliomas

Diffuse gliomas are the most commonly encountered tumor of the brainstem accounting for 58–75% of all tumors [5, 30]. On T1-weighted MRI scans, they appear hypointense with indistinct margins, reflecting the infiltrative nature of these high-grade lesions (Fig. 1). Diffuse gliomas of the brainstem are generally greater than 2 cm in size at time of presentation. They are characterized by diffuse infiltration and swelling (or hypertrophy) of the brainstem. The epicenter of the lesion is usually the pons; however, rostral or caudal tumor extension is not unusual. These diffuse gliomas are distinguished from focal tumors by their indiscrete hyperintensity on T2-weighted imaging. Gadolinium enhancement can be variable and has no prognostic implication [33]. These diffuse gliomas are typically malignant fibrillary astrocytomas (Grade III or IV).

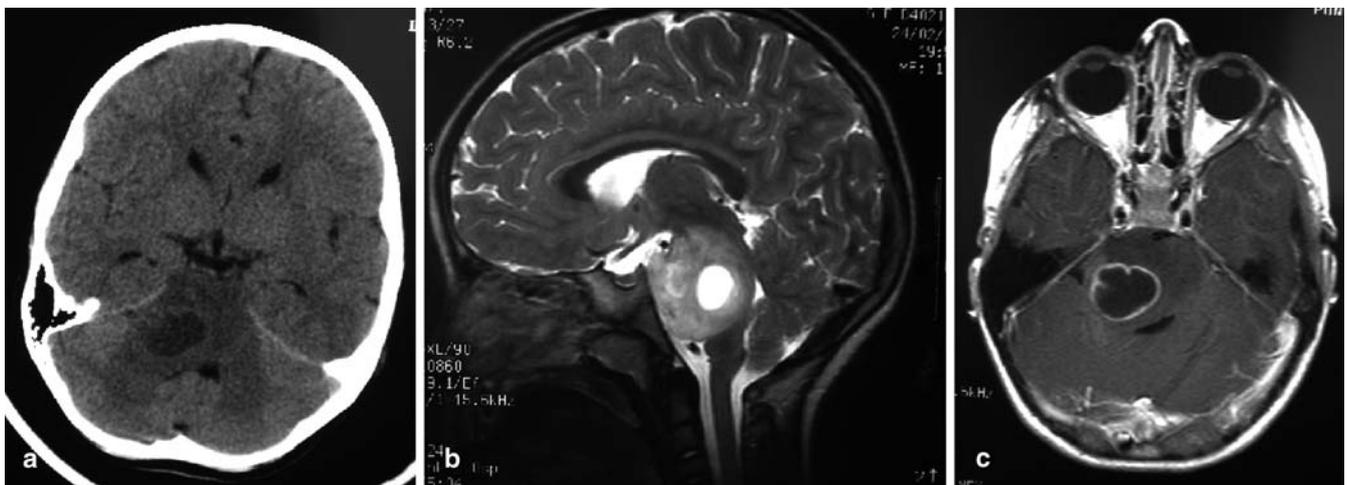
### Focal tumors

Focal tumors are defined as demarcated lesions of the brainstem found in the midbrain, pons or medulla. These focal tumors may be solid or cystic and they always have clear, distinct borders on MRI (Fig. 2). The tumor size and characteristics are similar on both T1 and T2 sequences because of the relative lack of infiltration and edema. Tumor enhancement following gadolinium administration may be variable, but uniform enhancement is suggestive of a juvenile pilocytic astrocytoma. These focal tumors are mostly histologically benign (Grade I or II) lesions; however, anaplastic gangliogliomas and PNETs have been reported [1].

### Exophytic tumors

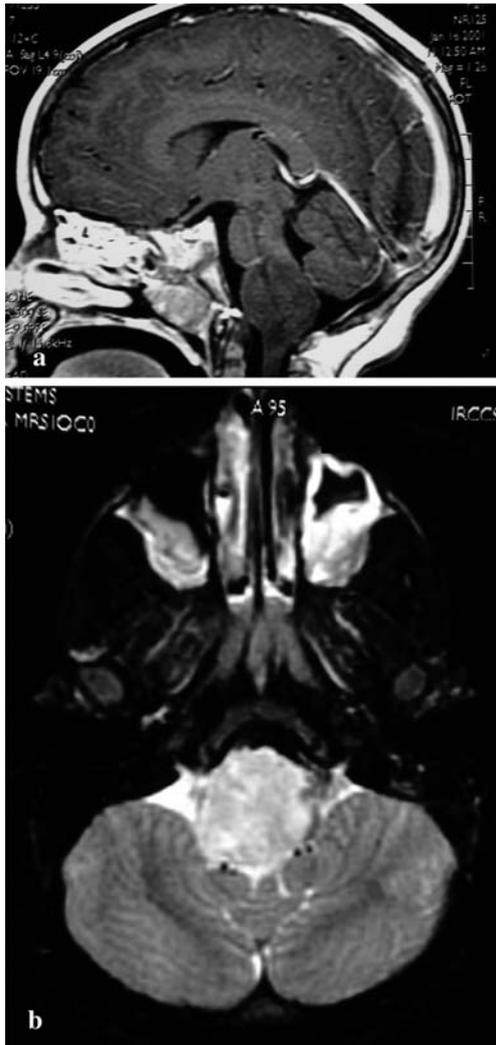
Dorsally exophytic brainstem gliomas are a group of tumors that arise from the subependymal glial tissue (Fig. 3). The bulk of the tumor resides within the fourth ventricle, which accounts for the relatively late onset of symptoms. MRI reveals a well-demarcated lesion with similar T1-hypointensity and T2-hyperintensity signal characteristics.

Histologically, these tumors are almost always low-grade gliomas. They tend to grow along paths of least resistance (into the fourth ventricle and into cisterns) rather than infiltrate the brainstem [39]. Most of these exophytic tumors will enhance with gadolinium, and can be difficult to distinguish from ependymomas or choroid plexus papillomas [14]. In our experience, exophytic tumors that grow laterally and ventrally into the brainstem are higher-grade tumors than those exophytic tumors that project dorsally into the fourth ventricle.



**Fig. 1a–c** Diffuse pontine glioma. **a** CT scan demonstrates the signal change within the pons associated with a necrotic center. **b** Sagittal T2-weighted MRI scan demonstrates an enlarged pons with

a necrotic area. **c** Axial T1-weighted image with gadolinium demonstrates the enhancing tumor with surrounding hypointense signal within the pons

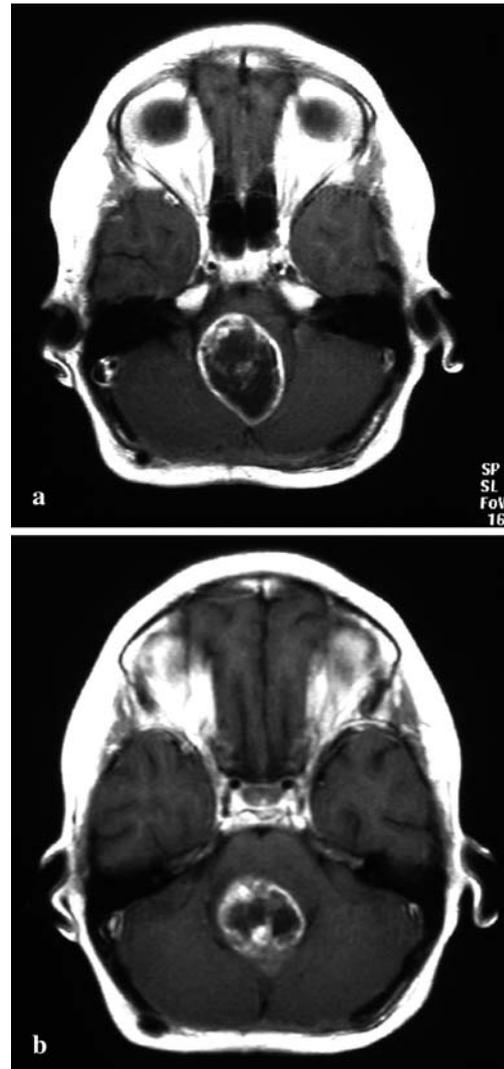


**Fig. 2a, b** Focal tumor. **a** Sagittal T1-weighted MRI with gadolinium demonstrates a minimally enhancing tumor within the medulla. **b** Axial T2-weighted image demonstrates the location within the medulla. Histology confirmed a ganglioglioma

### Cervicomedullary tumors

Cervicomedullary brainstem gliomas are similar to intramedullary spinal cord gliomas. The epicenter of these tumors may be either in the medulla or cervical spinal cord. On MRI, these tumors show mixed low and intermediate signal intensity within the solid part of the tumor. MRI assists in delineating the rostral and caudal pole of these tumors, as well as identifying any associated syrinx or cysts.

The majority of these tumors are benign low-grade astrocytomas, and they demonstrate distinct growth patterns [31, 39]. These tumors have almost no infiltrative capacity and as a consequence their growth is limited rostrally by the decussating white matter tracts of the



**Fig. 3a, b** Dorsal exophytic glioma. **a, b** T1-weighted axial MRI with gadolinium of an exophytic tumor within the fourth ventricle. Histology confirmed a juvenile pilocytic astrocytoma

corticospinal tract and medial lemniscus, which act as a barrier for further rostral growth. Tumors that arise within the medulla are confined by the decussating fibers and expand within the medulla, pushing the motor tracts and nuclei to the periphery. Thus, these low-grade tumors may appear exophytic and displace the medulla rostrally, while the upper cervical cord appears expanded. Only high-grade tumors with an infiltrative capacity grow rostrally into the brainstem.

### Management

The clinical history and presentation are important in the establishment of the tumor histology and overall prognosis.

**Table 2** Summary of surgically-treated dorsal exophytic brainstem tumors. *LGA* low grade astrocytoma, *JPA* juvenile pilocytic astrocytoma

Author	Patients	Histology	Surgery	Adjuvant Therapy	Outcome	Progression
[52]	18	16 LGA grade I or II 1 astrocytoma grade III 1 ganglioglioma	Near total	2 patients	17 alive (median, 113 months)	4 patients
[44]	12	11 JPA 1 LGA	6 near total 6 subtotal	2	11 alive (median, 26 months)	3
[33]	10	N/A	N/A	N/A	7 alive (mean, 35 months)	N/A

Near total >90% resection, subtotal >50% but <90%

sis. A careful history is obtained from both the child and a parent. This is important since, often, subtle changes may be unreported if both individuals are not interviewed. For example, old pictures may be necessary to date the onset of cranial neuropathies. Declining school performance, especially related to visual disturbances or symptoms of hydrocephalus, may be the only presenting signs. A detailed history should include previous upper respiratory tract infections, pneumonias, or changes in voice [4]. The length of the prodrome or symptoms is an indication of the tumor histology.

Malignant lesions invariably have a rapidly progressive course. Children with diffuse brainstem gliomas will often present acutely with multiple cranial nerve signs, ataxia, long tract signs, and cerebellar signs. Diffuse gliomas are unfortunately the most common brainstem lesion, and regrettably, this tumor portends the worst prognosis among the brainstem gliomas. Most children die within 18 months of diagnosis, which is similar to the clinical course for glioblastoma multiforme [6, 46]. There is no role for radical surgery or biopsy since stereotactic biopsy does not change the management strategy [7]. A biopsy should be reserved for indeterminate lesions on MRI accompanied by an unusual presentation or when mandated by a study protocol. Diffuse brainstem tumors, which are associated with neurofibromatosis need further investigation, because they tend to have a more favorable prognosis. These NF-1 brainstem tumors typically have an indolent course, reminiscent of their astrocytic counterparts in the hypothalamic/optic chiasm region [49, 54]. Careful clinical examination for the stigmata of neurofibromatosis and family history should help in the identification of these lesions. Magnetic resonance spectroscopy has also been shown to be useful in distinguishing diffuse lesions in NF-1 patients [20]. Radiation and/or chemotherapy are the current mainstays of treatment for diffuse brainstem gliomas [9].

In contrast, focal tumors are generally low-grade gliomas, and have a longer prodrome (months to years) before diagnosis when compared with the shorter period (weeks to months) for diffuse gliomas. The location of the focal tumor along the brainstem axis influences the clinical presentation. In general, upper brainstem tumors

tend to present with hydrocephalus, oculomotor dysfunction and/or cerebellar findings, whereas lower brainstem tumors present with lower cranial nerve deficits and long tract findings.

Midbrain gliomas of the tectum behave as very low-grade lesions [17]. Focal tumors of the tectum (tectal gliomas) begin to cause significant neurological symptoms when they enlarge and compress the aqueduct of Sylvius thereby producing obstructive hydrocephalus. Tegmental tumors can present with hydrocephalus and oculomotor paresis with or without associated long tract findings. Focal pontine gliomas generally have a poorer prognosis while focal tumors of the medulla are intermediate. Pontine lesions cause facial paresis, hearing loss or long tract findings. Concern should be raised when a child presents with a localized focal non-enhancing tumor with rapid progression of symptoms. Atypical tumors that present at a very young age and with leptomeningeal dissemination may be primitive neuroectodermal tumors (PNET) [68]. An excisional biopsy should be considered in this situation since treatment protocols for PNETs differ from those for brainstem gliomas.

Tumors of the medulla present with lower cranial nerve deficits, which manifest as changes in voice, swallowing difficulty or pneumonias due to microaspirations. Although these focal lesions are not infiltrative, they can carry a high surgical morbidity [2]. Preoperative medullary dysfunction warns of postoperative complications specifically in patients demonstrating frequent preoperative upper respiratory tract infections, preoperative pneumonia or alteration in voice [4].

Dorsally exophytic tumors may be regarded as a type of focal tumor (Table 2). There is usually a protracted yet progressive clinical course with symptoms due to either direct compression of the underlying brainstem or to elevated intracranial pressure from obstruction of CSF pathways. Young children may present with failure to thrive due to intractable vomiting. Older children may exhibit headache and ataxia. Papilledema and torticollis are common presenting signs, resulting from increased intracranial pressure and chronic tonsillar herniation. The majority of dorsally exophytic tumors can be managed

**Table 3** Summary of surgically-treated cervicomedullary tumors. *LGA* low grade astrocytoma, *JPA* juvenile pilocytic astrocytoma. Near total >90% resection, subtotal >50% but <90%, partial <50%

Author	Patients	Histology	Surgery	Adjuvant therapy	Outcome	Progression
[29]	20	11 LGA grade I or II 4 astrocytoma grade III 3 ganglioglioma 2 ependymoma	N/A	4 patients	16 alive (median, 24 months)	4/4 of high grade tumors 1/16 of low grade tumors
[56]	17	10 LGA 6 ganglioglioma 1 mixed astrocytoma	2 gross total 15 subtotal	2	15 alive (median, 48 months)	6 patients
[13]	4	3 JPA 1 ependymoma	N/A	N/A	N/A	N/A
[66]	39	15 LGA 9 ependymoma 7 ganglioglioma 3 JPA 3 anaplastic astrocytoma 2 mixed gliomas	12 gross total 7 near total 15 subtotal 5 partial	None	39 alive (mean, 48 months)	3/4 of high grade tumors 12/35 of low grade tumors

successfully with subtotal resection, and if necessary, CSF diversion [52].

Cervicomedullary brainstem gliomas are also associated with an indolent course. The presentation of these tumors is dependent on the epicenter of the lesion. Two presenting syndromes, a medullary and a cervical cord syndrome, have been described. Medullary dysfunction may manifest as failure to thrive due to nausea, vomiting, or dysphagia, upper respiratory tract infection, dysarthria, and sleep apnea. The cervical cord dysfunction will manifest as chronic neck pain and progressive cervical myelopathy with weakness and spasticity. Good long-term outcomes have been achieved with radical resection (Table 3) [13, 29, 56, 66].

### Surgical treatment

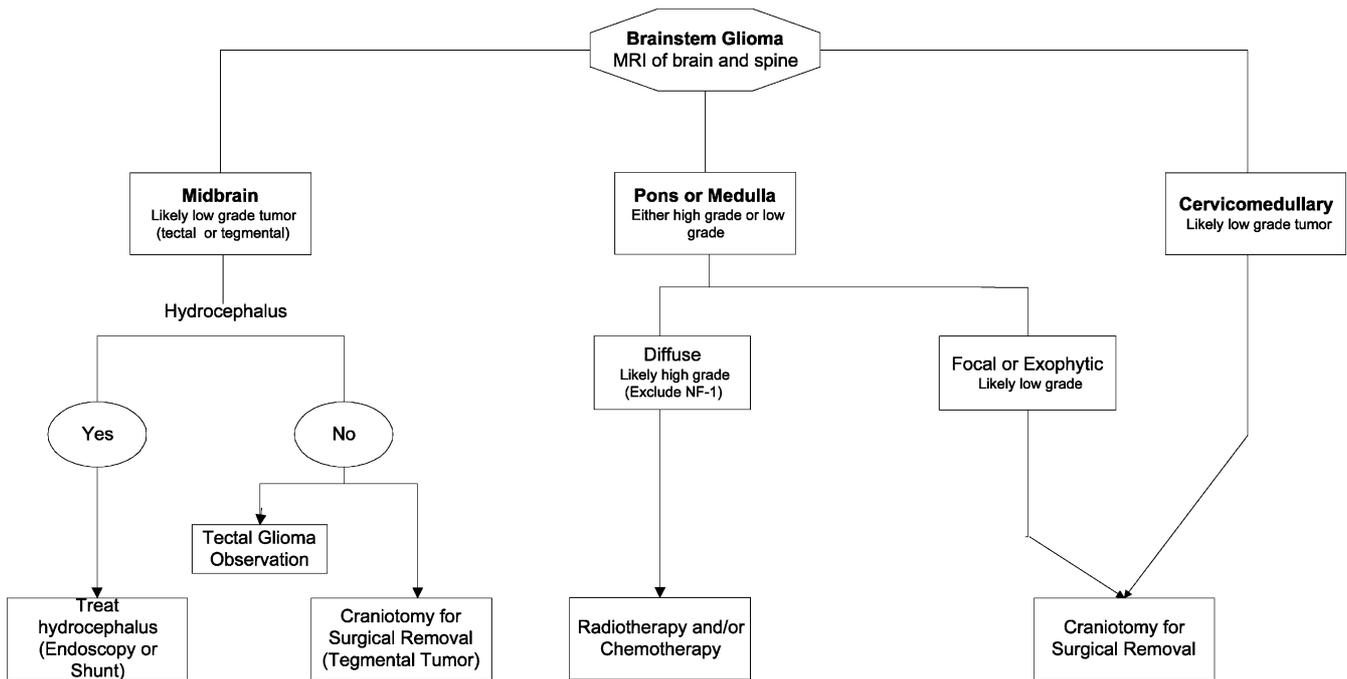
Careful patient selection is one of the underlying principles behind successful brainstem tumor surgery. The categorization of brainstem tumors has helped to predict growth patterns and identify surgically treatable lesions. Surgery for diffuse brainstem gliomas is generally not indicated. This section will address open surgical treatment of focal, dorsally exophytic, and cervicomedullary tumors. Certain focal lesions, particularly tectal gliomas, have an indolent natural history and do not generally require open surgical management. Tectal gliomas are managed by treatment of symptomatic obstructive hydrocephalus using endoscopic third ventriculostomy or shunting. The advantages of endoscopic third ventriculostomy include avoidance of an implant device and potential for a minimally invasive biopsy of the tumor mass. Our algorithm is depicted in Fig. 4.

We have favored early surgery as a first line intervention, particularly before significant progression

of symptoms and before other treatments such as radiotherapy or chemotherapy are administered. The goal of surgery is to decrease the tumor burden without incurring significant neurological complications. This goal can often be accomplished without gross total resection; however, there are significant potential morbidities, including tracheostomy and feeding gastrostomy.

Intraoperative neurophysiological mapping and monitoring is recommended for all brainstem cases [26, 50]. While MRI may provide accurate localization of the tumor, it does not provide information regarding the function of surrounding normal tissues. Although safe entry zones (suprafacial/intrafacial triangles, intercollicular midline incision) have been described, intrinsic tumors of the brainstem often distort the normal anatomy, thus obscuring normal landmarks [50]. Neurophysiological mapping overcomes this limitation by identifying displaced structures, and thus avoiding brainstem injury. In addition, continuous monitoring of standard evoked potentials (motor and sensory), and cranial nerve reflex circuits can be used to give real time feedback as to the integrity of the brainstem during tumor resection [26].

Special microsurgical equipment, which have greatly enhanced the operative technique, include the operating microscope, plated bayonets forceps [32], Nd:YAG contact laser [41], and the cavitron ultrasonic aspirator (CUSA) [24, 40]. The current CUSA models are equipped with smaller handsets that allow them to be safely used within the confined limits of the brainstem. The contact Nd:YAG laser provides precision cutting coupled with coagulation of adjacent tissues. It can be used for tumor resection with minimal injury to the surrounding brainstem cranial nerve nuclei. The laser does not interfere with the intraoperative neurophysiological monitoring, which is critical for surgery.



NF-1: Neurofibromatosis Type 1

Fig. 4 Management strategy for brainstem tumors

Surgical approaches to the brainstem are predominantly through the posterior fossa. The prone position provides excellent exposure of the entire brainstem except for upper midbrain tumors. Some surgeons prefer the sitting position [19]; however, the prone position reduces the risk of venous air embolism and pneumocephalus. In addition, the prone position provides a surgical field that is readily accessible to both the surgeon and assistant. The surgeon's arms are not elevated throughout the case and there is less general fatigue. Proper positioning, especially with regard to neck flexion and shoulder placement is important for adequate visualization of the anticipated lesion. There are many different skull base approaches available depending on the location of the tumor.

#### Midbrain

Although most tumors of the upper midbrain are managed conservatively with CSF diversion, some tumors in this area progress and require open surgery. The dorsal midbrain can be exposed by the infratentorial–supracerebellar approach first described by Kraus and then popularized by Stein [59]. A craniotomy is fashioned to incorporate the transverse sinus. The cerebellum and vermis may then be retracted caudally to expose the dorsal aspect of the mesencephalon. This approach allows

direct access to the midbrain without intervening brain tissue [11]. The deep venous drainage system, including the vein of Galen and internal cerebral veins, is generally above the surgical field and thus easily avoided. Lesions on the ventral medial aspect of the midbrain near the interpeduncular cistern are reached by a standard pterional approach. Ventral lateral masses of the midbrain may be reached by a subtemporal approach and usually involve splitting the tentorial incisura. It should be kept in mind, however, that the subtemporal approach has the disadvantage of potentially requiring prolonged retraction of the temporal lobe.

#### Pons

For dorsally situated tumors of the pons or medulla, a midline suboccipital craniotomy is the most common approach. A craniotomy is generally preferred over a craniectomy especially in children [37]. Replacement of the bone flap provides additional protection, and allows better restoration of anatomical tissue planes, which becomes important in the unfortunate patient who may require multiple resections [45]. The telovelar approach provides adequate exposure to all dorsally exophytic tumors [55]. Excessive traction on the cerebellar hemispheres and dissection on the vermis should be avoided because of the risk of cerebellar mutism and pseudobulbar

symptoms [53, 60, 67]. For focal intrinsic tumors, the resection begins after the floor of the fourth ventricle has been identified and mapped for safe points of entry. If distortion and discoloration of the floor are insufficient to localize the tumor, ultrasound can be used to determine where the tumor is closest to the floor.

Tumors of the ventral lateral aspect of the pons extending into the cerebellopontine angle may be reached with the lateral retrosigmoid approach. The asterion, which is formed by the lambdoid and temporal squamous sutures, is a useful landmark for planning the bony removal. The junction of the transverse and sigmoid sinuses is identified and used as a guide for dural opening. The tumor may be debulked with special attention to the location of the tracts of cranial nerves 5, 7, and 8, and, if involving the medulla, 9 and 10.

### Medulla and upper cervical spine

For intrinsic tumors of the medulla, a suboccipital craniotomy with removal of the dorsal lateral rim of the foramen magnum enhances the exposure of the bulging medulla. A cervical laminotomy or laminectomy is performed for tumors that extend caudally into the cervical region. This should encompass the most caudal aspects of the tumor. The medulla is typically displaced superiorly as the tumor grows posterior to the obex. The tumor is quite superficial here; almost invariably subpial in location. The posterior inferior cerebellar arteries, which may be displaced, must be preserved to avoid cerebellar or brainstem infarcts. However, superficial pial vessels may be taken if obstructing the intramedullary component of the tumor.

### Surgical considerations

One of the early considerations for a brainstem focal tumor is to determine a safe entry point. Cystic focal tumors are generally easier to treat than solid lesions because they can be more easily entered and their walls inspected for tumor nodules without having to manipulate the surrounding tissue. Discoloration and loss of surface markings may be used as rough guides in mapping the floor of the fourth ventricle when searching for safe entry zones. The contact laser is used to perform the initial incision or myelotomy into the brainstem. This process eliminates the superficial feeding blood vessels and initiates tumor retraction. The lack of tumor demarcation from the surrounding brain often hinders complete resection. The neurosurgeon must remember that complete resection is prohibitive in this situation due to the high probability of postoperative morbidity. It should also be kept in mind that a radical or gross total resection can be equally successful. It is important to minimize

retraction of surrounding neural tissue during the resection. The tumor is removed in a piecemeal fashion using a combination of suction-aspiration and the CUSA. Tumor debulking and dissection is achieved by working from the inside-out direction. The Nd:YAG laser is sometimes helpful in removing small amounts of tumor at the margins or in tight confines. Cautery is to be avoided at the margins of the tumor as this will frequently result in injury to the surrounding functional tissue. Mapping of the walls of the resection cavity can be performed in an attempt to define tumor margins. Tissue specimens are always sent early for frozen section analysis. If the histology is identified as a high-grade tumor the operation is stopped because there has been no proven long-term benefit to surgical debulking of these aggressive lesions.

Dorsally exophytic tumors were the first type of brainstem gliomas to be routinely treated with radical surgery [33, 44, 52]. Most of the dissection and removal is accomplished outside of the brainstem since these tumors are predominantly situated in the fourth ventricle. These tumors are approached via a standard midline suboccipital approach. One of the most important aspects of the case is to progressively debulk the tumor while keeping the floor of the fourth ventricle in view as it is important not to enter the brainstem parenchyma. Cranial nerves 6 and 7 are especially susceptible to injury because their nuclei and/or tracts are close to the dorsal surface of the stem and the floor of the fourth ventricle. The area immediately around the obex and calamus scriptorius should be avoided because of possible injury to cranial nuclei for 10 and 12. When these structures are injured, patients develop impaired swallowing, loss of coughing reflex, and dysphonia. A subtotal resection with preservation of neurological function is the goal of the surgery.

Patients with cervicomedullary tumors also benefit from radical surgical treatment [13, 29, 56, 66]. A midline suboccipital craniotomy and cervical laminectomies provide the necessary exposures. Excessive removal of cervical lamina is avoided to prevent the development of spinal deformity. Osteoplastic laminectomy is considered if a multilevel cervical laminectomy is required [3]. Although this technique may not always prevent deformity, there is reossification of the bone segments, which can avoid the cosmetic deformity frequently seen with multilevel laminectomies. The location of the tumor and any associated cysts is confirmed by ultrasound. A midline myelotomy is performed with the Nd:YAG laser in order to avoid injury to the posterior columns. The myelotomy is first directed over any associated rostral or caudal cyst and then extended over the solid part of the tumor. Identification of the dorsal root entry zones bilaterally is necessary to properly find the midline. The tumor's dorsal surface is exposed and the tumor entered, with a piecemeal removal performed from the center outwards. This is done with the CUSA and/or contact laser using the same techniques described earlier for

**Table 4** Summary of several chemotherapy and radiotherapy protocols for diffuse pontine gliomas. *MST* mean survival time, *PFS* progression-free survival

Chemotherapy	Radiotherapy (Gy)	Patients	Outcome
5-FU, CCNU, HDU, misonidazole	55	28	MST 44 weeks
COPP	56	7	Progression at 4 months
VCR, CCNU, prednisone	50–60	35 RT 39 RT + chemo	MST 9 months both arms
VP-16, trofosfamide	54	18	PFS 179 days
Carboplatin, VP-16	70.2	9	8/9 died at 44 weeks

intrinsic focal brainstem tumors. Meticulous care in the closure is important for the avoidance of a CSF leak—a complication not uncommon when operating on these tumors.

### Complications

Neurologically, the patient's preoperative symptoms may be transiently or permanently worsened after surgery. For this reason special care needs to be taken during the postoperative period [65].

If a significant amount of the medulla is involved with the tumor, the patient is left intubated for at least 48–72 h after surgery. This is critically important for any patient with evidence of dysfunction in the medulla's cranial nerves. Impaired central respiratory function may result in carbon dioxide retention and progressive hypoxia leading to respiratory arrest and further neurological injury, which is usually permanent [2]. The patient is weaned from the ventilator after 24 consecutive hours of stable respiratory drive.

Cranial nerve deficits are variable and dependent on the surgical approach. Surgery within the pons can result in transient diplopia due to internuclear ophthalmoplegia. This complication is often transient and improves. For persistent diplopia, ophthalmologic treatment with special eyeglass prisms may be necessary. Facial palsy can be devastating not only cosmetically but also functionally with regard to corneal injury. Several plastic surgical procedures have been developed to restore facial tone and protect the eye from corneal abrasions and keratitis [57]. Damage to the lower cranial nerves (9–12) can result in severe dysphagia, vocal cord paralysis, and loss of gag and cough reflexes. As a result, these patients are at risk of subclinical microaspirations, which may lead to recurrent and debilitating pneumonias. Formal swallowing evaluations are performed for all patients with questionable function before advancement of diet. Because of these latter risks we have learned to be aggressive in employing tracheostomy and feeding gastrostomy in the first several months after surgery when there is swallowing dysfunction.

### Oncologic outcome

The neurosurgeon should be aware of all the available protocols for brainstem gliomas. Radiation therapy has provided only marginal gains in the overall prognosis for diffuse high-grade tumors. Standard irradiation treatment combined with new chemotherapy protocols has had some mixed results (Table 4) [16, 21, 34, 35, 42, 43, 64]. These issues are reviewed elsewhere [9]. There are new therapeutic options under current investigation including convection-enhanced delivery [47, 58], slow-flow delivery [22, 61], radio-sensitizing agents, and hyperbaric and interstitial radiotherapy.

There have been minimal improvements in the long-term survival of patients with low-grade brainstem gliomas directly attributed to adjuvant therapy. Given the significant advances in surgical management of brainstem lesions and the decrease in surgical morbidity, second surgery has become a viable option [18]. Indications for second surgery have included:

1. Delayed, recurrent growth in either the solid or cystic component of the tumor resulting in new symptoms
2. Re-exploration after the initial resection was halted prematurely due to transient intraoperative injury confirmed by monitoring

The goal of the reoperation is identical to that of the first operation, i.e., sufficient debulking of the tumor so as to lessen symptoms without causing progression in neurologic deficits.

### Conclusion

Brainstem gliomas are a heterogenous group of tumors that may be diffuse, focal, dorsally exophytic, or cervicomedullary. These classification schemes help in predicting growth patterns and identifying surgically treatable lesions. Almost all diffuse tumors are malignant and nonresectable. The majority of other tumors are focal low-grade neoplasms that are amenable to surgery and long-term survival.

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