A study of safe entry zones via the floor of the fourth ventricle for brain-stem lesions

Report of three cases

KAZUHIKO KYOSHIMA, M.D., SHIGEAKI KOBAYASHI, M.D., HIROHIKO GIBO, M.D., AND TAKAYUKI KUROYANAGI, M.D.

Department of Neurosurgery, Shinshu University School of Medicine, Matsumoto, Japan

Direct surgery for intra-axial lesions of the brainstem is considered a hazardous procedure, and morbidity of varying degrees cannot be avoided even with partial removal or biopsy. The main causes of morbidity relate to direct damage during removal of the lesion, selection of an entry route into the brainstem, and the direction of brainstem retraction. The authors examined the possibility of making a medullary incision and retracting the brainstem, taking into account the symptomatology and surgical anatomy, and found two safe entry zones into the brainstem through a suboccipital approach via the floor of the fourth ventricle. These safe entry zones are areas where important neural structures are less prominent. One is the “suprafacial triangle,” which is bordered medially by the medial longitudinal fascicle, caudally by the facial nerve (which runs in the brainstem parenchyma), and laterally by the cerebellar peduncle. The second is the “infrafacial triangle,” which is bordered medially by the medial longitudinal fascicle, caudally by the striae medullares, and laterally by the facial nerve. In order to minimize the retraction-related damage to important brain-stem structures, the brainstem should be retracted either laterally or rostrally in the suprafacial triangle approach and only laterally in the infrafacial triangle approach.

Three localized intra-axial brain-stem lesions were treated surgically via the safe entry zone using the suprafacial approach in two and the infrafacial approach in one. The cases are described, and the approaches delineated. Both approaches are indicated for focal intra-axial lesions located unilaterally and dorsal to the medial lemniscus in the lower midbrain to the pons. Magnetic resonance imaging is useful in selecting these approaches, and intraoperative ultrasonography is helpful to confirm the exact location of a lesion before a medullary incision is made. These approaches can also be used as routes for aspiration of brain-stem hemorrhage as well as for tumor biopsy.

KEY WORDS • brain stem • suprafacial triangle • infrafacial triangle • fourth ventricle • anatomical study • surgical approach

The recent development of magnetic resonance (MR) imaging has made it possible to identify the exact location of a brain-stem lesion and has renewed interest in surgical approaches to the brainstem. However, these attempts have mostly been limited to exophytic lesions, and direct surgery for intraxial brain-stem lesions is still considered hazardous.

We report the cases of three patients whose localized intra-axial lesions were treated via new approaches to the brainstem. The choice of approach was based on symptomatological and anatomical considerations, which are described.

Case Reports

Case 1

This 31-year-old man suffered a pontine hemorrhage on August 24, 1989, causing headache and numbness of the lips and fingers on the right side. The headache developed gradually and numbness extended over the right side of the face. A computerized tomography (CT) scan revealed a high-density mass in the brainstem and an MR image showed a mass in the left side of the pons measuring 15 mm in diameter. No abnormalities were detected on the angiogram. The lesion was diagnosed clinically as a cavernous angioma and the patient was treated conservatively. On November 6, he suffered another episode of headache.

Examination. Neurological examination revealed left abducens paresis, nystagmus, numbness and hypoalgesia of the right side of the face, right sensory disturbance for touch and pain, and cerebellar signs predominantly on the right side, with gait disturbance. Computerized tomography revealed rebleeding in the brainstem, 28 mm in size, in the same area. A heterogeneous high-intensity mass with a thin low-intensity rim
was seen on a T1-weighted MR image and a high-intensity mass with a thin low-intensity rim was visualized on a T2-weighted MR image. The mass extended from the lower pons to the midbrain on the left side (Fig. 1 upper).

Operation. With the patient in the prone position, a median suboccipital craniectomy was carried out. The upper floor of the fourth ventricle and the orifice of the aqueduct were exposed with an approximately 2-cm section of the inferior cerebellar vermis. The surface of the fourth ventricle near the left superior cerebellar peduncle was yellowish and slightly protruded, and the median sulcus was shifted to the right side. After the location of the lesion was confirmed by ultrasonography, a 7-mm longitudinal medullary incision was made 5 mm laterally from the median sulcus. The hematoma capsule was recognized 2 mm deep under the surface of the fourth ventricle. Old hematoma was aspirated and a solid mass was completely removed together with some veins and arteries observed in the bottom of the tumor cavity. The intraoperative diagnosis was an arteriovenous malformation rather than a cavernous angioma. During removal of the lesion, special care was taken not to retract the brain stem medially, caudally, or (as much as possible) rostrally.

Postoperative Course. The patient was alert immediately postoperatively and showed no further neurological deficits except increased gait ataxia, which improved gradually. Over the following several months, he became ambulatory without disability in daily life. The left abducens paresis and nystagmus improved gradually and resolved completely over several weeks, and other symptoms almost entirely resolved. Postoperative MR imaging confirmed total removal of the lesion (Fig. 1 lower). Histological examination of the surgical specimen demonstrated a vascular malformation.

Case 2

This 42-year-old man, who had undergone nephrectomy for renal-cell carcinoma 1 year earlier, suffered brain-stem hemorrhage on October 17, 1989, with diplopia, numbness of the left extremities, and tinnitus on the left side.

Examination. Neurological examination showed right abducens paralysis, bilateral hearing disturbance, slight left hemiparesis with mild hyperreflexia, a left sensory disturbance, and mild right cerebellar signs. A CT scan revealed a contrast-enhanced lesion in the brain stem and the right frontal lobe. Magnetic resonance imaging demonstrated an enhanced intra-axial mass in the lower pons located on the left side (Fig. 2 upper and center).

Operation. One week after an uneventful removal of the metastatic tumor from the right frontal lobe, the tumor in the lower pons was removed with the patient in the prone position. A median suboccipital craniectomy was made and the floor of the fourth ventricle was exposed by minimally splitting the vermis. A longitudinal medullary incision was made on the floor of the fourth ventricle, about 5 mm rostrally from the caudal margin of the striae medullares and 4 mm laterally.
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![Image](image_url)

**FIG. 2.** Case 2, treated via the infrafacial approach. Upper and Center: Preoperative magnetic resonance (MR) images showing an enhanced intra-axial tumor in the lower pons. The image shown at upper left is not enhanced. Lower: Postoperative contrast-enhanced MR images showing total removal of the tumor. There is a high-intensity area around the route of approach and the tumor cavity, without enhancement.

from the median sulcus, after confirming the location of the tumor with ultrasonography. The tumor was recognized 5 mm deep under the surface of the fourth ventricle and was well demarcated with a capsule. Some vessels were identified at the base of the tumor. The tumor was totally removed *en bloc*, with special care taken not to retract the brain stem medially or caudally. The final medullary incision measured 1 cm and the excised tumor was 1 cm in diameter.

Postoperative Course. Neurological examination demonstrated moderate facial paresis, lateral right gaze disturbance, swallowing disturbance, and ataxic gait with loss of depth and position sense. The facial paresis and swallowing impairment resolved completely over several weeks. Pathological diagnosis was metastatic renal-cell carcinoma. Postoperative MR imaging confirmed total removal of the lesion (Fig. 2 *lower*). One year later the patient died of systemic metastasis.

Case 3

This 65-year-old man became aware in February, 1991, of sensory disturbance affecting his lips and check on the right side; right-sided hemiparesis gradually developed over the next 2 months. In April, 1991, these symptoms worsened rapidly.

Examination. Neurological examination revealed slight right-sided hemiparesis with sensory impairment for touch and position, hypesthesia and hypalgiesia of the right side of the face, right conductive hearing impairment, and ataxia of the right limbs. Magnetic resonance imaging revealed two well-enhanced lesions: a mass in the left pons to the midbrain and a lesion in the left occipital pole (Fig. 3 *upper*).

Operation. With the patient in the prone position, a median suboccipital craniotomy was carried out. The rhomboid fossa was exposed via 2.5-cm section of the inferior cerebellar vermis. No remarkable structural change was observed on the fourth ventricular floor. A 7-mm longitudinal medullary incision was made 5 mm laterally from the median sulcus. The lower end of the incision was approximately 1 cm away from the cranial margin of the satriae medullares. The tumor was identi

Postoperative Course. Neurological examination showed left abducens paresis and impairment of medial gaze with the left eye, both of which were improving. The cerebellar symptom had not worsened. Postoperative MR imaging revealed residual tumor in the rostral side of the tumor cavity (Fig. 3 *lower*).

Discussion

Direct surgery of the brain stem is considered one of the most difficult operations because of the special anatomical features of that area. The brain stem is densely composed of important neural structures such as nuclei and neural tracts; hence, high mortality and morbidity rates are reported even with biopsy in this area. Recent progress in microsurgery and neuroimaging enables a direct approach to brain-stem lesions with increased safety. Although there are a few reports describing entry zones for intra-axial lesions of the brain stem, none consider retraction of the brain stem itself. Baghai, *et al.*, reported a safe approach from the ventrolateral portion of the pons between the
points of emergence of the fifth and seventh cranial nerves, but this approach is only useful for biopsy and would be too narrow for direct surgery. Tapered brain retractors with a 2-mm wide tip connected with a lightweight, tapered, self-retaining titanium retractor for brain-stem retraction and a two-pronged hook for tumor retraction are essential tools for direct brain-stem surgery.11,12

Symptomatic Considerations

If it is not possible to avoid impairment of brain-stem function during surgery for a localized intra-axial brain-stem lesion, it is important to know what kinds of impaired function are tolerable for the patient in daily life. Severe disability caused by unilateral brain-stem impairment includes hemiplegia, swallowing difficulty, ataxia caused by impaired depth and position sense, and impairment of bilateral eye movement. At surgery, it is important not to damage the relevant structures: the corticospinal tract, lower cranial nerve nuclei, medial lemniscus, parapontine reticular formation, or corticonuclear tracts.

Motor impairment of the face or of unilateral eye movement including nystagmus may be tolerable. Of course it is far better to preserve such relevant structures as the facial nerve or nucleus, the medial longitudinal fascicle, the abducens nerve or nucleus, and the oculomotor nerve or nuclei.

Tolerable or compensatable disability caused by unilateral brain-stem impairment might include equilibrium impairment, cerebellar ataxia, unilateral hearing disorder, or impairment of face sensation. It might be acceptable at surgery, therefore, to damage the following relevant unilateral structures: vestibular nuclei, cerebellar peduncle, cochlear nuclei or lateral lemniscus, or trigeminal nuclei.

Anatomical Considerations

The dorsal aspect of the fourth ventricular floor, after removal of the cerebellum, is referred to as the rhomboid fossa. It is 3 x 2 cm in size and is bordered rostrally by the cerebellar peduncles and caudally by the tubercles of the gracilis nucleus and cuneate nucleus, and the tuberculum cinereum (Figs. 4 and 5). Other external structures include the median sulcus in the midline, sulcus limitans, facial colliculus, and striae medullares. The latter structures, running across the floor of the fourth ventricle, roughly indicate the border between the medulla oblongata and pons (Fig. 4). As internal structures, the medial longitudinal fascicle runs just lateral to the median sulcus, the nucleus of the abducens nerve courses under the facial colliculus, and the facial nerve originates from its nucleus, which is located laterally deep under the striae medullares and runs up to and around the nucleus of the abducens nerve (Figs. 4 and 5). The nuclei of the hypoglossal and vagus nerves are located just caudal to the striae medullares.

Important structures, which cause severe disability if
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**Fig. 4.** Schematic drawing of the anatomy and the safe entry zones to the brain stem via the floor of the fourth ventricle. Important neural structures are sparse in these safe entry zones. A = suprafacial triangle; B = infrafacial triangle; MLF = medial longitudinal fascicle; trochlear = trochlear nerve; facial = facial nerve; sup. inf. = superior and inferior; ambiguus = nucleus ambiguus; vagus = dorsal nucleus of the vagus nerve; hypoglossal = nucleus of the hypoglossal nerve.

Damaged, are not densely distributed in the area between the cerebellar peduncle and facial colliculus, nor between the facial colliculus and the striae medullares. We have named the former area the "suprafacial triangle" and the latter the "infrafacial triangle."

**Safe Entry Zones Into the Brain Stem**

Based on the symptomatology and surgical anatomy, we have analyzed the possibility of surgical incision and retraction of the brain stem and have identified two safe entry zones into the brain stem through the fourth ventricular floor via a suboccipital approach. These safe entry zones are located where important neural structures are sparse (Figs. 4 and 5). One is the suprafacial triangle, which is bordered medially by the medial longitudinal fascicle, caudally by the facial nerve (which runs in the brain-stem parenchyma), and laterally by the cerebellar peduncles. The second is the infrafacial triangle, which is bordered medially by the medial longitudinal fascicle, caudally by the striae medullares, and laterally by the facial nerve. At the bottom of these triangles are the medial lemniscus and corticospinal tract.

Structures potentially damaged by brain-stem retraction or other surgical procedures approached via the suprafacial or infrafacial triangle are listed in Table 1 with the symptoms related to them.

The brain-stem parenchyma is vascularized by the perforating arteries coursing from the ventral or lateral aspect of the brain stem, but not from the surface of the fourth ventricular floor. This means that on medullary incision from the fourth ventricular floor there is little possibility of causing brain-stem dysfunction by damaging perforating arteries. Furthermore, in parenchymal procedures approached from the fourth ventricular floor there is a low possibility of causing ischemic brain-stem damage to the remote area from the operative field. Thus, these two triangles can be designated safe entry zones in the brain stem for surgical treatment of a lesion located dorsal to the medial lemniscus.

**Suprafacial Approach.** On the suprafacial triangle (Fig. 6A), the most feasible brain-stem incision is made
longitudinally, up to 1 cm in length, caudal from the edge of the cerebellar peduncle and about 5 mm lateral to the median sulcus. The length of the linear incision may be about 7 mm, because it is extended by brain-stem retraction.

In order to minimize retraction-related damage to important brain-stem structures, the brain stem should be retracted either laterally or rostrally. Retraction to the rostral side is possible because the oculomotor nuclei are located far from the triangle. Cases 1 and 3 were operated on using this approach. In Case 3, medial-gaze disturbance and abducens paresis of the left eye were likely caused by some retraction medially and caudally during the procedure, damaging the medial longitudinal fascicle and the abducens nucleus or nerve.

**Infrafacial Approach.** The most feasible brain-stem incision in the infrafacial triangle (Fig. 6B) is made longitudinally, rostral from the caudal margin of the stria medullares and about 5 mm lateral to the median sulcus. The incision should be less than 1 cm in length. Brain-stem retraction is possible only laterally, because the facial nucleus is located deeper and the facial nerve courses upward to the abducens nucleus. This triangle is narrow and is surrounded by more important structures compared to the suprafacial triangle. An initial medullary incision approximately 5 mm in length is suitable. In Case 2, the lesion was removed via this approach. A metastatic tumor about 1 cm in diameter was removed en bloc with the brain stem retracted laterally and somewhat rostrally. Postoperatively, the patient showed temporary facial palsy and swallowing disturbance, lateral-gaze disturbance to the right, and hemisensory disturbance for touch or position accompanied by new ataxia. The lateral-gaze disturbance and facial palsy were caused by retracting the brain stem rostrally, resulting in damage to the parapontine reticular formation and the facial nerve around the nucleus of the abducens nerve. The swallowing impairment was caused when the brain-stem incision was slightly extended over the caudal edge of the stria medullares or the corticonuclear tracts were injured. It is important that surgical procedures not extend over the caudal edge of the stria medullares. Impaired position sense and related ataxia were caused by damage to the medial lemniscus during en bloc removal of the tumor.

### Conclusions

Potential brain damage, including neurological dysfunction, caused by direct brain-stem surgery may include: 1) damage caused by procedures for reaching the brain-stem surface, such as injury of the bridging vein, incision of the brain, or brain retraction; 2) injury to the brain stem caused by attempts to reach a lesion, such as injury of the perforating artery or neural tissue by medullary incision of the brain stem; and 3) injury to the brain-stem tissue around the lesion, caused by brain-stem retraction or surgical procedures to remove a lesion.

It follows that a suboccipital approach by partially splitting the inferior part of the vermis is also a relatively safe procedure for reaching the brain-stem surface because of the absence of bridging veins and minimum potential for retraction-related cerebellar damage. Therefore, the supra- or infrafacial approach is considered to be a relatively safe route to the brain stem.

The supra- or infrafacial approach is indicated for localized intra-axial lesions located unilaterally and dorsal to the medial lemniscus in the lower medulla to the pons. Magnetic resonance imaging is useful in selecting these approaches and intraoperative ultrasonography is helpful to confirm the exact location of a lesion before making a medullary incision. These safe entry zones can also be used as a route for aspiration of a brain-stem hemorrhage as well as for biopsy of a tumor.

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**TABLE 1**

*Structures potentially damaged by brain-stem retraction or other surgical procedures approached via the suprafacial or infrafacial triangles and relevant symptoms.*

<table>
<thead>
<tr>
<th>Position Relative to Surgery</th>
<th>Suprafacial Triangle</th>
<th>Infrafacial Triangle</th>
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<tbody>
<tr>
<td></td>
<td>Structure</td>
<td>Symptom</td>
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<tr>
<td>lateral</td>
<td>superior cerebellar peduncle</td>
<td>hemiataxia</td>
</tr>
<tr>
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<td>trigeminal nuclei</td>
<td>sensorimotor impairment of the face</td>
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<td>gaze palsy, nystagmus</td>
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<tr>
<td>rostral</td>
<td>superior cerebellar peduncle</td>
<td>hemiataxia</td>
</tr>
<tr>
<td></td>
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<td>oculomotor &amp; trochlear palsy</td>
</tr>
<tr>
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<td>nucleus of 6th nerve</td>
<td>abducens palsy</td>
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<td>PPRF</td>
<td>lateral-gaze palsy</td>
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<td>medial lemniscus</td>
<td>ataxia, depth perception</td>
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<td>lateral spinothalamic tract</td>
<td>impairment</td>
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<td></td>
<td>corticospinal tract</td>
<td>motor impairment</td>
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*Abbreviations: MLF = medial longitudinal fascicle; PPRF = parapontine reticular formation.

⁺ Damage of the MLF caudal to the nucleus of abducens nerve does not cause gaze palsy.*
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References


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Address reprint requests to: Kazuhiko Kyoshima, M.D., Department of Neurosurgery, Shinshu University School of Medicine, Asahi 3-1-1, Matsumoto 390, Japan.