ASNM Position Statement: Intraoperative Monitoring of Auditory Evoked Potentials

Committee

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1.0 Introduction:

Hearing is often *at-risk* during procedures involving access to the cerebellopontine angle (CPA) [1,2]. Damage may occur in the cochlea, along the auditory nerve or at higher levels along the auditory pathway [3]. Mechanisms of damage include mechanical (compression, avulsion, cutting, and stretching), ischemic (vasospasm of the acoustic artery [4]), and thermal (heat damage from electrocautery [5,6]). The auditory nerve is sensitive to mechanical manipulation [7] and is easily damaged. The key to reducing or eliminating permanent damage during surgery is to detect changes in function early enough to allow the surgical team to modify their procedure, permitting recovery or avoiding further damage to neural tissues. Intraoperative monitoring of auditory evoked potentials [8,9] can provide the surgical team with early warnings and enable them to avert damage to the auditory pathway and reduce the likelihood of causing hearing loss.

Procedures which place the auditory nerve *at-risk* include resection of vestibular schwannoma, vestibular nerve section [10,11] , microvascular decompression of cranial nerves V, VII, VIII and IX [12], resection of other CPA and fourth ventricle tumors, repair of CPA arteriovenous malformations, aneurysm repair and management of Arnold Chiari malformations. Neuromonitoring of auditory evoked potentials may reduce the risk of hearing loss or other neural damage in all of these procedures.

1.1 History:

In the early 1970's, Jewett and colleagues [13-15] conclusively demonstrated that a series of scalp-recorded potentials were generated by the ascending activation of the auditory pathway. In his earliest papers he commented on their potential application in neurodiagnostic evaluations. The activity was called the auditory brainstem response. During the next few years, other investigators demonstrated strong relationships between abnormalities of the ABR and neurological disorders [16-19]. ABR monitoring was introduced into operating rooms in the late 1970's. Early reports [20-24] indicated that intraoperative monitoring during resection of vestibular schwannomas was technically feasible and probably helpful in reducing morbidity.

1.2 Description of responses:

Three types of auditory evoked potentials are commonly monitored during surgery: the Auditory Brainstem Response (ABR), the Electrocochleogram (EcochG-gram) and the Auditory Nerve Compound Action Potential (AN-CAP).

The ABR is typically recorded from two electrodes placed on the scalp, one near the vertex and one near the stimulated ear. The resulting waveform is a series of between five and seven vertex-positive peaks that were designated by Roman numerals by Jewett [13]. The most commonly measured peaks are waves I, III and V due to their stability within and across subjects. The latency of each peak is determined as the time from the onset of the stimulus to the peak of the response and measured in milliseconds. The normal wave I has a typical post-stimulus latency of $\leq$ 2 ms when the auditory stimulator is at the ear. However, if insert earphones having tubes separating the transducer from the ear are used, one must account for the time needed for the acoustic impulse to traverse the distance between the stimulator and the ear. The typical acoustic delay introduced by such tubes is 0.88 ms and is a linearly increasing function of the tube length. Waves II through V are each present at approximately 1 ms intervals after wave I. Since the responses are recorded from the scalp, they are considered far-field responses and have low amplitudes (wave V is typically less than 0.5 µV). Due to the small amplitude relative to the background electrical noise, a considerable amount of pre-acquisition filtering and signal averaging must be performed in order to record them.

The electrocochleogram (EcochG-gram) consists of three responses. The cochlear microphonic (CM) and summating potential (SP) are generated in response to cochlear activation by an acoustic stimulus. They are not typically monitored during surgery, although the presence of a SP is consistent with the presence of cochlear perfusion. The initial activation of the myelinated segment of the auditory nerve results in a compound action potential (CAP) recorded in the EcochG-gram. It is referred to as the N_1, but it is identical to wave I of the ABR. EcochG responses are recorded from an electrode placed as close to the cochlea as possible, either on the tympanic membrane or directly on the basal turn of the cochlea (promontory) in the middle ear. Due to the proximity of the electrode to the source of the response, the amplitude of this near-field response is relatively large (2-20 µV), and less signal averaging must be performed to acquire a reliable response. This considerably reduces the time it takes to interpret the response. It should be noted that the EcochG N_1 represents only the most distal activity of the cochlear nerve. This limits the use of the N_1 in assessing the integrity of more proximal elements of the auditory nerve.

The CAP may also be recorded directly from an electrode placed on the AN (AN-CAP). The N_1 peak of this near-field response occurs at about the same latency as the ABR wave II, although it is not wave II and has a different mechanism of generation as will later be described. The N_1 of the AN-CAP requires little averaging because it is often large in amplitude (up to 50 μV).

2.0 Anatomy and Physiology

In some cases, preoperative sensorineural hearing loss, regardless of etiology, can preclude reliable intraoperative recording of the ABR. It is helpful to verify that an ABR can be recorded preoperatively and to determine the patient's preoperative pure-tone thresholds and speech discrimination capabilities. However, even if a pre-operative ABR cannot be obtained, it is often true that under general anesthesia an ABR may be recordable and so the absence of a pre-operative ABR does not eliminate the possibility of effective monitoring.

Increasing the stimulus intensity will compensate for a conductive hearing loss. A cochlear or retrocochlear hearing loss may provide a more difficult problem. It is important to understand that the earliest waves of the ABR are predominately generated by synchronous discharges of fibers from the basal, high-frequency end of the cochlea. A high-frequency sensory-neural hearing loss may decrease the amplitude of the ABR waves, making it difficult or impossible to monitor. In terms of retrocochlear lesions, the ABR is very sensitive to their presence, but not specific to either type of tumor (e.g. schwannoma or meningioma) or the nature of the lesion. A meningioma may disrupt the ABR and be responsible for a hearing loss, both of which can be reversed surgically. In other cases, a small intracanicular vestibular schwannoma may cause irreversible damage to hearing.

2.1 Generators of the auditory evoked potentials:

The auditory pathway begins in the modiolus of the cochlea where the myelinated dendrites of the auditory nerve pass into and through the spiral ganglia en route to forming a nerve bundle in the internal auditory canal. The acoustic and vestibular sections of the auditory nerve merge within the temporal bone and align with the intracranial section of the facial nerve. Together, they exit the internal auditory canal and connect to the brainstem. All auditory nerve fibers synapse at either the posterior ventral cochlear nucleus or the anterior ventral cochlear nucleus. Fibers that synapse at the posterior ventral cochlear nucleus also have connections with the dorsal cochlear nucleus. From the cochlear nucleus onward, there are several pathways and combinations of pathways. The vast majority of fibers cross the brainstem to the opposite side via the trapezoid body. Some synapse in either the medial or lateral superior olivary nuclei. Others pass through the lateral lemniscus en route to the inferior colliculus. All ascending fibers synapse at the inferior colliculus before ascending to the medial geniculate body at the level of the thalamus and then on to the primary auditory cortex.

The N_1 of the EcochG is equivalent to wave I of the ABR. Both are generated within the internal auditory canal by the most distal section of the myelinated auditory nerve.

ABR wave II occurs at about the same latency as N_1 of the AN-CAP, when the electrode is placed at the auditory nerve root entry zone adjacent to the brainstem [25,26]. N_1 of the AN-CAP is generated as the action potential passes across the recording electrode. N_1 is therefore a good indicator of all activity distal to the point of it's recording; however, Martin et al. [27] demonstrated that there was no relationship between the near-field recorded N_1 of the AN-CAP and the far-field wave II of the ABR The scalp recorded Wave II and the negative peak between Waves I and II (e.g.I_n) are "stationary potentials". A stationary potential is generated when the current density surrounding a nerve is distorted at a fixed point along the nerve. It can be a result of the nerve passing through a change in the volume or conductivity of the surrounding tissues or when the nerve makes a sharp change in direction. Stationary potentials are readily recorded at significant distances from the nerve pathway. Stationary potentials have also been described in response to peripheral nerve stimulation [28-35]. Scalp-recorded wave III has been recorded at the same time as near-field activity in the cochlear nucleus [36]. Other recordings from the area of the cochlear nucleus in the lateral recess of the fourth ventricle indicate activity that coincides with wave III_n (the negative peak between III and IV) [37,38]. Other results indicate that the auditory nerve may continue to be active during the generation of the scalp-recorded waves III and IV [39].

Several areas of the auditory pathway are active at the same time that wave IV can be recorded from the scalp including the cochlear nucleus, superior olivary complex, and the lateral lemniscus and possibly the trapezoid body [40]. Wave IV also appears to be generated by events contralateral to the stimulated ear.

It has been suggested that the sharp peak of wave V is generated by the lateral lemniscus as it terminates into the inferior colliculus, and that the activity of the inferior colliculus is responsible for the generation of the relatively slow and large negativity following the peak of V. This slow potential has also been called the SN10 potential [40]; however, there is compelling evidence that all activity at or beyond the peak of wave IV could be generated by the inferior colliculus contralateral to the stimulus [41].

Despite the continuing discussions about the exact mechanisms underlying the generation of the scalp-recorded ABR, clinical evidence has demonstrated that it is a highly sensitive indicator of auditory pathway disorders and of *alterations in function* as those induced by surgical manipulations. As such, the ABR remains a valuable tool for neuromonitoring. Using only ABR, it is not possible to assign waveform changes to specific structures; however it is safe to use changes in the ABR as direct evidence of a change in function along the pathway that may warrant the immediate attention of the surgical team.

3.0 Methods

3.1 Stimulus type, intensity and rate:

Brief-duration tone bursts have been used [40], but 100µs click stimuli are most frequently used by clinicians. A click provides a broad-spectrum stimulus activating much of the basilar membrane. The transient stimulus serves to synchronize the response of the auditory nerve fibers, resulting in well-defined peaks in the ABR. Click stimuli may be either rarefaction, condensation or alternating. If small electromagnetic earphones are used to generate the stimuli, alternating polarity clicks are preferred to reduce the high amplitude stimulus artifact. The effects of click polarity on the ABR are in general complex [38,70-72] and when using other transducers it is appropriate to begin with alternating clicks but to choose the polarity that provides the best waveform.

The stimulus intensity will be based upon the individual's preoperative hearing thresholds, their preoperative ABR results and the recording conditions within the operating room. It is important to stimulate at a high enough level to obtain maximum amplitude responses. Normally, this would be at or above 70 dB nHL. In the presence of a pre-existing sensory neural hearing loss, stimulus intensities of 90-95 dB nHL may be necessary.

The stimulus presentation rate should be as high as the recording situation permits. Stimulus rates of 30-50 Hz will permit nearly instantaneous recording of near-field potentials like the EcochG-CAP and AN-CAP, and will produce an adequate ABR in less than one minute. If the ABR is of low amplitude and difficult to record, slower stimulus rates may be needed. In all cases the stimulus rate should never be an even divisor of 60Hz. Interleaved stimulus presentation permits simultaneous averaging from both sides.

Effective stimulus presentation can be accomplished using commercially available insert earphones secured with tape, bioclusive, or bone wax. An acceptable alternative is to use small electromagnetic headphones as used in "Walkman" type personal listening systems. It should be noted that electromagnetic stimulators generate much larger stimulus artifacts than do insert earphones. Whenever adapting transducers to a particular evoked potentials system it is important to account for possible differences between the impedance of the transducers and the output impedance of the stimulator. In addition, it is important to note that most evoked potential machines are not calibrated using the electromagnetic earphones and so the delivered sound intensity will not necessarily be that indicated on the evoked potential machine.

Stimuli over 40 dB nHL can potentially be heard by the non-test ear through air and bone conduction [81-83]. Responses from the non-test ear can be attenuated by presenting white noise masking to the non-test at levels between 40 and 60 dB below the stimulus level. Insert ear phones can reduce the sound level to the non-test ear by about 70 dB and so masking may not be as critical but it is good practice to use masking noise when possible since masking noise levels 40-60dB below the stimulus level do not significantly affect the recorded responses [84]. In any case, pre-operative audiometric testing and recording of brainstem auditory evoked responses can be helpful in understanding and identifying the potential impact of these crossover effects before surgery.

3.2 Electrodes:

The standard electrode montage for recording the ABR is with the non-inverting (+) electrode located at the vertex (C_z) or high forehead and the inverting electrode (-) on the mastoid or ear lobe (M1 or M2; A1 or A2). It is unlikely that the mastoid will be available on the surgical side during a procedure, so the non-inverting electrode may be placed in the skin immediately anterior to the earlobe or tragus. This location will provide an ABR equivalent to that recorded using the more conventional montage. Alternative montages may be used, depending upon the number of recording channels available. A vertex (C_z) to contralateral (non-surgical) ear channel is useful for peak identification and can be used as an ipsilateral channel if the non-surgical side is to be monitored. Vertex (C_z) to a non-cephalic site (e.g., shoulder), recorded simultaneously with an ear to ear channel may be helpful if responses are difficult to record using other montages.

Standard EEG cup electrodes may be used for recording ABRs intraoperatively, but the application process is time consuming. Disposable "snap on" electrodes, like those used for electrocardiographic recordings may also be used but may not adhere on hairy areas. These electrodes may be purchased in several sizes, some small enough to be practical for ABR monitoring. Skin preparation is still required to reach low electrode-skin impedances appropriate for recording, and this takes time. Standard EEG needle electrodes can be quickly applied and secured, take up little area on the patient, and can be disposable or reused (although single use is preferred) given careful precautions. Needle electrodes provide consistent, stable electrode-skin impedances without skin preparation. Care must be given to avoid burns related to improper grounding of electrocautery equipment [40].

An electrode placed on the promontory or the tympanic membrane may record EcochG. The inverting electrode is placed near the cochlea and the non-inverting electrode placed on the one of several locations including the opposite ear, forehead or vertex. A method for transtympanic EcochG was described by Hall [42] in which the tip of a standard EEG needle electrode is passed through the tympanic membrane and placed on the promontory. This procedure should not be attempted without adequate training. The wire lead from the electrode passes out the external auditory canal to the biological preamplifier. The wire and needle are held in place by the insertion of the foam plug of an insert earphone. Similarly, a tympanic membrane electrode developed by Stypulkowski and Staller [43] can be secured in the ear canal. Pre-made tympanic membrane electrodes are commercially available. Another alternative is to insert the tip of a needle electrode into the ear canal close to the tympanic membrane and secure it in place with the foam tip of the insert earphone. This technique should be avoided in patients receiving full anticoagulation for extended periods of time since small amounts of bleeding may interfere with transmission of the auditory stimuli. Transtympanic electrodes provide the largest signal of the three options followed by the tympanic membrane electrode and then the canal recording.

The AN-CAP recording electrode must be placed on the auditory nerve by the surgeon. It should be placed as soon as possible following opening of the dura and exposure of the auditory nerve, in order to identify changes in function related to exposure and retraction of the cerebellum. There are at least two commercially-available electrodes that are appropriate for recording compound action potentials from the auditory nerve. One is a small, single contact disc electrode connected to a delicate lead wire. The disc is placed on the most proximal portion of the nerve. A cotton surgical pad may be placed over the lead wire to secure it against the cerebellum or brainstem and to keep it out of the way of the surgeon's field of work. An alternative is a Cueva, C-shaped self-retaining electrode [44]. This electrode is approximately 6 mm in diameter and is attached to the root entry section of the auditory nerve using an applicator. The lead from the electrode placed on the nerve is connected to the inverting input on the amplifier. The non-inverting input can be connected to a sterile needle electrode placed in an exposed muscle flap in the surgical field. Either of these options will provide stable conditions for recording the AN-CAP, but the described applications are limited to suboccipital or retrosigmoid surgical approaches. If a middle cranial fossa approach is necessary, the disc electrode may be placed between the floor of the internal auditory canal and the cochlear nerve, outside the dura as described by Roberson et al. [45]. Møller [35] has also noted that a small wick electrode (equivalent in size to the disc electrode) can be placed in the lateral recess of the fourth ventricle to perform near-field monitoring if the CPA tumor is of sufficient size that it precludes placing an electrode on the auditory nerve. Extreme care should be taken to insure no sharp edges of the fine silver wires that may inadvertently pierce the nerve.

3.3 Amplification and filtering:

Biological amplifiers and other intraoperative monitoring equipment are commercially available from a number of manufactures. It is important that the amplifiers provide appropriate isolation with a maximum of 20μA leakage.

The ABR has its primary spectral energy from 50 Hz to 1000 Hz; however, in clinical practice, high-pass filtering is used to attenuate frequencies lower than 100Hz. This dramatically reduces the 60 Hz interference without substantially degrading the ABR waveform. However, high-pass filtering can reduce the amplitude of wave V and so, especially in a patient with a preoperatively impaired auditory system, lowering the high-pass filter below 100 Hz to 30 Hz may be helpful[73-76]. A 60 Hz "notch" filter should not be used. It uses a steep filter that will cause distortion to the recorded waveform possibly leading to misinterpretation of results. Low-pass filter cut-off values of 1500-2000 Hz are adequate for intraoperative monitoring. The slope of the high-pass filter usually is 6 dB/octave. The slope of the low-pass filter may be steeper, up to 24 dB/octave. Zero phase-shift digital filtering has been described by Møller [40] and can enhance waveforms; however, care must be taken in interpretation because the extreme low frequency weighting can result in a noise contamination appearing as wave V. The biological amplifier should have exceptional common mode rejection capabilities ($\geq$120 dB) in order to assist in reducing competing electrical noise found in the operating room. The input impedance of the amplifier should be high (preferably $\geq$100 MΩ) and the amplifier should be able to tolerate up to + or – 1V of DC offset before saturating. These technical specifications will improve signal detection and reduce the possibility of errors in the amplification process.

The amplifier gain should be set at the highest level possible that will not produce excessive artifact rejection.

3.4 Digitization:

The duration of the sweep (also know as epoch or recording window) should be appropriate to give an accurate and easily measured picture of the response. EcochG and AN-CAP are short-latency responses that occur well within the first 10 ms following the stimulus. The ABR typically falls within that same time frame, but may be prolonged due to pathology; therefore, it is preferable to use a longer sweep duration of 15 to 20 ms for ABR recordings.

3.5 Averaging:

Averaging is the process most responsible for increasing the signal-noise-ratio of the response. The AN-CAP is by far the largest signal and will require as few at 5 or 10 sweeps to obtain an average, taking less than one second. The EcochG-CAP is also relatively large, and depending on the preoperative hearing ability, may take from 1-20 seconds to obtain an adequate averaged response. The ABR, by comparison, is much smaller and will require from 10 seconds to 2 minutes to obtain an average; however, the amount of averaging is dependent upon the quality of the amplifier, the filter settings, the ambient noise level and the amplitude of the ABR. For example, consider the situation in which the noise level is the same for the AN-CAP recordings and the ABR recordings. Since the AN-CAP may have an amplitude up to 5μV and the ABR only 0.2μV, the signal to noise ratio for the AN-CAP may be 25 times that of the ABR. Hence, since the signal to noise ratio depends on the square root of the number of averages, the AN-CAP may be resolved with only $1/(25^2)$ or 1/625 as many averages as the ABR in line with the above observations.

Some newer digital amplifiers can resolve an ABR in less than 5 seconds under excellent recording conditions. However, there may be times during the surgery when rapid feedback regarding the integrity of the cochlear nerve is required and at these times of critical surgical activity it may be helpful for the monitoring team to emphasize the AN-CAP and EcochG-CAP.

3.6 Measurements and interpretation:

During intraoperative monitoring, each patient serves as his or her own control, and comparisons are made between baseline recordings and measures taken at later times during the procedure. Repeated measures are made during monitoring, and interpretation is made in terms of the changes that are observed during the course of the operation.

By itself, EcochG is not helpful for neuromonitoring auditory pathway function because it only evaluates the most distal end of the auditory pathway. Surgical interventions may occur rostral to the generator of the EcochG-CAP, making it of little value for tracking the effects of surgical procedures. It remains useful as a stable and readily-recorded reference point from which interpeak intervals to later waves may be measured.

EcochG has been applied to monitoring the effectiveness of endolymphatic sac decompression. In those cases one expects to observe a significant decrease in summating potential amplitude following a successful decompression. EcochG may also be used in monitoring the effectiveness of streptomycin infusions for cochlear destruction.

Useful measures for the ABR during monitoring include the latencies of wave I, III and V, if not absent due to pre-existing pathology. The I-III, I-V and III-V interpeak intervals as well as the V/I amplitude ratio are also useful if present. In cases of pre-existing hearing loss, the wave I of the ABR may be too low in amplitude to readily record. In this case, the N_1 of the EcochG-CAP is an excellent alternative and reference point for measuring interpeak intervals. Wave I serves as the reference point to account for peripheral events. The interpeak intervals serve as indicators of neural conduction time. If increases are noted in the III-V interval, it suggests that there are changes in function of the structure rostral to the generators of wave III. In these cases, Møller [40] suggests that systemic changes, such as changes in cerebral circulation, could be occurring and that the anesthesiologist should be notified. If wave III can be recorded, changes in the I-III interpeak interval can be used to identify changes in auditory nerve function. Matthies and Samii [46] reported that the disappearance of wave III was the earliest and most sensitive predictor of postoperative deafness, and therefore recommend that special attention be paid to deterioration of wave III. They also noted that wave III was particularly sensitive to specific surgical maneuvers during eighth-nerve tumor resection. Specifically, pulling of the tumor-nerve bundle down or laterally, drilling and direct nerve manipulation caused deterioration of wave III, which was correlated with postoperative hearing loss. The loss of wave V was the most definite indicator of postoperative deafness, but it did not predict whether the loss would be permanent or temporary. The loss of V was the least helpful sign because it typically followed earlier warning signs, the loss of waves I and or III. In general, the ABR shows relatively high sensitivity but relatively poor specificity (high false positive rate) for predicting postoperative hearing loss [47].

The latency of the N_1 of the AN-CAP and the P_1-N_1 amplitude are valuable measures, however, the morphology of the AN-CAP is also very informative. The amplitude of the AN-CAP is directly proportional to the number of active auditory nerve fibers. If fibers are damaged, asynchrony or conduction blocks will decrease the amplitude of the AN-CAP. Stretching of the auditory nerve (e.g. during cerebellar retraction) will increase the latency of the AN-CAP N_1 but not necessarily decrease the amplitude. A nearly total conduction block of the auditory nerve will eliminate only the negativity (N_1) of the normally triphasic waveform, leaving only a positive (P_1) peak [9]. Normally, the initial positive peak in the AP-CAP is likely to be generated as the depolarizing front of the auditory nerve action potential approaches the recording electrode and the negative peak generated as the action potential passes over the electrode. If the nerve is damaged just distal to the electrode, the depolarizing front approaches, but never passes the electrode. Changes in the AN-CAP are the most responsive indicators of trauma to the auditory nerve that can currently be monitored [48].

3.7 Criteria for warning:

Some clinicians support an arbitrary warning criterion of a 50% decrease in amplitude and/or a 10% increase in latency for any evoked potential being monitored. This is not an unreasonable criterion, but it has not been demonstrated to be predictive of postoperative function for monitoring of the auditory system [79]. It is also likely that the optimal warning criteria depend on the type of surgical procedure [79,53]. It is important that the neurophysiologist attend as well to changes in the morphology of the various waves in the ABR, that in conjunction with latency and/or amplitude changes may suggest the possibility of injury to auditory pathways.

When monitoring the AN-CAP, it is preferable to report any change in the response beyond the test-retest variability permitted by the conditions that can not be accounted for by the effects of anesthesia or other technical factors.

4.0 Special Considerations

4.1 Anesthesia and temperature effects:

The EcochG-CAP and AN-CAP are extremely resistant to the effects of anesthesia. The ABR is minimally affected by barbiturates, benzodiazepines, ketamine, nitrous oxide, propofol and muscle relaxants [77]. Halogenated inhalational agents such as isoflurane probably have a mild effect on ABR latency and amplitude that is proportional to the administered dosage [49,50]. ABR latency and amplitude are systematically affected by core body temperature. As temperature is decreased below 35º there is a prolongation of latencies and interpeak intervals and a decrease in the amplitude of all waves [51,52,78].

4.2 Complications during drilling:

Drilling the skull during surgical exposure creates bone-conducted noise that is carried to the cochlea and will readily mask acoustic stimulation. Hence, AEPs recorded during drilling will be highly variable and not provide accurate information for monitoring purposes. The monitoring team should notify the surgical team of this fact prior to the procedure to avoid false expectations.

4.3 Cerebellar retraction:

Cerebellar retraction is required during most CPA surgeries. Depending on the direction of retraction, there can be significant increases in the I-V interpeak interval on the surgical side. Retraction induced latency changes are generally reversible but under certain circumstances [53,54] can be associated with postoperative hearing loss.

5.0 Strategies for application of AEP monitoring

5.1 Hearing preservation:

One common application of auditory evoked potential intraoperative monitoring is to improve the probability of hearing preservation during surgery. If a relatively small tumor is to be resected (< 2 cm diameter), it will often be possible to monitor the EcochG-CAP, AN-CAP and ABR on the surgical side. The same applies for removal of other CPA tumors, microvascular decompression procedures of cranial nerves VII, VIII, and IX, and vestibular nerve sections-. As tumor size increases, it is less likely that an electrode can be placed to record the AN-CAP. In those cases, EcochG-CAP and ABR on the operated side should be monitored along with ABR on the non-operated side. If hearing function is good, EcochG may not be necessary.

5.2 Hearing restoration:

A second, far less frequent, application of auditory evoked potential monitoring is for hearing restoration [55,56]. These reports give evidence of monitoring during tumor resection in which hearing was restored by the procedure.

5.3 Preserving Brainstem Function:

In cases having very large brainstem tumors (>3-4 cm diameter) it is unlikely that preoperative hearing will be present on the tumor side. In such cases it still may be useful to monitor ABR function for the purpose of preserving brainstem function**.** In these cases, the ABR contralateral to the surgical side may be monitored. Changes in wave V will represent changes in function of the pons to midbrain region of the surgical side and may assist the surgical team in evaluating the consequences of their efforts. It has been reported that changes in the ABR contralateral to the tumor preceded changes in blood pressure as a result of pressure on the brainstem [40]. The ABR is therefore useful to assist the surgical team in determining the safe limits of tumor resection.

The recording of ABR's can also be helpful in evaluating and protecting brainstem function during vascular procedures involving the posterior circulation. However, the site of injury in these procedures is often in the thalamus or other structures not in the auditory pathway, and so the sensitivity and specificity of the ABR used as a single modality of monitoring is poor [57-59].

6.0 <u>Efficacy:</u>

Several factors must be considered when determining the efficacy of intraoperative auditory evoked potential monitoring [8] and results must be evaluated in the context of these factors:

- The number of surgeons involved in the study, their skill levels and, more importantly, their personal philosophies regarding hearing preservation and utilizing monitoring.
- Different surgical approaches which may or may not be related to the location of the tumor.
- The types of procedure, the type of pathology, and the size of the lesions in the study.
- The type of monitoring applied in the study ranged from utilizing one (EcochG-CAP, AN-CAP or ABR), to all three.
- Different criteria for what was considered a critical change in the evoked potential response.
- A different criterion for what was considered hearing preservation. Some studies used a 50 dB PTA (Pure Tone Audiometry)/ 50 % word recognition criterion, others used 70 dB PTA / 15% recognition, and others used any hearing vs. no hearing.

Two studies contend that auditory evoked monitoring did not improve hearing preservation [1,60]. In contrast, at least 10 studies state that the monitoring did improve hearing preservation [46,47,48,55,61-66] and the NIH consensus report also suggested that auditory evoked potential monitoring may be helpful [69]. Of particular interest was a report by Colletti [48] in which outcomes of cases monitored by just ABR or ABR and AN-CAP were compared. Both groups were matched for preoperative audiometric pure tone averages (500 Hz – 3 kHz). Postoperatively, the ABR only group had significantly poorer pure tone averages (82.5 dB) than did the ABR and AN-CAP monitored group (54.1 dB).

Monitoring with the ABR alone should be done only in cases of large tumors, with no ipsilateral hearing, and when the contralateral ABR is to be monitored. Otherwise, EcochG-CAP may profitably be employed to insure the presence of a reliable wave I as a reference for interpeak measures. AN-CAP recordings are the most rapidly recorded and sensitive to changes in auditory nerve function, and are to be used whenever it is technically feasible. It should also be noted that somatosensory evoked potentials can be used to monitor brainstem function during resections of brainstem tumors and may be used in conjunction with or in lieu of the ABR.

7.0 Special techniques:

The previously described methods of recording AN-CAP used monopolar recording techniques. It is also possible to use a bipolar recording electrode, which has some distinct advantages and provides alternative methods of nerve identification. Rosenberg [67] developed a bipolar electrode recording probe and a technique for identifying the cochlear and vestibular divisions of the VIIIth cranial nerve. Colletti et al. [48] have used bipolar recording electrode probes for differentiating between the auditory nerve and an eighth-nerve tumor. Responses were obtained from nerve tissue, but not from tumor.

Butler [68] also used a bipolar recording electrode for identifying auditory nerve tissue to improve hearing preservation during vestibular schwannoma resection. Instead of using click stimuli and averaging the AN-CAP, a 500 Hz tone was presented continually via headphone to the patient. The unaveraged signal recorded from the bipolar recording probe was amplified and routed to a speaker so the surgical team could hear the activity. When the recording probe was in contact with auditory nerve tissue, a 500 Hz tone was immediately broadcast from the speaker. This is a clever but relatively unproven procedure at this time and has not received widespread application.

8.0 Conclusions:

Intraoperative neurophysiological monitoring of the auditory system is a useful tool to the surgeon when he or she anticipates the possibility of damage to auditory structures during a surgical procedure. Monitoring cannot compensate for poor technique, and cannot eliminate surgical errors. It can and does reduce postoperative morbidity by providing the surgeon with additional information about the functional status of the structures involved that would not be available otherwise. In the hands of a trained neuromonitoring clinician and an informed surgeon, appropriate, multi-level auditory evoked potential monitoring will surely benefit the patient.

9.0 Major Recommendations

Based upon scientific studies, case studies and the expert opinion of those in the intraoperative monitoring field, this summary contains a set of major recommendations regarding the use of auditory evoked potentials as well as an indication regarding the strength of evidence and the strength of recommendation supporting them. The scales are modified from those used by Nuwer et. al. [80] are used. In particular, the strength of evidence is graded as follows:

Kind of Recommendation

Standards. Generally accepted principles for the patient management that reflect a high degree of clinical certainty (i.e., based on Class I evidence, or when circumstances preclude randomized clinical trials, overwhelming evidence from Class II studies that directly address the question at hand or from decision analysis that directly addresses all the issues).

Guidelines. Recommendations for patient management that may identify a particular strategy or range of management strategies that reflect moderate clinical certainty (i.e. based on Class II evidence that directly addresses the issue, decision analysis that directly addresses the issue or strong consensus of Class III evidence).

Practice options or advisories. Other strategies for patient management for which there is some favorable evidence, but for which the community still considers this an option to be decided upon by individual practitioners.

Practice parameters. Results, in the form of one or more specific recommendations, from scientifically based analysis of a specific clinical problem.

Strength of Recommendation Ratings

Type A. Strong positive recommendation, based on Class I evidence, or overwhelming Class II evidence.
Type B. Positive recommendation, based on Class II evidence.
Type C. Positive recommendation, based on strong consensus of Class III evidence.
Type D. Negative recommendation, based on inconclusive or conflicting Class II evidence.
Type E. Negative recommendation, based on evidence of ineffectiveness or lack of efficacy.
Type F. No recommendation, based on divided expert opinion or insufficient data.

Quality of evidence ratings

Class I. Evidence provided by one or more well-designed, prospective, blinded, controlled clinical studies.
Class II. Evidence provided by one or more well-designed clinical studies such as case control, cohort studies, etc.
Class III. Evidence provided by expert opinion, nonrandomized historical controls or case reports of one or more.

9.1 *Recording of Auditory Brainstem Responses is of value in assessing gross brainstem function during surgical procedures involving the brainstem* (**Guideline, Type C, Class III recommendation**).

9.2 *Recording of Auditory Brainstem Responses is of value in assessing gross brainstem function during procedures during which there is a risk of injury to the posterior circulation* (**Guideline, Type C, Class III recommendation**).

9.3 *Recording of Auditory Brainstem Responses is of value in assessing the function of the VIIIth nerve during surgical procedures in the cerebellopontine angle (CPA)* (**Guideline, Type C, Class III recommendation**).

9.4 *Direct recording of the auditory nerve compound action potential (AN-CAP) is of value in assessing the function of the VIIIth nerve during select surgical procedures in the cerebellopontine angle* (**Practice option, Type C, Class III recommendation**).

9.5 *Recordings of the electrocochleogram (EcochG) can be of value in assessing cochlear function during select surgical procedures in the cerebellopontine angle* (**Practice option, Type C, Class III recommendation**).

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