Intraoperative identification of motor areas of the rhomboid fossa using direct stimulation

CHRISTIAN STRAUSS, M.D., JOHANN ROMSTÖCK, M.D., CHRISTOPHER NIMSKY, M.D., AND RUDOLF FAHLBUSCH, M.D.

Department of Neurosurgery, University Erlangen-Nuremberg, Erlangen, Germany

Intraoperative electrical identification of motor areas within the floor of the fourth ventricle was successfully carried out in a series of 10 patients with intrinsic pontine lesions and lesions infiltrating the brain stem. Direct electrical stimulation was used to identify the facial colliculus and the hypoglossal triangle before the brain stem was entered. Multichannel electromyographic recordings documented selective stimulation effects. The surgical approach to the brain stem was varied according to the electrical localization of these structures. During removal of the lesion, functional integrity was monitored by intermittent stimulation. In lesions infiltrating the floor of the fourth ventricle, stimulation facilitated complete removal. Postoperative morbidity of facial or hypoglossal nerve dysfunction was not observed. Mapping of the floor of the fourth ventricle identifies important surface structures and offers a safe corridor through intact nervous structures during surgery of brain-stem lesions. Reliable identification is particularly important in mass lesions with displacement of normal topographical anatomy.

KEY WORDS • brain-stem mapping • brain-stem surgery • direct electrical stimulation • fourth ventricle

During the last few years, technical and microsurgical advances have facilitated systematic approaches to surgery of brain-stem lesions. Operative morbidity is the major factor limiting progress in brain-stem surgery, although encapsulated lesions such as cavernous hemangiomas can be removed without additional morbidity. Neurological deficits during removal of intrinsic lesions can be caused by an approach through nuclei and pathways close to the surface of the brain stem. Removal of lesions infiltrating the brain stem can result in additional morbidity due to injury of superficial nerve structures. Reliable identification of these surface structures prior to dissection is mandatory for the preservation of brain-stem function.

As the approach via the fourth ventricle is commonly used for removal of brain-stem lesions, the topography of the rhomboid fossa is of particular interest for the surgeon. Lang and coworkers investigated the topographical relationships between superficially located nerve structures such as the facial colliculus and the visible anatomical landmarks, the most important of which are the medullary striae and the obex. According to their measurements, the distance from the facial colliculus to the obex varied between 11.5 and 18 mm, and distances from the uppermost striae varied between 9 and 15 mm. From these findings it was concluded that the medullary striae cannot be used as surgical landmarks, nor can measurements provide helpful information. This problem is enhanced by space-occupying lesions causing displacement of the normal anatomy. Efforts to avoid injury to the facial colliculus and the underlying optomotoric areas are therefore strictly based on clinical judgment.

Alternative methods for localization include electrical mapping. Electrical stimulation is presently employed during stereotactic brain-stem biopsies for control of the probe position and during mesencephalic pain procedures in the awake patient. We studied the effects of direct electrical stimulation for localization of superficial nerve structures within the floor of the fourth ventricle.

Clinical Material and Methods

Since July, 1990, we have investigated a series of 10 patients. Of these, seven harbored intrinsic brain-stem lesions (five cavernous hemangiomas, one hypertensive hemorrhage, and one anaplastic glioma grade III) and three patients were operated on for lesions adjacent to the fourth ventricle (one pilocytic astrocytoma) or infiltrating the floor of the fourth ventricle (one lymphoma and one papilloma).
Primary interest was focused on the facial colliculus because of its clinical importance for facial nerve and underlying optomotoric functions. The short distance (0.25 mm) to the ependyma made the facial nerve fibers ideal for stimulation. The hypoglossal nucleus with a distance ranging from 0.5 mm at the upper pole to 2.6 mm at the lower pole also seemed accessible for direct stimulation.

After routine induction, the level of anesthesia was maintained with constant intravenous perfusion of alfentanil (60 μg/kg/hr) and propofol (6 to 12 mg/kg/hr). The advantage of both substances in monitoring motor-evoked and sensory-evoked potentials has been previously documented. All lesions were operated on by the senior author (R.F.) using microsurgical technique via a standard suboccipital craniectomy, with the patient in the sitting position.

**Stimulation Technique**

Electrical stimulation was performed after exposure of the fourth ventricle and before the brain stem was entered. Both bipolar and monopolar setups were used. For bipolar stimulation, small silicone strips with embedded electrodes were applied (Fig. 1A). Stimulation intensity varied between 0.1 and 2 mA and duration between 50 and 400 μsec. Single rectangular stimuli and levels up to 10 Hz were employed. For constant-current stimulation, the stimulator unit of Pathfinder was used.

Monopolar stimulation was performed with a handheld probe, not insulated at the tip, which served as a cathode (Fig. 1B). A needle electrode, placed in the muscles of the wound served as an anode. Constant-current stimulation using the parameters described above and constant-voltage stimulation were applied. Rectangular impulses were given at a level of 10 Hz between 0.1 and 1 V. Pulse duration was 100 μsec. For constant-voltage stimulation, a nerve locator was employed. A maximum of 200 stimuli were given at each site.

**Recording Techniques**

Simultaneous four-channel recordings were made using a conventional electromyographic (EMG) technique, but with monopolar stainless steel needles instead of concentric electrodes (Fig. 2). For facial muscle recordings, the active electrodes were placed at the orbicularis oris muscles. An indifferent electrode was placed at the frontal midline.

---

*Pathfinder I stimulator unit obtained from Nicolet Instrument Co., Madison, Wisconsin.*

†Nerve locator, Model NI1, obtained from Grass Instrument Co., Quincy, Massachusetts.
Intraoperative identification of rhomboid fossa motor areas

Table 1: Effects of electrical stimulation on the rhomboid fossa at the side of the lesion

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs.)</th>
<th>Sex</th>
<th>Lesion</th>
<th>Preoperative</th>
<th>Stimulation</th>
<th>Brain-Stem Incision/Dissection</th>
<th>Postoperative</th>
<th>At Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Facial Nerve†</td>
<td>Hypoglossal Nerve‡</td>
<td>Facial Nerve</td>
<td>Hypoglossal Nerve</td>
<td>Facial Nerve†</td>
</tr>
<tr>
<td>1</td>
<td>20, M</td>
<td></td>
<td>cavernoma</td>
<td>IV</td>
<td>+</td>
<td>+</td>
<td>IV</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>6, F</td>
<td></td>
<td>cavernoma</td>
<td>I</td>
<td>+</td>
<td>+</td>
<td>M</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>32, F</td>
<td></td>
<td>cavernoma</td>
<td>I</td>
<td>+</td>
<td>+</td>
<td>III</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>19, M</td>
<td></td>
<td>cavernoma</td>
<td>IV</td>
<td>(+)</td>
<td>+</td>
<td>IV</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>42, M</td>
<td></td>
<td>cavernoma</td>
<td>I</td>
<td>+</td>
<td>+</td>
<td>III</td>
<td>I</td>
</tr>
<tr>
<td>6</td>
<td>58, F</td>
<td></td>
<td>astrocytoma  III</td>
<td>I</td>
<td>+</td>
<td>+</td>
<td>I</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>60, M</td>
<td></td>
<td>hematoma</td>
<td>V</td>
<td>NR</td>
<td>+</td>
<td>V</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>39, M</td>
<td></td>
<td>lymphoma</td>
<td>I</td>
<td>+</td>
<td>+</td>
<td>I</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>39, M</td>
<td></td>
<td>lymphoma</td>
<td>I</td>
<td>+</td>
<td>+</td>
<td>I</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>48, M</td>
<td></td>
<td>papilloma</td>
<td>II</td>
<td>+</td>
<td>+</td>
<td>II</td>
<td>2</td>
</tr>
</tbody>
</table>

* Motor responses could be evoked in all cases on both sides of the floor of the fourth ventricle (+), except for one case with pontine hemorrhage (Case 7; NR = no response elicited). In one case with seventh cranial nerve deficit, intensity had to be increased in order to obtain responses (Case 4; (+) = response at stimulation intensity of 2 mA).
† House and Brackmann: grading system.
‡ 1 = normal function; 2 = paresis.

For hypoglossal recordings, the active electrodes were positioned in the genioglossal muscles. In the latter cases we used one set of electrodes for both hypoglossal nerves, as it proved difficult to differentiate between stimulation effects on the right and left sides.

**Results**

In nine of the 10 patients, selective EMG responses could be evoked after electrical stimulation at the facial colliculus and the hypoglossal trigonum. The remaining patient (Case 7) had hypertensive hemorrhage, and no response on the side of the lesion could be evoked (Table 1). In the other nine patients, selective EMG responses could be recorded after stimulation on the side of the lesion and contralaterally. Stimulation effects were limited to the site and side of stimulation. Stimulation at the facial colliculus resulted in selective EMG responses of the facial muscles on the side of stimulation (Fig. 2A and C). In two of the latter cases, we documented additional horizontal eye movements upon stimulation at the area of the facial colliculus. The hand-held stimulator and the silicone strip were moved on the surface of the rhomboid fossa, and continuous stimulation was applied until muscle responses of maximal amplitude could be evoked. The intensity was then reduced to motor threshold. The threshold for facial colliculus stimulation varied between 0.1 and 0.4 mA (for technical reasons 0.1 mA was the lowest stimulus intensity available). Electromyographic responses from the "hot point" could be achieved with as little as 0.1 mA stimulation intensity after application of a single stimulus with impulse duration of 50 μsec. With increasing stimulation intensity, the surface area responding to stimulation increased. Only one patient (Case 4) with a seventh nerve paresis (House and Brackmann: Grade IV) required stimulation intensity of 2 mA (Fig. 2C). The same procedure was employed for localization of the hypoglossal triangle (Fig. 2B). Stimulation intensities varied between 0.2 and 2.5 mA. Motor thresholds corresponded to the distance of the stimulated motor area from the brainstem surface, and was lowest at the facial colliculus (0.25 mm) and highest at the lower pole of the trigone of the hypoglossal nerve (2.6 mm).

Both monopolar and bipolar stimulation techniques were successfully applied. Both modes achieved selective stimulation effects regarding the side and site of stimulation. Bipolar electrodes proved difficult to use for mapping, whereas monopolar stimulation with hand-held probes defined the area of stimulation more easily. In three patients with cavernous hemangiomas (Cases 1, 4, and 5), the approach into the brain stem was varied based upon the results of stimulation. The brainstem incision was not made at the site of the maximum bulging of the underlying cavernoma but was varied several millimeters to one side. In one patient with a neoplastic lesion infiltrating the brain stem (Case 10; see below for details), stimulation encouraged us to proceed with radical tumor removal. Functional integrity was checked during removal of the lesion by intermittent stimulation.

In two patients (Cases 5 and 10), we recorded EMG activity continuously. During removal of an infiltrating papilloma in Case 10, manipulation with the microdissector and the suction probe resulted in rapidly increasing EMG activity, when dissection was directed toward the trigone of the hypoglossal nerve (see Fig. 7). Motor responses also increased during enlargement of the initial brain-stem opening toward the facial colliculus in Case 5, similar to the dissection demonstrated (see Fig. 4 lower). The EMG activity ceased immediately when dissection was interrupted. In both cases transient morbidity of facial and hypoglossal nerve function was encountered.

Patients were continuously monitored for possible side effects. Heart rate, blood pressure, and heart rhythm as parameters of the sympathetic and parasympathetic systems were of particular concern. We did not
C. Strauss, et al.

FIG. 3. Magnetic resonance images in Case 4 showing a left pontine cavernous hemangioma. The lesion can be seen bulging into the ventricle.

observe side effects at any stimulation intensity, stimulus duration, or frequency.

Illustrative Cases

Case 4

This 19-year-old man was admitted for evaluation of the sudden onset of facial weakness and diplopia. Clinical signs included facial paresis (House and Brackmann Grade III), sixth nerve paresis, and trigeminal hypesthesia on the left side. Rotatory nystagmus and gait ataxia were also noted. Magnetic resonance (MR) imaging was suspicious for pontine cavernous hemangioma (Fig. 3). After exposure to the rhomboid fossa, a discolored area bulging with displacement of midline structures to the right side could be seen. Medullary striae were displaced upward and to the midline (Fig. 4 upper). Bipolar and monopolar constant-current stimulation identified the facial colliculus (Fig. 4 center). Right-side stimulation was successful at 0.5 mA; however, 2 mA stimulation on the paretic side was required to obtain results (Fig. 2A and C). The trigone of the hypoglossal nerve could also be located (Fig. 2B). The approach into the brain stem was altered, with dissection of surface structures below the facial colliculus. The lesion was completely removed (Fig. 4 lower). After surgery, rapid recovery of neurological symptoms could be observed, and follow-up examination revealed that the facial weakness had resolved.

Case 10

This 48-year-old man was admitted for treatment of recurrent papilloma of the choroid plexus of the fourth ventricle. He had previously been operated on via a left cerebellopontine angle approach. Neurological examination revealed residual fifth, seventh, and eighth cranial nerve involvement and a massive ataxia. Symptoms were limited to the left side. The MR images showed a contrast-enhanced lesion of 2.5 cm within the fourth ventricle bulging into the left foramen of Luschka (Fig. 5). During surgery, infiltration of tumor into the floor of the fourth ventricle was seen at the

FIG. 4. Intraoperative photographs in Case 4, a patient with cavernous hemangioma. Upper: The rhomboid fossa is exposed on the left side showing a bulge with displacement of medullary striae upward and medially. Center: Localization of the facial colliculus with bipolar electrodes. Lower: Incision into the brain stem based on the results of stimulation.
lower left quadrant (Fig. 6 upper). The area of the facial colliculus as indicated by stimulation was free of tumor (Fig. 6 center). Stimulation identified the trigone of the hypoglossal nerve at the medial border of the tumor. Intermittent stimulation was used to ensure functional integrity, and the tumor was removed completely (Fig. 6 lower). In this case, we also performed continuous EMG recording of the genioglossal muscle. Electromyographic activity increased notably during periods of manipulation using the microdissector or the suction probe within the vicinity of the hypoglossal trigonum (Fig. 7). After surgery, transient weakness of ipsilateral hypoglossal nerve function and transient spontaneous horizontal nystagmus was observed. No facial weakness and no conjugate gaze palsies were encountered.

Discussion

Intraoperative electrical stimulation of motor areas of the seventh and 12th cranial nerves within the floor of the fourth ventricle was successfully performed under general anesthesia in 10 patients during surgery for brain-stem lesions. Stimulation was successful using monopolar and bipolar as well as constant-current and constant-voltage procedures. Intravenous anesthesia with Propofol and Alfentanil proved useful for monitoring and did not prolong anesthesia after surgery.

Monopolar stimulation with a hand-held probe was superior to bipolar stimulation with small strip electrodes. In cases with constant-current stimulation, drainage of cerebrospinal fluid resulted in shunting effects, as noted by others;1 other than that, our preliminary data showed no difference between constant-voltage and constant-current stimulation.

For mapping purposes the following regimen proved helpful and time saving. Suprathreshold stimulation at a rate of 10 stimuli/sec is used for initial mapping. At this rate, continuous movement with the stimulation electrode will not leave relevant motor areas uncovered, which may be overlooked when a stimulation rate of one stimulus/sec is applied. Suprathreshold stimulation rapidly defines an area of maximum amplitude of the evoked EMG response. The area is then stimulated with gradually decreasing intensity until motor threshold is
reached. Moving the stimulator away from the "hot point" at threshold intensity will result in disappearance of motor evoked responses. This regimen reliably identifies the facial colliculus and the trigone of the hypoglossal nerve within minutes. The effects of stimulation are limited to the side and site of stimulation. Stimulation at the facial colliculus of one side resulted in motor evoked response exclusively of ipsilateral facial muscles. We did not encounter any side effects relating to the cardiovascular system; however, we do not stimulate at intensities orrates higher than those described. In stereotactic surgery, higher intensities and rates have been employed; however, these procedures were limited to mid-brainesites.

Electrophysiological identification of the facial colliculus guided the surgical approach into the brain stem in all cases with cavernous hemangiomas, and actually caused the approach to be modified in three cases. Instead of brain-stem incision at the level of maximum bulging, a different site was chosen because the facial colliculus was located at the maximum bulging site. In none of these cases did we observe complications relating to the seventh and the underlying sixth nerve resulting from incision into the brain stem. Access to the brain stem is a crucial step, with considerable risk for sixth and seventh cranial nerve function. Intermittent stimulation can be used to document functional integrity of the seventh and 12th nerves during removal of both intrinsic and extrinsic brain-stem lesions. Continuous recording of EMG activity may also be employed for monitoring.

In cases with neoplastic lesions infiltrating the floor of the fourth ventricle, localization of surface structures outside the area of infiltration encouraged the surgeon to proceed with complete tumor removal. In one patient with infiltrative papilloma, removal of the tumor from the lateral floor of the fourth ventricle resulted in severe transient spontaneous nystagmus due to irritation of vestibular nuclei.

Conjugate gaze palsies are at least as disabling for the patient as facial nerve paralysis. In order to protect motor areas responsible for conjugate eye movements, reliable identification of the abducens nucleus and nearby optomotoric structures is necessary. Identification has been achieved in our last two cases with visual control of motor effects resulting from stimulation at the facial colliculus. The close proximity of facial nerve fibers to the abducens nucleus illustrates the clinical importance of the colliculus.

The site of stimulation remains speculative. Postsynaptic axonal origin of the evoked motor responses can be assumed from stimulation parameters. As the motor thresholds corresponded with the distance of the investigated structures to the brain-stem surface, nuclei (12th nerve) and fibers (seventh nerve) can be regarded as the presumed site of stimulation. The selectivity of evoked responses at the side and site of stimulation excludes stimulation of root exit zones.

Identification of the facial colliculus and the hypoglossal triangle through selective stimulation and monitoring of EMG responses is a first step toward "brain-stem mapping," which can be helpful for surgery of intrinsic brain-stem lesions. This is particularly important in the absence of reliable anatomical landmarks within the fourth ventricle and with displacement of normal anatomy due to mass lesions.

Whether this mapping technique and EMG monitoring will actually be found valuable and will aid in the resection of particularly problematic lesions is questionable, and should be assessed by evaluation of larger patient series in this otherwise small percentage of tumor population. Both methods proved practical, reliable, and not time-consuming in the hands of neurosurgeons with neurophysiological training. The preliminary results are promising, as indicated by the high level of reproducibility and the functional outcome of monitored structures.

Advanced mapping, including monitoring of optomotoric function, might contribute further to the identification of a safe corridor into the brain stem, avoiding morbidity due to the surgical approach. Monitoring with intermittent stimulation and continuous recording of EMG activity during removal of a lesion could ensure functional integrity during the procedure. Both techniques could eventually add to more radical removal of intrinsic brain-stem lesions and tumors infiltrating the brain stem.

Acknowledgments

We thank G. Kraus, M.D., of the Department of Anesthesia and P. Thierapf, M.D., of the Department of Pathology for their collaboration. We also thank R. Laumer, M.D., for providing us with the data on Case 6.

References

3. Bullard DE, Makuchinas TT, Nashold BS Jr: The role of monopolar stimulation during computed-tomography-
Intraoperative identification of rhomboid fossa motor areas


Manuscript received November 6, 1992. Accepted in final form February 16, 1993.
Address reprint requests to: Christian Strauss, M.D., Department of Neurosurgery, University of Erlangen-Nuremberg Schwabachenlage 6, 91054 Erlangen, Germany.