Continuous electromyography monitoring of motor cranial nerves during cerebellopontine angle surgery

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Object. Electromyography (EMG) monitoring is expected to reduce the incidence of motor cranial nerve deficits in cerebellopontine angle surgery. The aim of this study was to provide a detailed analysis of intraoperative EMG phenomena with respect to their surgical significance.

Methods. Using a system that continuously records facial and lower cranial nerve EMG signals during the entire operative procedure, the authors examined 30 patients undergoing surgery on acoustic neuroma (24 patients) or meningioma (six patients). Free-running EMG signals were recorded from muscles targeted by the facial, trigeminal, and lower cranial nerves, and were analyzed off-line with respect to waveform characteristics, frequencies, and amplitudes. Intraoperative measurements were correlated with typical surgical maneuvers and postoperative outcomes.

Characteristic EMG discharges were obtained: spikes and bursts were recorded immediately following the direct manipulation of a dissecting instrument near the cranial nerve, but also during periods when the nerve had not yet been exposed. Bursts could be precisely attributed to contact activity. Three distinct types of trains were identified: A, B, and C trains. Whereas B and C trains are irrelevant with respect to postoperative outcome, the A train—a sinusoidal, symmetrical sequence of high-frequency and low-amplitude signals—was observed in 19 patients and could be well correlated with additional postoperative facial nerve paresis (in 18 patients).

Conclusions. It could be demonstrated that the occurrence of A trains is a highly reliable predictor for postoperative facial palsy. Although some degree of functional worsening is to be expected postoperatively, there is a good chance of avoiding major deficits by warning the surgeon early. Continuous EMG monitoring is superior to electrical nerve stimulation or acoustic loudspeaker monitoring alone. The detailed analysis of EMG-waveform characteristics is able to provide more accurate warning criteria during surgery.

KEY WORDS • electromyography • cranial nerve • cerebellopontine angle • monitoring • waveform pattern

The surgical management of large posterior fossa lesions aims at complete removal of the tumor with functional preservation of cranial nerves.\(^1,2,16\) In cases of extended skull base lesions, avoidance of disfiguring facial nerve weakness is desirable; however, the integrity of the ninth, 10th, and 12th cranial nerves is essential to life if the patient suffers from the postoperative disorders of swallowing and aspiration.

Intraoperative electrophysiological monitoring was developed to reduce the incidence of postoperative morbidity.\(^1,3,3,6,21,23,27\) In surgery for acoustic neuromas, EMG neuromonitoring has become a routine tool used to identify and protect the seventh cranial nerve; however, additional postoperative facial paresis has been reported in 10 to 27% of cases, especially following excision of large tumors.\(^7,18,19,28,29,31\) The rate of anatomical and functional preservation of the facial nerve was significantly lower in the era before standard EMG monitoring was applied routinely.\(^10,29\)

Electrical stimulation of the facial nerve during removal of large acoustic neuromas has been widely used for longer than 20 years.\(^3,23,30\) One of its purposes is to identify facial nerve fibers directly or to detect areas on the tumor surface at which dissection can be performed with no risk of sacrificing portions of the flattened nerve bundle. A second purpose involves intermittent stimulation, which reassures the surgeon that the nerve has been preserved distal to the stimulation site at a given time. To monitor the facial nerve continuously during ongoing dissection, EMG responses were made audible\(^4,26\) and three major acoustic patterns (bursts, trains, and pulses) were defined and related to their causative mechanisms and postoperative clinical outcomes.\(^15,25,26\)

Although the benefit of using these standard techniques is obvious, there are several disadvantages. In surgery for large acoustic tumors (> 25 mm), the use of electrical nerve stimulation is limited during the early steps of dissection. According to individual tumor growth patterns, the facial nerve cannot be stimulated across the lesion near the brainstem exit zone, which is inaccessible to the stimulating probe during dissection of a dorsal tumor capsule and during intracapsular removal. In acoustic nerve monitoring, the unwanted effects of cerebellar retraction, bipolar coagulation, and mechanical irritation of the nerve have been clearly delineated;\(^3,20,21\) analogous effects on the facial nerve must be suspected.

Acoustic loudspeaker monitoring was introduced to provide an easy-to-use procedure for continuous intraop-
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Corrective monitoring; it assumes that any kind of so-called “train activity” or “neurotonic discharge” that is audible during dissection indicates possible harm to the nerve. Although a variety of EMG patterns have been demonstrated, all previous studies were based on the EMG sounds and occasional monitor screen views of representative waveforms only. The aim of this prospective study was to perform a detailed analysis of EMG waveform patterns spontaneously arising during the ongoing operation, in relation to surgical maneuvers and postoperative clinical findings. Continuous recording and evaluation of EMG activity during the entire surgical procedure was performed to define qualitative and quantitative criteria that may warn the surgeon of possible nerve damage.

Clinical Material and Methods

Patient Population

Following a prospective study protocol, we monitored a consecutive series of 30 patients (13 women and 17 men) undergoing surgery on CPA tumors larger than 1 cm in extrameatal diameter. The patients underwent surgery for either acoustic neuroma (24 patients) or meningioma (six patients) via the lateral suboccipital approach. The mean age of the patients was 54.2 years (range 28–78 years). All patients underwent magnetic resonance imaging preoperatively, as well as 3 and 12 months postoperatively. The extrameatal tumor averaged 2.8 cm in diameter, with a range from 1.2 to 5.5 cm. Neurological and otological examinations were performed before surgery, as well as 1 week and 1 year postoperatively. The House–Brackmann grading system was used to determine facial nerve function. Preoperatively, in 21 of the 30 patients normal cranial nerve function was displayed, excluding hypacusis, and in nine patients facial nerve weakness (House–Brackmann Grade II or III) was demonstrated with or without additional motor cranial nerve deficits.

Anesthesia and Recording Procedure

Total intravenous anesthesia was induced in all patients. Following induction of anesthesia with midazolam, nitrous oxide, and a short-acting nondepolarizing muscle relaxant (atracurium besylate), the endotracheal tube was inserted and a pair of noninsulated monopolar steel-needle electrodes (length 12 mm, 26 gauge) was placed into the pharyngeal wall, the soft palate, and the genioglossal muscle to monitor the ninth, 10th, and 12th cranial nerves. After the patient had been placed in position, noninsulated 30-mm-long needle electrodes (25 gauge) were placed into the lateral orbicular muscle of the eye, the nasal muscle, and the orbicular muscle of the mouth (representing the three major branches of the peripheral facial nerve) to pick up EMG signals from the face. For all recordings one monopolar needle electrode served as the anode and one as the cathode; they were inserted into the muscle, parallel to each other at a distance of 10 mm, and cables were taped to the patient’s cheek to avoid their dislocation. Selective monitoring of the motor portion of the fifth cranial nerve was obtained using 25-gauge teflon-insulated electrodes that were 20 mm long with 3 mm of the tip exposed. The electrodes were inserted perpendicularly into the masseter muscle. The abducent nerve’s target muscle (the lateral rectus muscle) was examined using 20-mm uninsulated needle electrodes, which were inserted laterally to the eyeball into the orbit. One channel was used to record the EMG signals of the orbicular muscle of the mouth on the contralateral side in five patients; in the other 25 patients this channel served to pick up electrocardiography signals. Following electrode placement, muscle relaxants were avoided and anesthesia was maintained using Propofol (6–12 mg/kg/hr) and alfentanil hydrochloride (60 µg/kg/hr) until skin closure. The acoustic nerve was monitored using brainstem auditory evoked potentials in patients presenting with any degree of perceptible hearing that had been measured using pure-tone audiometry before surgery.

The modular recording system consisted of an eight-channel bioamplifier (Jaeger-Toennies GmbH, Hoechberg, Germany), a switchboard, and a personal computer with two 12-bit analog–digital conversion boards (DT2814; Data Translation, Inc., Marlboro, MA). Analog filter settings of 2 Hz to 4 kHz were used without a notch filter. A Modula-2 program was developed for the computer to perform data processing at a sampling rate of 8.5 kHz/channel, digital antialiasing filtering, and continuous data display and storage on hard disks. Recordings and storage started immediately after the patient was placed in position and ended with skin closure.

Waveforms could be displayed on the computer monitor with a variable time base of 10 msec/division to 120 seconds/division and were stored on a tape streamer for off-line analysis. Each single channel and any combination of channels could be selected for acoustic loudspeaker monitoring. No mute sensors or artifact rejection systems were used, and all waveforms were recorded including noise from any artifact sources, for example, bipolar cautery. The ongoing surgical procedure was recorded on videotape that was time locked with the waveform recordings, and comments on specific surgical events were noted routinely.

Electrical nerve stimulation was performed repeatedly by using a hand-held concentric bipolar probe (Inomed GmbH, Teningen, Germany) connected to a constant-current stimulator (Neurosign 100; Magstim Co., Ltd., Whitland, UK). Stimulation intensity was selected between 0.05 mA and 0.5 mA with a pulse width of 200 µsec and a stimulus frequency of 30 Hz.

Statistical Analysis

One of the authors was present during each monitoring session to detect and categorize any spontaneously arising EMG activity. Artifacts were immediately correlated with specific maneuvers, for example, movement of cables or the use of electrocautery and ultrasonic aspiration. Data files were evaluated quantitatively, as an off-line analysis, by continuously scrolling through the entire recording session and displaying eight simultaneously recorded waveforms on the computer monitor. An off-line horizontal sweep time of traces was set to 50% of the original on-line oscillographic display. Software tools for automatic detection of EMG potentials were strictly avoided because of the unwanted effect of possibly excluding subthreshold activity from the raw EMG data. Any EMG phenomena recorded from the cranial nerves’ targeted muscles were
with one large peak. In some patients, thousands of spikes mainly arising from exhibiting an almost uniform appearance in one channel. Spikes abruptly arise from and decline to baseline, per.

FIG. 1. Electromyographic tracings. Spikes (upper) and bursts (lower) are the basic components of the intraoperative EMG signals. They are either elicited by direct nerve contact or arise spontaneously at any time during surgery. Expanding the horizontal time axis from 100 msec/division (center) to 20 msec/division (right) reveals typical triphasic and polyphasic waveform patterns.

Patterns of Trains

The term “train” was introduced for sustained periodic EMG activity that lasts for seconds. Three typical train patterns with specific rhythmic features were observed.

The A Train. The A train is a distinct EMG waveform of sinusoidal pattern that produces a high-frequency sound from the loudspeaker. It always started suddenly and had typical maximum amplitudes ranging from 100 to 200 μV and never exceeding 500 μV. Off-line measurement of frequency showed a range of 60 to 210 Hz, and the A train duration varied between milliseconds and several seconds (Fig. 2 left). We repeatedly recorded A trains of short duration with a more or less rhythmic sequence.

The B Train. This regular or irregular sequence of single components with maximum intervals of 500 msec lasted up to several minutes or even hours. According to their predominant components, a B train with spikes and a B train with bursts could be distinguished (Fig. 2 right [B]). The onset of these trains was gradual, usually being introduced by isolated spikes and bursts of low amplitude.

The C Train. The C train is characterized by continuous irregular EMG activity that is composed of numerous overlapping components (Fig. 2 right [C]). Amplitudes are distributed accidentally around the baseline, ranging from 20 to more than 5000 μV.

Electromyography Activity During CPA Surgery

Both spikes and bursts were encountered immediately following the direct manipulation of a dissecting instrument close to the cranial nerves. Contact activity of large bursts (> 500 μV) typically was seen in the pharyngeal and mimetic muscles when arachnoidal planes between the tumor and the corresponding nerve were separated. Another event causing mechanically evoked bursts was drilling and decompressing of the internal auditory canal during acoustic neuroma removal. These bursts provided additional feedback information to the surgeon during dissection along the nerve fibers. During this period of surgery, direct electrical nerve stimulation with minimum intensity (0.05 mA) was performed repeatedly not only to ensure that the nerve remained intact but also to find out to what extent the nerve bundle was flattened or even split. Spikes and small bursts (< 500 μV) were recorded throughout surgery, even when the nerves had not yet been exposed, such as when cerebellar retraction or intracapsular tumor removal was performed. Both spikes and bursts were encountered during craniotomy and wound closure, as well as on the contralateral side in two patients. This spontaneous activity could not be predicted or correlated to specific surgical maneuvers; however, there was the mimetic muscles were counted during operations that lasted several hours.

Bursts represent an isolated complex of superimposed spikes having spindlelike shapes (Fig. 1 lower). The duration from the more gradual onset of the bursts to the decline is much longer than that found in spikes and lasts up to several hundred milliseconds. Usually bursts exhibit several prominent peaks extending up to 5000 μV of amplitude and, on the whole, they occur less frequently than spikes.

Results

It was possible to obtain multichannel recordings in all patients without adverse effects or complications. Equipment setup and positioning of the electrodes typically took 15 to 20 minutes before skin incision. The surgeon was not impeded at any time; he was informed about EMG activity either by listening to background sounds emitting from the loudspeaker or by the monitoring staff. Although artifact suppression devices were avoided, physiological EMG potentials were easily distinguished from noise, which exhibited typical electrical characteristics (for example, high-amplitude activity from electrocautery and high-frequency, low-amplitude waveforms observed during ultrasonic surgical aspiration). There was no interference with brainstem auditory evoked potential monitoring.

Electromyographic activities revealed a wide range of amplitudes, at most reaching 5000 μV. The lowest potentials that were clearly identified as physiological activity displayed 20 μV of amplitude, which typically was twice the voltage of the background noise.

Prass and Lüders introduced the terms “spike,” “burst,” and “train” to describe spontaneous facial activity as registered by EMG. Based on this nomenclature, five typical EMG waveform patterns could be classified: spikes, bursts, and A, B, and C trains.

Spikes and Bursts

Spikes are clearly defined bi- or triphasic potentials with one large peak (≤ 2000 μV of amplitude; Fig. 1 upper). Spikes abruptly arise from and decline to baseline, exhibiting an almost uniform appearance in one channel. In some patients, thousands of spikes mainly arising from
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![EMG Waveform Patterns](image)

**Fig. 2.** Electromyographic train activity. Left: Examples of A trains of various duration and frequency. The upper tracings show the abrupt onset and termination (arrows) of this sinusoidal waveform pattern, which lasted 1600 msec. The fourth train from the top of the figure shows repeated short-term periods of activity, ranging in duration from 100 to 120 msec each. The lower A train, which was simultaneously recorded from two facial muscle groups, gives an impression of frequency variability between 120 Hz and 190 Hz. Right: Waveforms defined as B trains with spikes (B_s) and B trains with bursts (B_b) as predominant single components. The black and white arrows mark two individual B trains with spikes of higher and lower amplitudes recorded in the same channel. The lowest tracing represents irregular EMG activity, called a C train.

A tendency for sporadic spikes and bursts to develop gradually into a B train or a C train while possibly painful surgical steps were performed, such as cutting of the periosteum and stitching of the skin. The B trains could be recorded in any of the muscles under examination, whereas the C trains arose exclusively from pharyngeal muscles targeted by the glossopharyngeal and vagus nerves.

In contrast with spikes, bursts, and B and C trains, an A train was not observed in any patient before tumor dissection was performed in the immediate proximity of the facial nerve. The first emergence of an A train during the surgical procedure could always be correlated with certain surgical activities, mainly dissection of large tumors near the brainstem surface and intrameatal decompression. After the first A train had been elicited, usually a series of spontaneously arising A trains followed, even if surgery was stopped for a while or was continued at a distant site. In some patients this phenomenon of repeated A train activity was recorded until the dura was closed, but not longer.

The A trains were seen exclusively in the mimetic muscles, except in two patients. In one of them this activity occurred in the masseter muscle without clinical consequences. In contrast to B and C trains, which were the prominent waveform patterns in pharyngeal muscles, A trains were obtained in the lower cranial nerves’ targeted muscles in only one patient.

**Correlation of EMG Waveform Patterns and Surgical Outcome**

**Clinical Results.** Figure 3 summarizes the surgical results of facial nerve function in 30 patients who underwent surgery for tumors of the CPA. Of the six patients treated for CPA meningiomas, only one patient experienced mild weakness of the orbicular muscle of the mouth postoperatively, with complete recovery after 1 year.

Of the 24 patients with acoustic neuromas, four patients kept their preoperative status and eight patients had mild weakness of the mimetic muscles 1 week after surgery, dropping one grade in the House–Brackmann system. At the follow-up examination performed 1 year later, seven of these patients had regained their preoperative status and only one patient who had deteriorated from Grade II to Grade III postsurgery continued to have Grade III paresis. Five patients dropped two grades, four patients three, and three patients four House–Brackmann grades postoperatively. All of these patients experienced a secondary functional improvement of one or two grades after 1 year, except one patient who had harbored a large acoustic neuroma 4.5 cm in extrameatal diameter. That patient had presented with a Grade III paresis preoperatively and had a Grade VI paresis immediately after surgery. Because he displayed no tendency to recover, this patient required surgical correction of lagophthalmia.

Figure 3 demonstrates that the incidence of postoperative facial nerve paresis was highly correlated with preoperative clinical findings. Nine patients were admitted with a Grade II or III facial weakness, and this worsened in eight of them to some degree postoperatively. Seven patients had tumors measuring 35 mm or more in extrameatal diameter; in six of them the mimetic muscles displayed additional postoperative weakness.

No additional postoperative deficits were seen in the motor portion of the trigeminal nerve or the abducent nerve. During removal of a large cystic acoustic neuroma (4.5 × 5 cm) that extended into the lower CPA, an A train was recorded from the pharyngeal muscles. Postoperatively, a slight and reversible paresis of the ipsilateral palatal velum was demonstrated in this patient.
Results of the chi-square test were highly significant ($\chi^2 = 14.6, p < 0.001$), suggesting that the presence of A trains reliably indicates additional postoperative facial nerve paresis.

Figure 5 provides illustrative examples of intraoperative events. The upper waveforms (Fig. 5I), which were recorded from the orbicular muscle of the mouth in a 57-year-old patient, produced some low-amplitude B-train activity that lasted for 3 minutes. Following intracapsular tumor decompression and dissection of the arachnoidal plane near the inner auditory canal, the facial nerve was identified easily by direct electrical stimulation (black arrows). Several minutes later, bleeding from a small vessel on the surface of the tumor capsule required electrocautery. When the artifact produced by bipolar coagulation disappeared, the facial EMG signal remained flat and silent until the end of surgery. The next attempt to stimulate the facial nerve proximal to the site of bipolar coagulation was futile (white arrows). Postoperatively, the patient’s preoperative facial paresis, which had been
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House–Brackmann Grade III, worsened to a paralysis of Grade VI. One year later, only an incomplete recovery to Grade IV had been achieved. It is obvious that the facial nerve was injured indirectly by electrocautery.

The lower tracings (Fig. 5I) were recorded from the nasal muscle in a 34-year-old patient during surgery for a medium-sized (28-mm) acoustic neuroma. The waveforms remained flat until electrical stimulation (0.2 mA) of the facial nerve (black arrow) was performed for localizing purposes. Instantly this resulted in A-train activity (triangle), which was scarcely audible via the loudspeaker because of the masking effect of the stimulus artifacts. Dissection was stopped and continued at a remote site. Mild additional paresis was displayed postoperatively (deteriorating from Grade I to Grade II), but the patient recovered completely within 3 months. These tracings demonstrate silent EMG events observed in two typical situations: in one case the nerve was severely damaged and in the other it remained almost intact.

Discussion

Intraoperative motor cranial nerve monitoring has three major goals. 1) The risk of nerve injury is minimized if immediate online feedback on the nerve’s functional status is available. In the case of a monitoring event, the surgeon is able to adapt and refine his microsurgical procedure before functional deterioration has become irreversible. 2) The anatomical course of cranial nerves close to a space-occupying tumor must be identified at the earliest possible moment. Information about the degree of flattening of the nerve bundle and splitting into isolated fiber portions is crucial. 3) A prognostic statement on the anatomical and functional integrity of the cranial nerve is desirable to plan additional therapeutic strategies, such as administration of vasoactive medication during the early postoperative period.

Direct electrical stimulation of motor cranial nerves has become a standard adjunct to skull base surgery. It has proved to be extremely useful to identify nerve structures and to reassure the surgeon that the nerve is still intact at a given time. However, its practical value is limited because it can only be used intermittently and because nerves covered by large tumor masses cannot be stimulated at all. Prass and colleagues introduced EMG loudspeaker monitoring as an approach to monitor the facial nerve continuously. They described several typical sounds that warn the operative team of possible nerve injury (for example, “bomber potentials” and “popcorn activity”). Data shown on the screen of the oscilloscope were printed whenever EMG activity was audible. Prass and Läders distinguished two major waveform patterns, bursts (synchronous, nonrepetitive discharges) and trains (variable, repetitive discharges). They explained the presence of bursts mainly by citing mechanical contact activity, but multiple other mechanisms of elicitation were assumed, such as free irrigation with Ringer’s solution. Trains were seen most commonly following facial nerve traction, but also following direct mechanical trauma, irrigation, or electrocautery of the tumor capsule. Typically, the onset of trains was not elicited immediately, but with some variable delay.

Equally Eisner, et al., found spontaneously arising EMG activity during brainstem surgery. Following Prass and colleagues’ terminology of trains and bursts, Eisner, et al., distinguished between “contact activity” and...
“pathological spontaneous activity (PSA).” On the basis of the oscillographic display and the sounds, they gave an impression of the extent of EMG activity by using terms such as “some contact activity,” “short-duration PSA,” “strong EMG activity,” or “extreme PSA.” They found that in their series of 16 patients a silent EMG signal indicated normal postoperative neurological function.

Harner and colleagues\textsuperscript{8,10} statistically examined the benefit of continuous EMG monitoring during removal of acoustic neuromas by using 48 matched pairs of patients with and without monitoring. Although no difference was seen in facial nerve function immediately after surgery, better functional outcome was revealed in the monitored group after 3 months. Harner and coworkers\textsuperscript{8,10} described fibrillation, motor unit, and myokymic potentials that must be distinguished from neurotonic discharges. A strong correlation between the extent of neurotonic discharges and surgical outcome was found. These waveforms were characterized as “uniform triphasic potentials of less than 30 ms duration, firing irregularly in bursts with interpotential intervals of 5 to 20 ms.”\textsuperscript{10}

A multiplicity of waveforms has been described so far. This may be due to different recording methods. Noninsulated\textsuperscript{4,23} and partially insulated\textsuperscript{4} needle electrodes were used, as well as wire-hook electrodes\textsuperscript{8,11,26} that were inserted into different muscles. With the exception of recordings of the masseter muscle, bare-needle electrodes separated by a distance of 5 to 10 mm seem to be superior, because they cover a large number of motor units within the volume-conducting muscle. Using multichannel recordings from at least three facial muscles, sensitivity and specificity will be optimized.

In this study eight channels of EMG potentials were recorded, stored, and analyzed for several hours. Numerous spikes, bursts, B trains, and C trains were obtained between skin incision and dura opening, although direct mechanical irritation of the nerve had not occurred. As this showed no correlation with postoperative functional deficits, it becomes evident that this type of EMG activity is widespread and irrelevant for monitoring purposes. These waveform patterns occasionally were obtained at rather high amplitudes, and thus the shear estimation that any kind of strong EMG activity represents pathological effects cannot be supported.

Because the significance of the EMG potentials was not related to their amplitudes, the main criterion of continuous motor cranial nerve monitoring is waveform pattern. It could be demonstrated that the A train represents a characteristic type of muscle activity highly correlated with additional postoperative motor deficits. Because its amplitude may be rather low, it might easily be missed when using conventional monitoring equipment. In a multichannel setup it is especially difficult to detect A trains when they underlie simultaneously arising harmless activity from other channels, if only acoustic loudspeaker monitoring is used. At present it is necessary to check both the various sounds and the oscillographic display at sufficient horizontal sweep times of less than 500 msec.

The nomenclature of intraoperative spontaneous EMG activity has not yet been standardized. Intraoperative EMG monitoring and recording of spontaneous discharges at rest in a conventional setup cannot be compared directly. Two monopolar needles are inserted into the muscle for intraoperative measurements, whereas bipolar concentric needle electrodes are commonly used for examination of diseases of nerve and muscle in the awake patient. It is obvious that recruitment and interference potentials following voluntary muscle contraction and insertion activity cannot be studied when the patient is in a state of general anesthesia.

Diagnostic EMG studies in clinical neurology distinguish between neuropathic and myopathic patterns. Harner, et al.,\textsuperscript{7} found preoperative EMG abnormalities in 78% of patients with acoustic neuromas. Because our intraoperative recordings did not reveal any difference between patients suffering from preoperative motor paresis and those who were not, some of our patients might have undergone slight degrees of denervation processes previously.

It is well known that muscle fibers produce spontaneous activity several days after denervation but not instantly. Thus, the term “spontaneous activity” should be used carefully when conventional and intraoperative EMG patterns are studied. Strictly speaking, bursts that follow mechanical irritation of the motor cranial nerve during surgery do not arise spontaneously. Thus they should be compared with electrically evoked compound-muscle-action potentials. However, they also were recorded without any mechanical or electrical stimuli during craniotomy. Repeated burst activity was called a B train; morphologically, it is similar to myokymic discharges, but the pathophysiological mechanism underlying this pattern is not clear. Similarly, we question why potentials we called a C train look like an interference pattern during maximum voluntary muscle contraction, although patients remained in deep steady-state anesthesia.

The A train, a series of high-frequency discharges with abrupt onset and termination, is highly suggestive of complex repetitive discharges that are defined as a continuous train of uniform spikes at a regular frequency of up to 150 Hz.\textsuperscript{13,17} They are found in chronic denervation processes and myopathies, and single-fiber EMG studies have shown that they are initiated by a spontaneously fibrillating muscle fiber that activates several adjacent muscle fibers. One of them ephatically reactivates the principal pacemaker fiber. Although complex repetitive discharges are not expected after acute denervation, the mechanism of ephatic spread of discharges would be plausible for surgical dissection close to a motor cranial nerve. If a small portion of the nerve bundle has been injured, muscle fibers of the corresponding motor units might become unstable and serve as a principal pacemaker because they are no longer under neural control.\textsuperscript{17} This is supported by our findings. The A train indicates additional paresis irrespective of clinical severity; once initiated, it is recorded repeatedly, and the maximum degree of paresis is not necessarily seen in the muscle fibers from which the A train was recorded.

Although the A train was extremely specific and sensitive in indicating facial nerve irritation, one false-positive and three false-negative results of monitoring were seen. One might suppose that the patient in whom an A train is recorded but no additional facial weakness is present might have suffered slight facial nerve injury during surgery that was not sufficient to produce a neurological deficit. In three patients a motor paresis was not indicated by...
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A trains. They may possibly have been missed because of occasional low amplitudes and an accidental distribution among the three facial muscle groups.

Conclusions
Continuous EMG monitoring of motor cranial nerves is a helpful adjunct to CPA surgery.\textsuperscript{10,11,22} In contrast to conventional loudspeaker monitoring, this study demonstrates that EMG activity may be harmless, as in the case of spikes, bursts, B trains, and C trains, or highly predictive of additional postoperative morbidity, as in the case of A trains. It could be shown that waveform pattern definition is crucial, whereas amplitude, duration, and frequency of EMG potentials are irrelevant. The definition of physiological and pathological EMG patterns provides the basis for automatic monitoring systems by using pattern-recognition algorithms.

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