Intraoperative Cranial Nerve Monitoring During Posterior Skull Base Surgery

Abstract—Intraoperative monitoring of neurophysiologic function is rapidly evolving as an important adjunct during skull base surgery to reduce the incidence of neurologic deficit. Facial nerve monitoring is an excellent model, since electrical and mechanical evoked potentials can be directly presented to the surgeon in real-time through an acoustic loudspeaker display. The lower cranial nerves may also be monitored using similar electromyographic techniques. Auditory system monitoring is more difficult due to the low amplitude response that requires averaging and filtering to extract the evoked potential. In conjunction with auditory monitoring, improved hearing preservation may be further enhanced by concomitant facial nerve monitoring, since the surgeon is alerted to traumatic manipulations that may affect both facial and cochlear nerves. Techniques and interpretative issues are presented to maximize the efficacy and safety of cranial nerve monitoring.

Neurologic deficits, once considered routine in removing lesions of the skull base, are being reduced with the advent of intraoperative neurophysiologic monitoring (IOM). The purpose of IOM is to alert the surgeon to ongoing changes in neural function. The surgeon must then determine whether these changes should result in an operative modification. IOM can aid the surgeon in: (1) identifying the neural structure at risk, (2) enhancing neural preservation by minimizing trauma, and (3) assessing neural integrity after dissection is complete.

INTRAOPERATIVE FACIAL NERVE MONITORING

Preserving facial nerve integrity and function has become a priority in skull base surgery.¹⁻¹⁴ A variety of intraoperative techniques, including visual observation (Gantz⁸), motion transducers (Sugita and Kobayashi⁹ and Silverstein et al¹⁰), and electromyographic (EMG) monitoring^{1,4,5,6} have been used to assess facial function. We

favor the EMG technique because it is the most sensitive detector of minute, subclinical responses and because it minimizes the possibility of trigeminal nerve artifacts that can occur with motion detector-based systems.⁷ EMG responses can be monitored on an oscilloscope and, more importantly, can also be presented through a loudspeaker, allowing the surgeon direct, ongoing feedback (Moller and Jannetta¹). We currently use a dedicated two-channel device with circuitry that reduces cautery artifact (Nerve Integrity Monitor, Xomed-Treace, Jacksonville, FL).

EMG monitoring has been used in all types of skull base surgery but has been particularly helpful in acoustic tumor resections. There is a growing trend in the literature that demonstrates improved preservation of facial nerve function using EMG monitoring, such as comparisons made by Harner et al,⁶ Dickens and Graham,¹¹ and Kwartler et al.¹² Double-blind, randomized studies, however, are unlikely to be seen, since most surgeons are reluctant to forego EMG facial monitoring once it has become established in their practice.

Monitoring has also been useful in glomus tumor

surgery, since the facial nerve must often be mobilized anteriorly.¹³ The nerve sustains less trauma during decompression since mechanical evoked potentials are elicited as the drill burr approaches the nerve sheath. Furthermore, the surgeon is alerted following transposition if undue traction occurs directly or secondary to a self-retaining retractor.

Facial nerve monitoring has been helpful during vestibular neurectomy, parotidectomy, and approaches to the lateral skull base. Facial nerve monitoring is particularly important during microvascular decompression for hemifacial spasm. Intraoperative changes in the facial EMG baseline as well as eradication of an abnormal antidromic response are often observed following successful decompression.¹⁴

TECHNIQUE

The mechanics of facial nerve monitoring are straightforward. Grass E-2 monopolar electrodes are placed intramuscularly in a multichannel bipolar montage.⁴ Close pairs of electrodes are placed in the ipsilateral orbicularis oculi muscle and in the facial musculature at the nasolabial groove. A ground electrode is placed high on the forehead (Fig. 1). Muscle relaxants should not be used unless short-acting and reversed well in advance of anticipated neural stimulation. Cautery ground pads should be secured to prevent shunting of current to the facial electrodes.

Monopolar electrical stimulation is the most appropriate technique for neural localization (Fig. 2). Because of current spread, the relative position of the facial nerve can be assessed despite intervening tissue between nerve and the stimulus probe. This is important in identifying the facial nerve hidden within or behind a large tumor mass. Typical stimulus intensities used at the cerebellopontine angle range from 0.05 to 0.30 mA. Higher current levels are required more distally along the nerve due to progressive amounts of epineurium and during instances of neural fatigue due to dissection. An infrequent drawback to monopolar stimulation is false-positive facial responses that can occur when stimulating the adjacent cochlear, vestibular, or trigeminal nerves because the inherent current spread around the cathode may depolarize the adjacent facial nerve (current jump). Bipolar stimulation reduces the possibility of current jump by the close apposition of cathode to anode (Fig. 3). Although bipolar stimulation allows for more precise neural localization, it is used only during differentiation of adjacent nerves due to a lesser degree of sensitivity compared with monopolar mapping.

Any stimulator used in the cerebellopontine angle is at risk for false-negative responses due to current shunting. Current may be lost into the adjacent cerebrospinal fluid, resulting in inadequate current at the electrode-nerve interface, particularly with low levels of electrical stimulation. Prass and Luders⁴ have demonstrated that insulation of the stimulus probe flush to the tip reduces

Figure 1. EMG recording montage used for two-channel facial nerve monitoring. Close electrode pairs are inserted at the nasolabial and orbicularis oculi regions. Ground electrode is placed high on forehead (FPZ). (From Kartush.⁷ Reprinted with permission.)

Figure 2. Monopolar electrical stimulation in and around acoustic neuroma maximizes sensitivity to tumor mapping. (From Kartush.⁷ Reprinted with permission.)

Figure 3. Bipolar stimulation maximizes selectivity in differentiating facial nerve from adjacent cochlear, vestibular, and trigeminal nerves. (From Kartush.⁷ Reprinted with permission.)

current shunting. Moller and Jannetta¹ use an alternative method in which constant voltage stimulation reduces the effect of shunting.

Electrical stimulation is also used to assess neural integrity after the dissection is complete. Using a low stimulus intensity of 0.05 mA at an area proximal to the site of surgical dissection appears to improve prognostication regarding postoperative function. We believe that

delayed facial palsies may in part be due to progressive edema. If the nerve appears edematous following tumor dissection and demonstrates an increased threshold to electric stimulation, we may proceed to decompress the nerve at the meatal foramen.⁴⁰ This is the site of maximal anatomic entrapment, as Fisch¹⁵ has described in regard to inflammatory etiologies.

Whereas monopolar or bipolar stimulation typically creates a synchronous compound muscle action potential ("pulse" response), mechanical evoked responses can be seen as "burst" or "train" responses as categorized by Prass and Luders⁴ (Fig. 4A, B). Direct surgical manipulation of the nerve typically triggers a synchronous compound muscle action potential. Prolonged manipulation or traction on the nerve generally results in a sustained, asynchronous response (train). Cold caloric stimulation (irrigation) may result in atraumatic trains, whereas laser heat may cause a significant train response or an elevation of the EMG baseline activity indicative of neural heating. Train responses of the nerve are most likely due to persistent areas of depolarization within the nerve.¹⁰

A special set of surgical instruments (Stimulus Dissectors, Xomed-Treace) has been developed to allow continuous monopolar stimulation with sharp surgical dissection, since sharp dissection may elicit little or no mechanical evoked responses (Fig. 5). These instruments are insulated up to their cutting edge to reduce current shunting and attach directly to the stimulator unit. Since the cutting edge of the instruments must be free of insulation, current shunting is at times possible. Additional insulated instruments, such as self-retaining retractors, reduce the possibility of static artifact, which can occur

Figure 4. A: Elicitation of "burst" facial evoked response. B: Elicitation of "train" facial evoked response. (From Kartush.⁷ Reprinted with permission.)

Figure 5. A special set of insulated surgical instruments (Kartush Stimulus Dissectors) connect directly to the stimulator, which allows simultaneous monopolar mapping during sharp surgical dissection. In addition, commonly used instruments, such as self-retaining retractors and suction tips, are also insulated to reduce "static artifact," which can occur when two metal objects make contact around the surgical field.

when two metal objects contact each other around the surgical field. Such artifact can occasionally be misinterpreted as facial nerve depolarization when uninsulated instruments are used. Nonetheless, assessing the relevance of any response must be done in context to the ongoing surgical events. Monitoring should be considered an adjunct and not a replacement for surgical decision-making.

INTRAOPERATIVE MONITORING OF THE AUDITORY SYSTEM

Sensorineural hearing loss can occur through a variety of mechanisms during skull base surgery, including violation of the labyrinth, injury of the cochlear nerve, compromise of blood supply to the inner ear or eighth nerve, and injury of the endolymphatic sac (although this latter mechanism has not been demonstrated clinically).¹⁶ Intraoperative methods of evaluating cochlear and auditory function are evolving. A primary goal of intraoperative monitoring is to alert the surgeon to ongoing changes in neural function as quickly as possible.¹⁷ Although instantaneous feedback of facial nerve function is practical, a delay exists in acquiring information from the acoustic nerve because the acoustically evoked potentials must be extracted from a background obscured by ongoing electroencephalographic activity.

Signal averaging and filtering are two methods that

allow auditory evoked potentials to be extracted. The signal-to-noise ratio is increased by a function that is the square root of the number of averaged responses. In addition, reducing components of the electrical signal outside the frequency range where the auditory potentials have most of their energy will allow more efficient extraction of the auditory signal. Moller¹⁷ has refined this technique using digital filters that allow attenuation of unwanted high and low frequency components without introducing phase shifts (shifts in peak latencies) as occurs with analogue filters.

Auditory evoked potentials are divided into the broad categories of far- and near-field responses with respect to the type of recording technique used to obtain the response. Far-field techniques record responses at a greater distance from the neural generator site compared with near-field techniques. Far-field responses are smaller in amplitude and are less sensitive to the location of the recording electrode.¹⁸ Within the auditory system, far-field responses have amplitudes in the range of 0.2 to 3 μ V, whereas near-field responses can exceed 20 μ V.¹⁸ The type of recording technique has a bearing on the number of responses needed to be averaged. Larger magnitude potentials from near-field responses require less averaging time and can therefore be quickly obtained.

The auditory system generates several evoked potentials, which can be recorded with either far- or near-field techniques. These include the short vertex potential or auditory brainstem-evoked response (ABR), middle and

late vertex potentials, and electrocochleographic (ECoG) and direct eighth nerve action potentials (NAP). To date, the most useful intraoperative auditory potentials include the ABR, ECoG and NAP.

Auditory Brainstem-Evoked Responses

Initially described by Jewett and Williston,¹⁹ the ABR is the most frequently monitored eighth nerve potential during posterior and middle cranial fossa surgery. The response, obtained with a far-field recording technique ranges in amplitude from 0.2 to 3 μ V. It consists of seven waves, each marked with a Roman numeral (Fig. 6). The neural generators of this response include time-varying contributions from the cochlea, cochlear nerve, and the nuclei and ascending pathways within the brainstem. Møller and Jannetta²⁰ have demonstrated that the first two peaks, waves I and II, originate from the extracranial and intracranial components of the auditory nerve. Wave III is generated within the cochlear nucleus, wave IV from the superior olivary complex, and wave V originates at the level of the lateral lemniscus. The generators of waves VI and VII are unknown. These potentials all occur within 20 msec following stimulation. The ABR is rarely altered by anesthetic agents, in contrast to middle and late vertex responses. Waves I, III, and V of the ABR are the most reliable, with wave V being the most stable. Changes in the ABR during surgery are compared to a baseline recording and thus there are different priorities in assessing intraoperative ABRs compared with office-based diagnosis. Alterations, such as decreased amplitude and latency shifts, usually imply that some degree of injury has occurred along the auditory pathway. Human^{21,22} and animal studies²³ have shown that compression or a stretch injury to the acoustic nerve result in a prolongation of the I-V latency interval. Rapid loss of the ABR is believed to be due to ischemic injury to the eighth nerve complex.

Typical stimulus parameters include a 100 μ sec rarefaction click of 100 dB nHL at a rate of 27.7 clicks per second presented through an insert earphone. Recording

parameters include a 15 msec time window, filters set to pass between 150 and 1500 Hz and number of sweeps between 500 and 2000, depending on response morphology. Grass type E-2 subdermal electrodes, placed in the vertex and the preauricular regions, are used to measure the far-field response.

Whereas the baseline of facial nerve monitoring is electrical silence from which any change is readily apparent, the baseline of auditory monitoring is a relatively complex waveform from which slight changes may have important implications. Thus, auditory brainstem recording does not allow for real-time feedback directly to the surgeon, as does EMG monitoring wherein the abrupt onset of action potentials can be displayed through a loudspeaker. In contrast, a quantitative alteration of the evoked potential must be recognized and interpreted by the monitoring personnel before the information is conveyed to the surgeon. There are currently no data to indicate what routinely represents a "critical" change in the ABR.²¹⁻³⁰ A 2 msec prolongation of the I-V latency has been described as a significant alteration,²⁴ as have latency changes greater than 1 msec or ongoing changes greater than 0.1 msec/min.²⁵ Abramson et al²⁶ suggested that preservation of an intraoperative ABR recording during acoustic tumor removal appears to predict a successful hearing preservation result. More recently,⁹ loss of wave V during acoustic tumor removal has been correlated with poor postoperative hearing, whereas preservation of wave V, despite increases in wave V latency of up to 3 msec over baseline levels, resulted in successful hearing preservation. Others have found the predictive value of maintaining wave V not as precise. Watanabe et al²⁷ observed postoperative hearing loss despite preservation of wave V as well as preservation of hearing despite loss of wave V. Friedman et al²⁸ observed that loss of wave V after cerebellar retraction can be associated with good postoperative hearing. More experience with intraoperative ABR recording is necessary to determine the relationship between wave V stability, including latency shifts and amplitude reductions, and postoperative hearing results. Nonetheless, if an abrupt or progressive change in the ABR is encountered, the surgeon should be alerted. Corrective measures such as relaxation of retractors or temporary cessation of dissection can be taken. Although aberrations in the ABR may or may not represent reversible injury, surgical trauma is more likely to be minimized the earlier it is identified and addressed. By modifying the surgical dissection based on ABR changes, hearing preservation results have improved.²⁴⁻³⁰

Changes in the ABR do not always imply surgical trauma. Examples include irrigation, opening dura, lowering core body temperature, blood in the middle ear, and displacement of the insert earphone or electrodes. These intraoperative events should be considered if changes occur in the ABR that do not correlate with surgical dissection. The operative monitoring team should carefully follow the course of surgery to anticipate changes in the ABR

Figure 6. Auditory evoked brainstem response showing the seven waves.

based on surgical events, such as irrigation, cautery, or lasering. One important technical point to be aware of is that even if current from a bipolar cautery does not flow directly through a nerve, injury can still occur by conduction of heat.

Applications for intraoperative ABR monitoring include: (1) skull base tumors (such as acoustic neuroma, meningioma, and glomus tumor) when hearing is serviceable and when its preservation is a realistic goal, (2) vestibular neurectomy, and (3) microvascular decompression of the fifth, seventh, and eighth cranial nerves.

Direct Nerve Action Potential Recording

Direct recording of the eighth NAP was introduced by Moller and Jannetta in 1983.³¹ The NAP is a near-field recording of the same neural generator that is represented by wave I on ABR. A small Teflon-insulated wire with a bare tip is positioned on the acoustic nerve. Oxcel can be placed at the electrode tip in order to increase the surface area and stabilize the electrode. A reference electrode is placed subdermally in the temporal scalp. A click stimulus, identical to that used for ABR, is presented via an insert earphone. Utilizing this near-field recording technique, the NAP appears as a large (25 to 30 μ V) triphasic response (Fig. 7). Due to the large amplitude of the signal, only a small number of responses need to be averaged to obtain a good waveform. Thus, the response is nearly instantaneous (1 or 2 sec).

Intraoperative amplitude reductions are initially observed and usually signify significant trauma to the eighth cranial nerve. The wave V response on ABR may remain normal despite marked changes in the NAP.¹⁸ The instantaneous changes observed with NAP recordings may not be reflected for several minutes in the ABR tracings. Thus, vascular changes, believed to cause immediate changes within the auditory system, may be detected earlier by monitoring the NAP.

Figure 7. Direct cochlear nerve action potential.

Despite being an instantaneous measure of acoustic nerve function, there are several drawbacks to direct NAP recording: (1) the cochlear nerve may not be sufficiently exposed to allow suitable electrode placement due to tumor mass or the surgical approach (such as middle fossa craniectomy), (2) placement of the electrode within the operative field may restrict the surgeons visibility, (3) the electrode is easily displaced, and (4) pooling of cerebrospinal fluid may create frequent impedance changes at the electrode-nerve interface. Clinically, NAP recordings have proved to be useful during acoustic neuroma surgery when hearing preservation is desired. This technique has also been used during surgery for hemifacial spasm³² and vestibular neurectomy.³³

Electrocochleography

ECoG, a near-field recording technique, was introduced by Aran and LeBert³⁴ in the late 1960s. This recording method is generally performed by placing an electrode through the tympanic membrane to rest on the promontory of the inner ear. A modification of this method involves first placing the electrode through the tragus to allow for stabilization.³⁵ Another technique consists of inserting a ball-tip electrode directly on the round window membrane via a tympanomeatal flap or facial recess approach.

Three different auditory potentials may be recorded: (1) the cochlear microphonic (CM), (2) the summing potential (SP), and (3) the NAP. By alternating click polarity (rarefaction and condensation), the CM can be eliminated, allowing superior resolution of the NAP. The SP is observed as a DC shift at the onset of the NAP (Fig. 8) and is believed to originate from the organ of Corti. These potentials have a large amplitude on near-field recording and require little averaging time (30 to 60 sec) to obtain a clear response. The NAP and SP have found use in intraoperative monitoring.

Decreases in NAP amplitude and prolongation of

Figure 8. Transtympanic electrocochleography demonstrating summing the potential (SP) and nerve action potential.

latency may signify cochlear or eighth nerve injury. Changes in the amplitude of the SP are believed to represent ongoing changes within the organ of Corti. Clinically, ECoG has been proposed as an adjunct to the ABR during operative monitoring of the eighth cranial nerve during acoustic neuroma surgery^{36,37} and vestibular neurectomy.³³ Silverstein et al³³ observed that the greater the latency shift of the ECoG, the more likely there was to be a pure-tone neural hearing loss following vestibular neurectomy. A shift of 0.3 msec was associated with a 16 to 20 dB hearing loss. They noted no correlation between direct eighth nerve recordings and postoperative hearing results.

We have found the Tiptrode (Nicolet Medical Co, Madison, WI) a useful adjunct to enhance wave I. The Tiptrode combines an insert earphone with an active recording electrode. Using this device, wave I can usually be well identified without requiring a transtympanic electrode.

The role of intraoperative ECoG in Meniere's disease is currently being investigated.³⁸ The amplitude of the SP often increases with distortion of the basilar membrane, such as occurs in endolymphatic hydrops. Arenberg and Gibson³⁸ have recommended the use of intraoperative ECoG as an adjunct during endolymphatic sac surgery. Their investigations indicate that an abnormally elevated SP (often present during active endolymphatic hydrops) may be reduced intraoperatively if the endolymphatic duct is appropriately cannulated. Further studies will be required to assess the possible benefits of this technique.

For intraoperative monitoring to be useful for hearing preservation, the evoked potentials must be sensitive enough to detect early reversible changes in the auditory system. Even with continuing improvements, auditory evoked potentials will not likely become as sensitive an indicator of injury as EMG is for motor nerves. In conjunction with auditory monitoring, improved hearing preservation may be further enhanced by concomitant facial nerve monitoring, since the surgeon is alerted to traumatic manipulations that may affect both facial and cochlear nerves.

LOWER CRANIAL NERVES

In addition to seventh and eighth nerve monitoring, cranial nerves IX, X, XI, and XII can also be evaluated. Since these nerves have large motor components, needle electrodes within their respective musculature can offer ongoing EMG recordings similar to those obtained with intraoperative facial nerve monitoring. Muscle groups commonly monitored include the stylopharyngeus for cranial nerve IX, the laryngeal musculature for the vagus nerve, the sternocleidomastoid muscle for the spinal accessory nerve, and the tongue for the hypoglossal nerve. Monitoring the activity of the laryngeal musculature associated with the recurrent laryngeal nerve is receiving increased attention during thyroid surgery.³⁹

EVOLUTION OF OPERATIVE MONITORING

Effective neurophysiologic monitoring requires knowledge of the anatomy and physiology of the neural system of interest, selection of an appropriate monitoring procedure based on the structures at risk, proper technique, and appropriate interpretation based on knowledge of the normal evoked response. The monitoring team must convey relevant, accurate information in a timely fashion. This should not be a static warning once changes indicative of injury have occurred, but an ongoing communication so that the surgeon is aware of trends and dynamic changes. Monitoring personnel should be sufficiently knowledgeable about the evoked potential to understand how surgical and nonsurgical factors can affect the response. Ultimately, the surgeon must determine whether the information provided should result in an operative modification.

Operative neurophysiologic monitoring is an evolving field. Training programs will require supplementing their curricula to ensure that surgeons have an understanding of pertinent neurophysiology while audiologists and physiologists obtain additional training to transfer effectively their existing skills in office-based diagnostic testing to the dynamic environment of the operating room.

REFERENCES

1. Moller A, Jannetta P: Preservation of facial function during removal of acoustic neuromas: Use of monopolar constant voltage stimulation. *J Neurosurg* 61:752-760, 1984
2. Prass R, Luders H: Constant current/constant voltage stimulation. *J Neurosurg* 62:622-623, 1985
3. Kartush J, Niparko J, Bledsoe S, et al: Intraoperative facial monitoring: A comparison of stimulating electrodes. *Laryngoscope* 95:1536-1540, 1985
4. Prass RL and Luders H: (Acoustic loudspeaker) facial electromyography monitoring: Evoked electromyographic activity during acoustic neuroma resection. *Neurosurgery* 19:392-400, 1986
5. Kartush J, Prass R: Facial nerve testing—electroneurography and intraoperative monitoring. In Johnson J, et al (ed): *American Academy of Otolaryngology—Head and Neck Surgery Instruction Courses*, vol. I, St. Louis: C.V. Mosby, 1968; pp 231-247
6. Harner S, et al: Improved preservation of facial nerve function with use of electrical monitoring during removal of acoustic neuromas. *Mayo Clinic Proc* 62:92-102, 1987
7. Kartush JM: Electroneurography and intraoperative facial monitoring in contemporary neurology. *Otolaryngol Head Neck Surg* 101:496-503, 1989
8. Gantz B: Intratemporal facial nerve surgery. In Cummings et al (eds): *Otolaryngology—Head and Neck Surgery*, St. Louis: C.V. Mosby, 1986; pp 3353-3366
9. Sugita K, Kobayaski S: Technical and instrumental improvements in the surgical treatment of acoustic neuromas. *J Neurosurg* 57:747-752, 1962
10. Silverstein H, Smouha E, Jones R: Routine intraoperative facial nerve monitoring during otologic surgery. *Am J Otol* 9:269-275, 1988
11. Dickens J, Graham S: Presented at the American Otologic Society, West Palm Beach, FL, April 1990
12. Kwartler J, Luxford W, Atkins J, Shelton C: Facial nerve monitoring. *Otolaryngol Head Neck Surg* 1990 (in press)

13. Leonetti J, Brackmann D, Prass R: Improved preservation of facial nerve function in the infratemporal approach to the skull base. *Otolaryngol Head Neck Surg* 101:74-78, 1989
14. Moller A, Jannetta P: Monitoring facial EMG responses during microvascular decompression for hemifacial spasm. *J Neurosurg* 66:681-685, 1987
15. Fisch U: Surgery for Bell's palsy. *Arch Otolaryngol* 107:1-10, 1981
16. Kartush J, Telian S, Graham M, Kemink J: Anatomic basis for labyrinthine preservation during posterior fossa acoustic tumor surgery. *Laryngoscope* 96:1024-1028, 1986
17. Moller AR: A digital filter for brainstem evoked responses. *Am J Otolaryngol* 1:372-377, 1980
18. Jacobsen GP, Tew JM: Intraoperative evoked potential monitoring. *J Clin Neurophysiol* 4:145-176, 1987
19. Jewett DL, Williston JS: Auditory evoked far fields averaged from the scalp of humans. *Brain* 94:681-696, 1971
20. Moller AR, Jannetta PJ: Neural generators of the brainstem auditory evoked potentials. In Radar RH, Barber C (eds): *Evoked Potentials II. Second International Evoked Potentials Symposium*. Woburn, MA; Butterworth Press, 1984
21. Levine RA, Montgomery WM, Ojemann RG, McGaffigan PM: Monitoring auditory evoked potentials during acoustic neuroma surgery: Insights into the mechanism of the hearing loss. *Ann Otol Rhinol Laryngol* 93:116-123, 1984
22. Ojemann RG, Levine RA, Montgomery WM, McGaffigan PM: Use of intraoperative auditory evoked potentials to preserve hearing in unilateral acoustic neuroma removal. *J Neurosurg* 61:938-948, 1984
23. Sekiya T, Jwabuchi T, Kamata S, Ishida T: Deterioration of auditory evoked potentials during cerebellopontine angle manipulation. *J Neurosurg* 63:598-607, 1985
24. Kemink JL, LaRouere MJ, Kileny PR, Telian SA, Hoff JT: Hearing preservation following suboccipital removal of acoustic neuromas. *Laryngoscope* (in press)
25. Wilkins RH, Radtke RA, Erwin CW: The value of intra-operative ABR potential monitoring in reducing the auditory morbidity associated with microvascular decompression of cranial nerves. Presented at the North American Skull Base Surgery Meeting, Marina Del Rey, California, Feb. 17-21, 1990
26. Abramson MA, Stein BM, Pedley TA, Emerson RG, Wazen JJ: Intraoperative BAER monitoring and hearing preservation in the treatment of acoustic neuromas. *Laryngoscope* 95:1318-1322, 1985
27. Watanabe E, Schramm V, Strauss C, Fahlbusch R: Neurophysiologic monitoring in posterior fossa surgery: II BAEP—waves I and V and preservation of hearing. *Acta Neurochir (Wien)* 98:118-128, 1989
28. Friedman WA, Kaplan BJ, Gravenstein D, Rhoton AL Jr: Intra-operative brainstem auditory evoked potentials during posterior fossa microvascular decompression. *J Neurosurg* 62:552-557, 1985
29. Moller AR, Moller MG: Does intra-operative monitoring of auditory evoked potentials reduce incidence of hearing loss as a complication of microvascular decompression of cranial nerves. *Neurosurgery* 24:257-263, 1989
30. Schramm J: Detailed analysis of intraoperative changes monitoring brainstem acoustic evoked potentials. *Neurosurgery* 22:694-702, 1988
31. Moller AR, Jannetta PJ: Monitoring auditory function during cranial nerve microvascular decompression operations by direct recording from the eighth nerve. *J Neurosurg* 59:493-499, 1983
32. Moller MB, Moller AR: Loss of auditory function in microvascular decompression for hemifacial spasm. Results in 143 consecutive cases. *J Neurosurg* 63:17-20, 1985
33. Silverstein H, Wazen J, Norrell H, Hyman SM: Retrolabyrinthine vestibular neurectomy with simultaneous monitoring of eighth nerve action potentials and electrocochleography. *Am J Otol* 5:552-555, 1984
34. Aran JM, LeBert G: Les réponses nerveuses cochléaires chez l'homme, image due fonctionnement de l'oreille et nouveau test d'audiométrique objective. *Rev Laryngol Otol Rhinol (Bord)* 87:361-378, 1968
35. Prass RL, Kinney SE, Luders H: Transtragal, transtympanic electrode placement for intraoperative electrocochleographic monitoring. *Otolaryngol Head Neck Surg* 97:343-350, 1987
36. Prasher AK, Gibson WPR: Brainstem auditory evoked potentials and electrocochleography: Comparison of different criteria for the selection of acoustic neuroma and other cerebellopontine angle tumors. *Br J Audiol* 17:163-174, 1983
37. Levine RA: Monitoring auditory evoked potentials during acoustic neuroma surgery. In Silverstein H, Norrell H (eds): *Neurological Surgery of the Ear*, vol 2. Birmingham, AL: Aesachapeus, 1980
38. Arenberg IK, Gibson WPR: 1988 ECOG Seminar and Workshop, Denver, Colorado, February 15-17, 1988
39. Rice DH: Intraoperative monitoring of the recurrent laryngeal nerve. Abstract presented at the American Academy of Otolaryngology—Head and Neck Surgery, New Orleans, 1989
40. Kartush J, Graham M, Larouere M: Meatal decompression following acoustic neuroma resection—minimizing delayed facial palsy. *Laryngoscope*, in press, 1991