Continuous intraoperative electromyographic monitoring of cranial nerves during resection of fourth ventricular tumors in children

Paul A. Grabb, M.D., A. Leland Albright, M.D., Robert J. Sclabassi, M.D., Ph.D., and Ian F. Pollack, M.D.

Division of Pediatric Neurosurgery, University of Alabama at Birmingham, The Children's Hospital of Alabama, Birmingham, Alabama; and Departments of Neurological Surgery and Pediatric Neurosurgery, University of Pittsburgh, The Children's Hospital of Pittsburgh, Pittsburgh, Pennsylvania

The authors reviewed the results of continuous intraoperative electromyographic (EMG) monitoring of muscles innervated by cranial nerves in 17 children whose preoperative imaging studies showed compression or infiltration of the fourth ventricular floor by tumor to determine how intraoperative EMG activity correlated with postoperative cranial nerve morbidity. Bilateral lateral rectus (sixth) and facial (seventh) nerve musculature were monitored in all children. Cranial nerve function was documented immediately postoperatively and at 1 year.

Of the 68 nerves monitored, nine new neuropathies occurred in six children (sixth nerve in four children and seventh nerve in five). In five new neuropathies, intraoperative EMG activity could be correlated in one of four sixth nerve injuries and four of five seventh nerve injuries. Electromyographic activity could not be correlated in four children with new neuropathies. Of 59 cranial nerves monitored that remained unchanged, 47 had no EMG activity. Twelve cranial nerves (three sixth nerves and nine seventh nerves) had EMG activity but no deficit. Of four children with lateral rectus EMG activity, three had new seventh nerve injuries.

Lateral rectus EMG activity did not predict postoperative abducens injury. The absence of lateral rectus EMG activity did not assure preserved abducens function postoperatively. Likely because of the close apposition of the intrapontine facial nerve to the abducens nucleus, lateral rectus EMG activity was highly predictive of seventh nerve injury. Although facial muscle EMG activity was not an absolute predictor of postoperative facial nerve dysfunction, the presence of facial muscle EMG activity was associated statistically with postoperative facial paresis. The absence of facial muscle EMG activity was rarely associated with facial nerve injury. The authors speculate that EMG activity in the facial muscles may have provided important intraoperative information to the surgeon so as to avoid facial nerve injury.

Key Words * abducens nerve * brainstem * facial nerve * tumor * electromyography * child

Fourth ventricular tumors in children are treated with the goal of complete surgical resection to effect a
cure or to optimize tumor control. Complete resection can be thwarted or made more treacherous by tumor invasion into the floor of the fourth ventricle. Despite tremendous advancements in neuroimaging, it is often difficult to determine the degree of brainstem involvement preoperatively. The degree of brainstem involvement can vary from only compression by tumor, to minor tumor adherence to the floor of the fourth ventricle, to frank brainstem invasion, to the intraoperative realization that the tumor is a dorsally exophytic brainstem lesion filling the fourth ventricle.

In children with tumors of the fourth ventricle with imaging suggestive of tumor abutting or invading the brainstem, we have routinely used neurophysiological monitoring to stay out of the brainstem and to minimize brainstem manipulation in an effort to reduce the risk of brainstem injury during tumor resection. Elegant microsurgical and neurophysiological techniques have been described with the purpose of safely operating within the brainstem by identifying "safe areas" for brainstem entry to resect intrinsic brainstem lesions.[1,3-5,8] The approach we used in our patients contrasts both technically and strategically with these recently discussed techniques. This report describes our experience in the resection of fourth ventricular tumors in children in whom we have used continuous electromyographic (cEMG) monitoring of the muscles innervated by the sixth and seventh cranial nerves so as to remain extrinsic to the brainstem and lessen the likelihood of brainstem injury. The purpose of this study is to correlate the results of cEMG monitoring in children during the resection of fourth ventricular tumors with postoperative cranial nerve function.

Clinical Material and Methods

Patient Population

During a 30-month period 17 children had preoperative imaging studies that were consistent with abutment of invasion of the fourth ventricular floor by a tumor within the fourth ventricle. Cerebellar tumors that distorted the fourth ventricle or brainstem but did not directly contact and compress the floor of the fourth ventricle were not included in this study. There were 10 boys and seven girls, ranging in age from 6 months to 16 years (median age 6 years) at the time of operation. Three children had a partial sixth nerve deficit and one had a partial seventh nerve deficit preoperatively. All children underwent operation in the prone "angulated Concorde" position and microsurgical techniques were used in each case. Four children underwent surgery for recurrent tumor; three of these four had initially undergone operation at other institutions.

Neuroanesthetic Techniques

We used neuroanesthetic techniques, such as narcotic and nitrous oxide administration or isoflurane anesthetic, that avoided the need for complete pharmacological muscle relaxation. Subdermal platinum needle electrodes were placed percutaneously in a bipolar configuration into the region of the orbicularis oculi, orbicularis oris, and mentalis muscles, and in the lateral rectus muscles bilaterally, and they were taped in place to the face in all children. An instrumentation rack containing an eight-channel switchable auditory monitor was used to listen for myogenic potential responses, either on all channels simultaneously or on any one of the channels individually. This technique provided immediate real-time feed-back to the surgeon that an EMG response had been induced, as well as specific information on which cranial nerve had been stimulated. No abnormal EMG activity was detected prior to the intradural dissection in any child. The neurophysiologist kept a written record of all EMG responses, what the surgeon was doing at the time of the EMG responses, and whether surgical techniques were altered because of the EMG responses. Electromyographic responses were graded as: 1) no activity, 2) irritation
activity, 3) injury activity, or 4) a "killed-end" response.[7] Irritation activity is a soft intermittent flutter consistent with working near the nerve or its nucleus. Injury activity is a continuous, nonaccelerating tapping that can indicate permanent nerve injury. A killed-end response is an accelerated firing pattern that unequivocally indicates nerve injury. Prass and Luders[6] have described the loudspeaker data obtained by EMG monitoring of the facial nerve during acoustic neuroma resection.

**Histopathological Diagnoses and Follow-up Care**

Histopathological diagnoses included seven ependymomas, six astrocytomas, and four medulloblastomas. Children were examined immediately (within 12 hours) after the operation for any new neurological deficits. All children received follow-up care in the neurosurgical clinic at The Children's Hospital of Pittsburgh for at least 1 year after the operation. Final cranial nerve assessments in all children were obtained at the 1-year follow-up visit; no child with a deficit had further cranial nerve improvement after 1 year. Immediate postoperative and 1-year cranial nerve function were graded as baseline, increased paresis, or palsy. Each child's immediate postoperative and 1-year cranial nerve function were correlated with the intraoperative cEMG findings.

Contingency tables were constructed to apply chi-square analysis to the following three null hypotheses: 1) sixth nerve EMG activity is not associated with postoperative abducens dysfunction; 2) seventh nerve EMG activity is not associated with postoperative facial paresis; and 3) sixth nerve EMG activity is not associated with postoperative facial paresis. The null hypotheses were rejected when probability values were less than 0.05.

**Results**

**Effect of cEMG Monitoring on Operative Technique**

When EMG activity was initiated, microsurgical efforts were immediately halted and a change in technique instituted. The initial EMG activity was most often from the seventh nerve. In only one case was sixth nerve activity encountered preceding seventh nerve activity. Common technique changes included working on a different region of tumor, reducing the settings on the continuous ultrasonic aspirator, reducing the bipolar cautery power, or abandoning bipolar cautery for other techniques of hemostasis or tumor removal. Also, if EMG activity was encountered unexpectedly by the surgeon because of the presumed anatomical region being manipulated, the dissection was halted and anatomical orientation was confirmed or corrected. In one case of an ependymoma that extended into the cerebellopontine angle through the foramen of Lushka, cEMG monitoring allowed both identification of the facial nerve during mechanical microsurgical manipulation of the tumor-nerve complex and anatomical and physiological preservation of the cisternal segment of the nerve embedded in tumor. Thus, any EMG activity may serve as a warning to the surgeon of possible manipulation of cranial nerve nuclei or tracts as well as a source of orientation should the normal fourth ventricular floor anatomy be hidden or distorted by tumor.

**Correlation of cEMG Activity and Cranial Nerve Function**

Of the 68 cranial nerves monitored, 17 nerve distributions in 12 children showed intraoperative cEMG activity graded as "irritation activity" in four lateral recti, and 13 facial nerve distributions. Two children showed bilateral facial cEMG activity. Three children had unilateral lateral rectus and facial cEMG activity. There was no EMG activity that was consistent with either "injury activity" or a "killed-end response." Four children with normal facial nerve function preoperatively had self-sustained EMG...
"irritation activity" within muscles supplied by the facial nerve, which continued after ceasing microsurgical manipulation. Two of these children had no new seventh nerve deficit, whereas the other two awoke with complete seventh nerve palsies.

Of the 68 cranial nerves monitored, nine new cranial neuropathies were documented in six children immediately after the operation (Table 1). There were four new sixth nerve injuries, and five new seventh nerve injuries. Two of four sixth nerve injuries and two of five seventh nerve injuries had improved at 1-year follow-up evaluation. Of these nine new cranial neuropathies, five had intraoperative EMG responses that correlated with new neurological deficits: one of four sixth nerve injuries and four of five seventh nerve injuries (Table 2). Of the nine new postoperative cranial neuropathies, four had shown no intraoperative EMG activity in three of four sixth nerve injuries and in one of five seventh nerve injuries.

Lateral rectus activity did not correlate with postoperative sixth nerve dysfunction (Table 3). In the four children with intraoperative lateral rectus activity, three had postoperative facial nerve dysfunction. Two of these three children with postoperative facial paresis had facial muscle EMG activity. Thus, the presence of sixth nerve EMG activity intraoperatively was a strong predictor of facial nerve dysfunction postoperatively (p less than 0.001). Of the 13 facial nerves displaying intraoperative EMG activity, only four had postoperative facial nerve dysfunction. Although facial EMG activity was not an absolute predictor of postoperative facial nerve dysfunction, the presence of facial EMG activity was associated statistically with postoperative facial paresis (p less than 0.010). The relatively low incidence of facial nerve dysfunction compared to the incidence of facial nerve EMG activity may relate to the change in surgical technique when the EMG response was induced, which prevented an injury.
DISCUSSION

The ability afforded by neurophysiological techniques to map brainstem cranial nerve nuclei and tracts can provide definitive localization of important structures which may result in reduced morbidity. Kyoshima, et al.,[4] described two "safe entry zones" based on anatomical landmarks: the suprafacial and infrafacial triangles. Because the brainstem is often distorted by the disease process, requiring neurosurgical attention, entering the brainstem based on anatomical landmarks alone may not prove to be the safest means of locating cranial nerve nuclei and tracts.

Katsuta, et al.,[3] described physiological localization of the facial colliculus by facial EMG monitoring and the use of a stimulating bipolar electrode on the floor of the fourth ventricle to enter the pons and remove a cavernous malformation without damaging the facial nerve. Strauss, et al.,[8] reported on 10 patients with intrinsic brainstem lesions in whom the fourth ventricular floor was mapped for the facial colliculus and hypoglossal trigone to aid in safe brainstem entry. In only two patients did they perform cEMG monitoring. In these two patients the authors noted increasing EMG activity as they approached either the facial colliculus or hypoglossal trigone. In both cases transient cranial nerve morbidity occurred. They did not comment on whether the cEMG activity influenced their microsurgical technique.

Morota, et al.,[5] used brainstem mapping of the seventh, ninth to 10th, and 12th nerves by evoking responses with a handheld monopolar stimulator to resect intrinsic brainstem tumors; however, they did not use cEMG monitoring. Their study showed poor correlation with the intraoperative ability to stimulate a specific nerve and its postoperative function. Eisner, et al.,[1] reported their experience with cEMG monitoring of motor cranial nerves in primarily intrinsic brainstem lesions in 15 adults and one child. Only three of their patients had lesions described as having a fourth ventricular component; thus, they used this technique to operate primarily within the brainstem rather than to stay out of it. A technique similar to ours was used: this consisted of broadcasting the EMG activity over a loudspeaker to provide instantaneous feedback to the surgeon. They graded the evoked EMG activity as short duration "contact activity," or "pathological spontaneous activity" of three degrees: slight, strong temporary, and strong persistent. The authors stated that it was not their intent to "analyze the relationship among severity of EMG activity, any surgical manipulation, and the postoperative deficit."[1 ]

In contrast to the above mentioned reports in which monitoring was used to assist in the resection of intraaxial tumors, we used cEMG monitoring to facilitate the resection of fourth ventricular tumors with possible brainstem involvement in the children discussed in this report. The purpose of using cEMG monitoring in these children was to aid in avoiding injury to cranial nerve motor nuclei and tracts by staying out of the brainstem and avoiding inadvertent brainstem manipulation during resection of fourth ventricular tumors. Although our experience by no means proves that cEMG monitoring lessens the morbidity of radically resecting these tumors, we believe that it provides useful intraoperative

<table>
<thead>
<tr>
<th>Null Hypothesis</th>
<th>p Value</th>
<th>Accepted or Rejected</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI EMG activity is not associated with postop VI paresis</td>
<td>&gt; 0.25</td>
<td>accepted</td>
</tr>
<tr>
<td>VII EMG activity is not associated with postop VII paresis</td>
<td>&lt; 0.010</td>
<td>rejected</td>
</tr>
<tr>
<td>VII EMG activity is not associated with postop VII paresis</td>
<td>&lt; 0.001</td>
<td>rejected</td>
</tr>
</tbody>
</table>
In regard to correlating postoperative abducens nerve function and cEMG activity, only one of four abducens palsies had correlative lateral rectus EMG activity. There was no associated facial muscle EMG activity. Sixth nerve injury in these three children without correlative EMG activity may have occurred remote from the abducens nucleus and, therefore, was not represented by EMG activity during tumor resection. Support for this contention is the vulnerability of the sixth nerve to injury from neural traction secondary to cerebrospinal fluid and brainstem shifts, which undoubtedly occurred in these children with large compressive tumors and hydrocephalus. Two children had resolution of their abducens paresis over the period of a few months, which would not be expected with a nuclear injury. In addition, there was no associated binocular gaze paresis as would be expected from a direct injury to the abducens nucleus and contiguous paramedian pontine reticular formation. Intraoperative cEMG monitoring of the lateral rectus, therefore, was not a sensitive detector of intraoperative sixth nerve morbidity, possibly because the sixth nerve injury was remote in time and place from the tumor resection. Three children had lateral rectus EMG activity and no postoperative sixth nerve deficit; therefore, lateral rectus EMG activity did not predict postoperative sixth nerve dysfunction. The occurrence of intraoperative sixth nerve EMG activity, however, was a strong predictor of postoperative facial paresis, as three of the four children with lateral rectus EMG activity had a postoperative facial paresis. Because the intrapontine facial nerve wraps around the abducens nucleus, it is somewhat intuitive that to "irritate" the abducens nucleus requires transmitting a force across the facial nerve at the level of the colliculus. Hence, cEMG activity of the lateral rectus may serve to indicate that the surgeon is manipulating the brainstem proper and that facial nerve injury already may have occurred.

In regard to correlating postoperative facial nerve function and EMG activity, four of the five postoperative facial nerve injuries had correlative EMG activity. Nine facial nerves had EMG activity with no evidence of facial nerve injury postoperatively; thus, although facial EMG activity was associated statistically with postoperative facial paresis, the EMG activity did not absolutely predict postoperative facial paresis. Four children had self-sustained EMG activity from the facial nerve well after surgical manipulation was halted. Two of these children awoke with normal facial function and two awoke with permanent facial palsies. Hence, the seemingly more concerning presence of self-sustained EMG activity was not a strong predictor of postoperative facial nerve dysfunction. In all cases of EMG activity of the facial nerve, operative strategies were affected. The relatively low incidence of facial nerve paresis (five patients) compared to the incidence of facial EMG activity (13 patients) may relate to the change in microsurgical strategies or techniques prompted by the facial EMG activity. Electromyographic activity of the facial nerve may have provided a warning to the surgeon that the facial nerve was being manipulated before the threshold for injury was reached, which allowed the surgeon to prophylactically alter the operative technique. Of concern was one child who had no intraoperative facial EMG activity but who awoke with a transient facial paresis (House-Brackmann Grade III).[2] In this child the presence of lateral rectus EMG activity signaled to the surgeon that brainstem structures were being manipulated. Thus, although EMG activity from the sixth nerve may be an indication that facial nerve damage has already occurred, cEMG monitoring of the facial nerve may help to avoid injury to the facial nerve.

CONCLUSIONS

In the resection of fourth ventricular tumors with brainstem involvement in children, EMG monitoring of muscles innervated by cranial nerves six and seven provided the following cliniconeurophysiological
correlation: 1) lateral rectus EMG activity did not correlate with postoperative abducens palsy; 2) the absence of lateral rectus EMG activity did not assure normal postoperative abducens function; 3) facial muscle EMG activity was sensitive to facial nerve injury; 4) the absence of facial muscle EMG activity was rarely associated (one case) with facial nerve injury; and 5) facial paresis was most strongly predicted by lateral rectus EMG activity.

Although the data indicate that cEMG monitoring offers useful intraoperative information, particularly in favor of preserving seventh nerve function, it is impossible to "prove" that cEMG monitoring enhanced operative safety and facilitated aggressive tumor removal. Centers that have expertise in such monitoring techniques are in the best position to accrue neurophysiological and clinical data in a prospective manner so as to define the benefits of this technique.

References


Manuscript received June 18, 1996.

Accepted in final form July 16, 1996.

Address reprint requests to: Paul A. Grabb, M.D., Division of Pediatric Neurosurgery, ACC 400, The Children's Hospital of Alabama, 1600 Seventh Avenue South, Birmingham, Alabama 35233.