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Anatomical Limitation of Posterior Spinal Myelotomy for Intramedullary Hemorrhage Associated with Ependymoma or Cavernous Malformation of the High Cervical Spine

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Abstract

Spinal intramedullary tumors such as ependymoma or vascular lesions such as cavernous malformation are often at risk of intramedullary hemorrhage. Surgical procedures involving the high cervical spinal cord are often challenging. This technical note included four patients who presented with acute, subacute, or gradual onset of spinal cord dysfunction associated with intramedullary hemorrhage at the C1 or C1/2 level of the high cervical spine. The mean age was 46.3 years (16-74 years). All patients underwent posterior spinal cord myelotomy of the posterior median sulcus or posterolateral sulcus. It was not to exceed the caudal opening of the fourth ventricle (foramen of Magendie) and was assumed to be as high as the caudal medulla oblongata. Total removal of the intramedullary ependymoma or cavernous malformation occurred in three of four cases, and the remaining case had subtotal removal of the ependymoma. None of the patients showed postoperative deterioration of the neurological condition. Pathological examination of all cases revealed intramedullary hemorrhage was associated with ependymoma or cavernous malformation. Posterior spinal myelotomy should be limited to the caudal opening of the fourth ventricle (foramen of Magendie), that is the caudal medulla oblongata, to avoid the significant deterioration after surgery.

Keywords: cavernous malformation, ependymoma, medulla oblongata, myelotomy, spinal intramedullary tumor

Introduction

Spinal intramedullary tumors such as ependymoma or vascular lesions such as cavernous malformation are often at risk of intramedullary hemorrhage.[1-3] When it occurs at the cervical spine level, there is a risk of serious deterioration of neurological symptoms. Although the surgical resolution is required, surgery is often challenging because of concerns about worsening neurological symptoms associated with surgery. The complexity of the high cervical portion of the spinal cord makes surgery technically demanding. We report surgical cases of intramedullary hemorrhage associated with ependymoma or cavernous malformation of the high cervical spine and discuss the anatomical understanding required for a successful surgery.

Case Report

Subjects

This study included four patients (two males and two females) with acute, subacute, or gradual onset of spinal cord dysfunction caused by intramedullary hemorrhage associated with ependymoma or cavernous malformation of the C1 or C1/2 level of the high cervical spine. The mean

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Table 1. Summary of Intramedullary Hemorrhage Cases Associated with Ependymoma or Cavernous Malformation of the High Cervical Spine

Case No.	Age	Sex	Onset	Spine level	Surgery		Functional grade			Pathological diagnosis
					Surgical approach	Tumor removal	Preop.	Postop.		
								< 30 days	> 6 months	
1	74	F	Subacute	C1	PMS	Total	5	5	4	EP
2	58	M	Gradual	C1/2	PMS	Total	3	3	2	CM
3	37	M	Gradual	C1	PMS	Subtotal	3	2	2	EP
4	16	F	Acute	C1	PLS	Total	5	4	2	CM

PMS, posterior median sulcus; PLS, posterolateral sulcus; EP: ependymoma; CM: cavernous malformation

age was 46.3 years (16-74 years). We assessed neurological conditions before and after surgery based on the modified McCormick functional schema.[4-9]

Surgical technique

The basic concept of surgery for spinal intramedullary tumors has been described previously in the literature.[5-9] The patient was placed in the lateral oblique or prone position under general anesthesia. The patient's thorax was elevated 15 degrees while we maintained the head in neutral flexion without any rotation. Transcranial motor evoked potentials were routinely set up for intraoperative neurophysiological monitoring. Laminectomy was performed in the usual manner. After making a small midline craniectomy of the suboccipital bone, except in Case 2, the high cervical spine laminectomy was long enough to expose the entire lesion and widened to the medial pedicular surface. We opened the dura mater while preserving the arachnoid membrane. We opened the arachnoid membrane carefully to avoid damage at the points of arachnoid adherence or vascular connection. We inspected the vascular pattern or spinal cord swelling first, compared with magnetic resonance imaging, before surgery with the help of indocyanine green videoangiography. A linear incision on the posterior median sulcus (PMS) or posterolateral sulcus (PLS) was made just on the tumor location after careful inspection of the spinal cord's dorsal surface. We extended the myelotomy rostrally or caudally by meticulously splaying the spinal tissue using a micro-dissector to avoid exceeding the caudal opening of the fourth ventricle (foramen of Magendie), which is assumed to be as high as the caudal medulla oblongata. After encountering the tumor, we gently dissected the tumor-cord interface in the longitudinal plane over the extent of the tumor. The entire procedure was performed in a field without significant bleeding as much as possible. The shape of the spinal cord was restored by suturing the pial edges. The arachnoid membrane was then closed with the dura mater to reduce the chance of postoperative arachnoid adhesion. The resected lamina of C2 was constructed as a lift-up style of the cervical spine using a titanium mini-plate and screws.

Ethical approval

All procedures performed in studies involving human participants complied with the ethical standards of the institutional research committee and with the 1964 Declaration of Helsinki and its later amendments. All participants provided informed consent to participate in this study.

Postoperative assessment

The mean operation time was 8 hours and 54 minutes, and the mean total estimated blood loss during surgery was 285 mL. None of the patients received a blood transfusion. Pathological examination demonstrated that intramedullary hemorrhage was associated with ependymoma or cavernous malformation. Three of four cases achieved total removal of the intramedullary tumor, and Case 3 achieved subtotal removal of the tumor. None of the patients showed deterioration of neurological condition after surgery. Table 1 summarizes the clinical data.

Illustrative case: Case 4

A 16-year-old woman complained of acute onset of neck pain and tetraparesis over several days. After emergency admission, she demonstrated further deterioration of neurological function, including disturbance of consciousness. The neurological assessment suggested grade 5 modified the McCormick functional status. Preoperative imaging studies revealed a hemorrhagic tumor at the C1 spine level (Fig. 1A, B). Surgery was performed using the PLS approach on the right side (Fig. 1C-E). After the posterior surface of the spinal cord was exposed, the myelotomy using PLS approach on the right side was first started to remove an acute hemorrhage at the level of C2 to recover the spinal cord condition. The dissection above the hemorrhagic tumor was minimized. The whole area around the hemorrhagic tumor was carefully delineated and, finally, removed safely in an en bloc fashion. The functional status of the modified McCormick functional schema early after surgery slightly improved to grade 4, and further improved to grade 2 6 months after surgery (Fig. 1F). The pathological diagnosis was cavernous malformation.

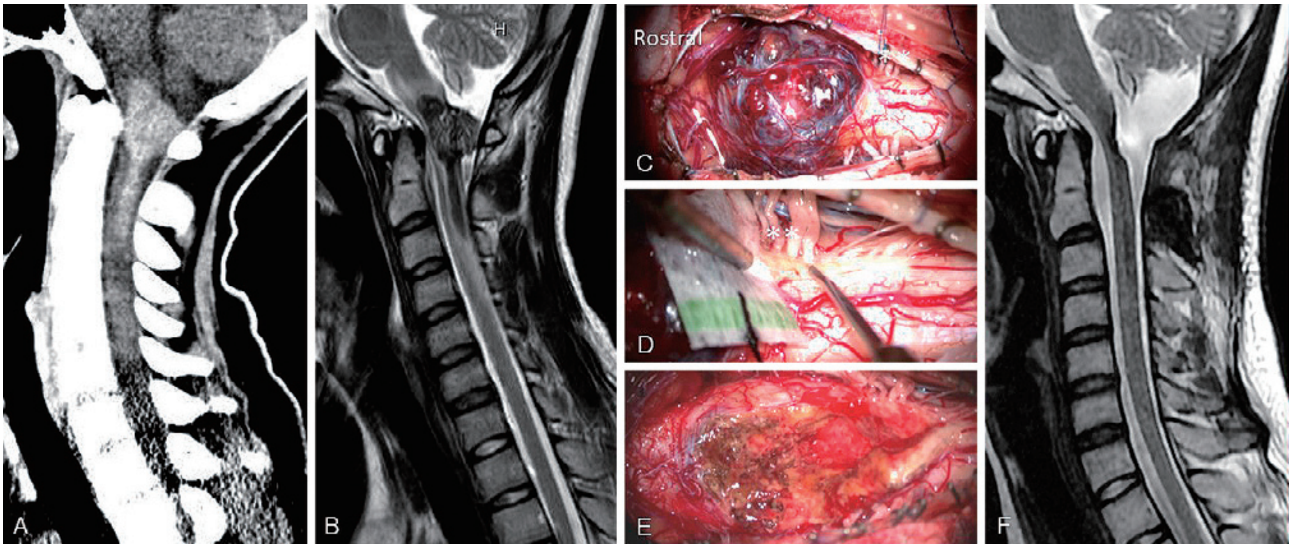

Fig. 1 Case 4, Cavernous malformation
A, B: Preoperative Computed Tomography (CT) and T2-weighted magnetic resonance (MR) images showing a hemorrhagic tumor at the level of C1.
C, D, E: Intraoperative photographs showing the spinal cord's dorsal surface suggest an acute hemorrhagic tumor, the opening of the posterolateral sulcus at the level of C2, and total removal of the tumor. Please note the location of the C2 dorsal nerve (**).
F: Postoperative T2-weighted MR images showing the total removal of the cavernous malformation.

Discussion

In the surgery of spinal intramedullary tumors, one of the keys to successful surgery is how safely and widely the intramedullary tumor can be exposed.[10,11] The spinal cord blends indistinguishably into the medulla oblongata of the brainstem. The junction of the spinal cord and medulla oblongata is situated at the rostral margin of the first cervical root.[12] In the brainstem, there are cranial nerve nuclei, major descending fiber bundles, such as the corticospinal tract or corticonuclear tract, and major ascending fiber bundles, such as the medial lemniscus or spinothalamic tract. Some of the tract fibers cross at the level of the medulla oblongata. Although the myelotomy should be long enough to expose the tumor safely, extending it upward to the brainstem may carry the possible risks of damage to the cranial nerve nuclei or amputating the crossing nerve fibers of the critical descending or ascending tract the level of the medulla oblongata.

The medulla oblongata is divisible into the rostral and caudal parts based on the absence or presence of the lower fourth ventricle (Fig. 2).[13-16] The hypoglossal nucleus, the dorsal motor nucleus of the vagus nerve, and solitary tract and nucleus are in the dorsal area of the rostral medulla oblongata, grouped around the central canal. The corticospinal tract fibers run through the posterior limb of the internal capsule, cerebral peduncle of the midbrain, ventral part of the pons, pyramid of the medulla oblongata, and finally reach the lateral fasciculus of the spinal cord. Most of those fibers form the decussation of pyramids in the caudal medulla oblongata and descend on the opposite side called the lateral corticospinal tract.[17] On the other hand, there are two major ascending tracts of medial lemniscus and lateral spinothalamic tract.[18] These tracts carry sensory information from the spinal cord to the cerebral cortex. The lateral spinothalamic tract bears pain and temperature information from secondary neurons in the contralateral spinal cord, passing upward without an additional synaptic relay at the brainstem level, finally reaching the thalamus. Other sensory information of vibration and position sense enters the posterior funiculus of fasciculus cuneatus and fasciculus gracilis. This tract reaches the nucleus cuneatus and nucleus gracilis at the dorsal side of the caudal medulla oblongata. It ascends while crossing within the medial lemniscus (decussation of medial lemniscus) of rostral medulla oblongata, passes through the thalamus, and finally reaches the sensory area of the cerebral cortex. There is a significant risk of surgical damage to the dorsal midline structure of the caudal medulla oblongata by PMS approach or the dorsal lateral structure of the caudal medulla oblongata by PLS approach. In the case of ependymoma, the tumor is removable by exposing it from the caudal side using PMS approach, even with intramedullary hemorrhage. It is practically possible for surgeons to avoid the excessive upward myelotomy by recognizing the foramen of Magendie. In the case of cavernous malformation with intramedullary hemorrhage, it is safe for surgeons to remove the hemorrhage from the caudal side first, using PMS or PLS approach. Then, surgeons should carefully dissect the area below the cavernous mal-

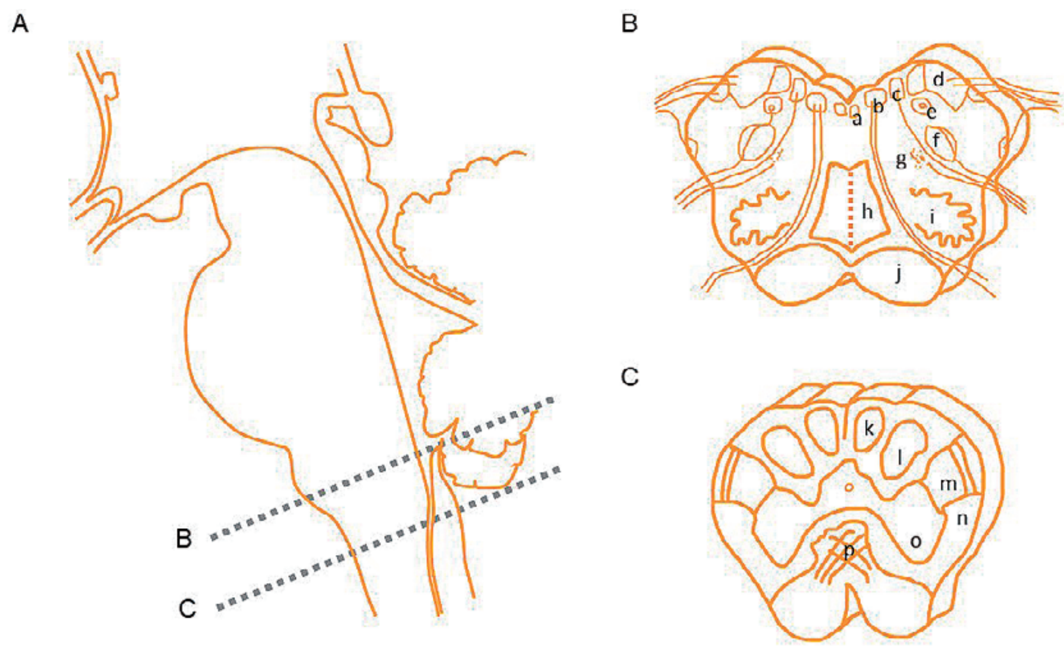

Fig. 2 Schematic drawings highlighting the major neural tract and their relationship to adjacent neuroanatomical structures. A: Sagittal image of brainstem, B, Axial image of rostral medulla oblongata, C: Axial image of caudal medulla oblongata.
a: Medial longitudinal fasciculus; b: Hypoglossal nucleus; c: Dorsal motor nucleus of vagus nerve; d: Vestibular nucleus; e: Solitary nucleus and tract; f: Descending spinal tract of trigeminal nerve; g: Ambiguous nucleus; h: Medial lemniscus; i: Inferior olivary nucleus; j: Corticospinal tract; k: Nucleus gracillis; l: Nuclues cuneatus; m: Spinal nucleus of trigeminal nerve; n: Spinothalamic tract; o: Ventral horn of C1; p: Decussation of corticospinal tract

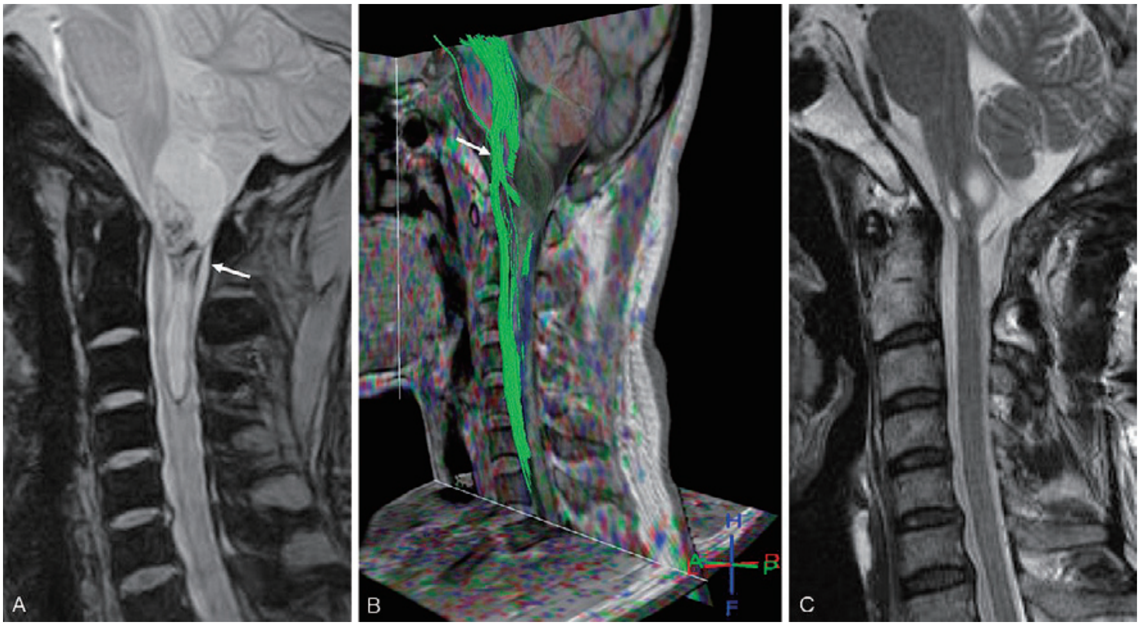

Fig. 3 Case 3, Ependymoma
A: Preoperative T2*-weighted magnetic resonance (MR) images showing the tumor accompanying the hemorrhagic change (arrow) at the level of C1.
B: Diffusion tensor tractography of corticospinal tract showing the possible decussation of nerve fibers at the ventral part of the medulla oblongata (arrow).
C: Postoperative T2-weighted MR images showing the subtotal removal of the ependymoma.

formation itself and avoid excessive dissection above the cavernous malformation. Finally, the whole area around the cavernous malformation should be carefully delineated and safely removed in en bloc fashion. However, it is also of great importance for surgeons to assess the clinical course of early neurological deterioration caused by medullary hemorrhage. That is because the early neurological deterioration may predict unfavorable outcomes with medullary hemorrhage.[19] The extent of the medullary hemorrhage along the neural tract may significantly deteriorate. Surgeons should identify important neural tracts before surgery; however, this is not easy. Diffusion tensor imaging and tractography (DTT) can help surgeons determine the critical neural tracts, although those imaging techniques may suffer from relatively poor spatial resolution and image distortion.[20-23] These images may help surgeons select the surgical approach or determine the entry zone into the lesion. In Case 3, the ventral part of the ependymoma, which was presumed to be close to the decussation of the corticospinal tract in the caudal medulla oblongata, was intentionally left behind concerning the preoperative DTT (Fig. 3).

Conclusion

This technical note is limited because of the small number of subjects and the lack of functional imaging studies before or after surgery. Although the surgical concept proposed here is not novel and was based on clinical experience and anatomical considerations, such a concept should be shared among surgeons who try to accomplish it safely. It is necessary to avoid damage to important neural structures of cranial nerve nuclei and neural tracts located in the rostral and caudal medulla oblongata in the posterior spinal myelotomy of the high cervical cord. Posterior spinal myelotomy should be limited to the caudal opening of the fourth ventricle (foramen of Magendie), the caudal medulla oblongata, to avoid significant deterioration after surgery.

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Conflicts of Interest Disclosure

No benefits in any form have been or will be received from any commercial party related directly or indirectly to the subject of this manuscript. All authors report no conflicts of interest concerning the materials or methods used in this study or the findings specified in this paper. All authors who are members of The Japan Neurosurgical Society (JNS) have registered online Self-reported COI Disclosure Statement Forms through the website for JNS members.

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