Direct brainstem recording of auditory evoked potentials during vestibular schwannoma resection: nuclear BAEP recording

Technical note and preliminary results

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Intraoperative monitoring of brainstem auditory evoked potentials (BAEPs) using conventional ear-to-vertex recording provides new information on the functional state of the auditory pathway every 30 to 90 seconds. Under ideal conditions and by means of exponential averaging, this time course may be reduced to 20 seconds. Recording of cochlear nerve action potentials by direct nerve recording has been advocated because of its faster delivery of information, even though this is restricted to the control of the cochlear nerve. However, that technique is applicable only in cases of very small tumors, in which at least some portion of the nerve is not covered by tumor, and electrode dislocation is still a frequent problem.

As previously shown, the activities of the cochlea, the acoustic nerve, and the brainstem nuclei need to be jointly monitored. These are the relevant structures that are endangered, but whose functions need to be maintained to preserve hearing during surgery of cerebellopontine angle (CPA) lesions. Since 1994, a method of positioning electrodes on the cerebellar retractor and directly recording at the cerebellomedullary junction (that is, in the closest vicinity of the anterior cochlear nucleus) has been developed and applied in 40 patients. Using this method, large BAEP amplitudes are obtained, facilitating "on-line" information within 5 to 15 seconds. The electrode does not interfere with microsurgical activities. In some patients who have good or moderate hearing, but absent or severely diminished conventional BAEP responses, the BAEP responses become clear using this direct recording and the surgeon can proceed with continuous monitoring to achieve successful hearing preservation.
Electrode Setup

Two monopolar small-tag electrodes are prepared. Each electrode is composed of a 1- to 2-mm-diameter tag made of silver or copper coated by silver with silicone-insulated wires (upper). These are attached to the retraction side of the cerebellar retractor using sterile drapes with the strings hidden at the back of the blade, and the uninsulated tags are placed at the distal end of the retractor blade (lower).

Method of Recording Direct Nucleus BAEPs

Electrode Setup

Two monopolar small-tag electrodes are prepared. Each electrode is composed of a 1- to 2-mm-diameter tag made of silver or copper coated by silver with silicone-insulated wires (Fig. 1 upper). The electrodes are attached to the retraction side of the cerebellar retractor, using sterile drapes with the strings hidden at the back of the blade, and the noninsulated tags are placed above the distal end of the retractor blade (Fig. 1 lower). In CPA surgery, after suboccipital craniotomy, dura incision, and cerebrospinal fluid (CSF) drainage from the pontomedullary cistern, have been achieved, the retractor is inserted and placed over the cerebellum as usual for cerebellar retraction. In this way, the two electrode tips are placed at the medullocerebellar junction (Fig. 2 upper left) or, in large tumors, at the tumorocerebellar junction; as the tumor becomes reduced during surgery (Fig. 2 upper right), the electrodes move into closer contact with the medullocerebellar junction. They remain in place in the vicinity of the cochlear nerve entry zone throughout the dissection until complete tumor removal is accomplished (Fig. 2 lower).

Direct BAEP Technique

Using earphones with an attached air tube, acoustic stimulation is achieved by applying 100-dB click stimuli at 11 to 20 Hz to the side of the lesion; the contralateral side is masked by white noise at 60 to 80 dB. The BAEP response is recorded on one channel using a conventional ear-to-vertex setup (with subcutaneous needle electrodes); direct BAEP recording is performed on a second channel using the electrodes that are attached to the retractor.

Two methods exist for direct brainstem recording. Direct bipolar nucleus recording using both monopolar tag electrodes is applicable if the electrode is positioned precisely at the cochlear nucleus; this is the case in small tumors that may touch but not cover the brainstem. Direct nucleus recording using a monopolar tag electrode-to-vertex reference may be used with the conventional vertex electrode; this is the method that is best and most frequently used when the tag electrodes are placed at some distance from the nucleus, as at the start of surgery of large tumors.

Filters are set at 200 to 2000 Hz; sensitivity is set at 20 to 100 $\mu$V for direct recording and at 2 to 5 $\mu$V for conventional recording; the time base is 10 $\mu$sec; and the stimulus duration is 100 to 200 $\mu$sec. The BAEPs on the direct nucleus recording are correlated with conventional BAEP components.

Results

Of 34 patients with vestibular schwannomas, 24 exhibited some conventional BAEP responses at the start of surgery; in eight of these patients there was partial wave loss, with only component waves I and V visible and with limited chances for continuous monitoring. In all 24 patients direct BAEP recording at the brainstem was technically possible: in 17 monopolar recording was performed using a conventional reference; in one patient bipolar recording was used; and in six patients both types of direct recording were performed. In 19 patients direct BAEP responses and hearing were preserved. In two cases in which there was a loss of conventional BAEP responses during dissection, the direct BAEP responses were preserved and correlated correctly with hearing preservation.

In 10 of 34 patients conventional BAEP responses were lost at the start of surgery. In three of these cases, the BAEP responses were detected on direct recording: in two patients the direct BAEP responses and hearing were preserved; and in one patient the direct BAEP responses and hearing were lost. If both conventional and direct BAEP responses could not be recorded, the correct technique and position were verified by recording crossactivity during contralateral stimulation of the healthy side.

Typical BAEP responses were obtained using the direct recording electrodes. Component waves I to V were correlated according to their latencies, amplitudes, and morphology with conventional BAEP responses. The polarity of the direct BAEP–recorded negative and positive component waves I (P-I and N-I, respectively) may be inverted compared with conventional BAEP responses, but the waves can be identified according to their time correlation with the conventional BAEP recordings and by their reproducibility. Component wave II shows normal polarity and morphology (sometimes inversion). Typically component wave III is especially large, generally the largest of all the component waves. If the conventional BAEP response shows severe BAEP deformation, such as broadening or splitting of component wave III, there are several peaks belonging to this component to be identified on
direct recording. Component waves IV and V are generally smaller than III. Using direct recording, the BAEP amplitudes of all these component waves are 10 times larger (range 4–20 times) than those obtained using direct recording. On direct bipolar recording, the amplitudes are two to 10 times larger, but are more smoothly formed than on the monopolar tag electrode-to-vertex electrode orientation.

The correlation between direct and conventional BAEP components is demonstrated by Fig. 3. All the negative upward components (P-I to P-V) of conventional BAEP responses (Fig. 3A) were also identified on direct recording (Fig. 3B and C); the main difference was the inversion of P-I. The amplitudes continued to be 10 (Fig. 3B) to 100 times larger up to the end of surgery (Fig. 3C).

Direct BAEP monitoring is faster in two respects: because the responses are well delineated, shorter sampling periods are sufficient and important changes (deteriorations as well as improvements) are detected earlier, as is illustrated by Fig. 4. In a 53-year-old woman with an intrameatal–extrameatal tumor, a conventional BAEP response was recorded showing components P-I to P-V during CSF drainage and retractor positioning (Fig. 4A). At cerebellar retraction when the direct electrodes were placed, the BAEP response was slightly delayed, and the direct BAEP provided 10-fold larger responses (Fig. 4B) with all components being present although component wave P-I was inverted. During tumor dissection and up to closure of the internal auditory canal, the direct BAEP response was preserved, occurred slightly earlier again, and stayed significantly larger (Fig. 4C) than the conventional BAEP response at the end of surgery (Fig. 4D). Hearing was preserved at the preoperative level (preoperative loss of 45 dB and postoperative loss of 40 dB at 1–3 kHz).

Because significant BAEP changes can be detected immediately during tumor dissection, any further deterioration can be counteracted promptly by taking short breaks in the surgical procedures; thereby, BAEP and hearing preservation can be supported in especially delicate cases such as a patient with hearing in only one ear. Figure 5 demonstrates the monitoring sequence in a 56-year-old patient who presented with right-sided deafness and left-sided vestibular schwannoma. Traces A1, B1, C1, D1, and E1 display the direct recordings and traces A2, B2, C2, D2, and E2 the conventional recordings. The BAEP component waves I, II, III, and V were stable at retractor fixation (Fig. 5A). After some drilling, component waves III and V appeared later (Fig. 5B). As the tumor was dissected off the nerve, direct recording showed some amplitude reduction in component wave III (C1), although the conventional recording remained stable (C2). During short breaks, the BAEP stabilized and surgery was continued. At the point at which the tumor was pulled upward and dissected at the tumor–nerve border, component wave III latency occurred later (Fig. 5D). This signaled the surgeon to release all structures for a short period to await their functional recovery. During
muscle closure of the internal auditory canal, the direct recording (E1) signaled an amplitude increase and an earlier onset of component wave III. The earlier detection of some deterioration and of some improvement by direct recording was useful in this case and supported the preservation of hearing “in the last ear.”

Discussion

The introduction of neurophysiological monitoring into neurosurgery has significantly influenced our understanding of the impact of microsurgical actions on neural structures. Although increasing rates of hearing preservation are reported, the value of monitoring in this respect is still in dispute. The two most frequently discussed topics in neurophysiological monitoring are its insufficient speed due to the summation and averaging processes (the lack of on-line information) and its limited reliability (too many false negative or false positive monitoring results). Recording in the vicinity of BAEP generators has been designed to counteract both problems.

Advantages of Direct Versus Conventional BAEP Monitoring

Conventional BAEP monitoring consists of a continuous recording of so-called far-field potentials from the scalp surface. This requires summation and averaging of generally 500 responses, under ideal conditions 100 sweeps; the latter is rarely achieved. This implies relatively small amplitudes and relatively long sampling periods lasting approximately 30 seconds; the time period is rarely shorter and generally longer. In our conventional recording technique, we have reduced the sampling period to a minimum of 20 seconds by means of exponential averaging. However, in cases in which there are more prominent artifacts or in severe BAEP deterioration, longer sampling periods are necessary. The closer the electrodes are positioned toward the generators of the BAEP components, the stronger (that is, more visible) these components should become, thereby shortening the sampling period to approximately 5 to 15 seconds. With more “original” recording close to the BAEP origins, monitoring should become faster and neurophysiological changes can be identified more closely with the microsurgical process.
Direct brainstem recording of auditory evoked potentials

Several investigators have reported fast and successful monitoring of direct recording from the cochlear nerve. However, they have had to admit that they require placement of an intracranial electrode in such a way as to contact the cochlear nerve without interfering with surgical access. Direct nerve recording is impossible to use in tumors reaching or even compressing the brainstem and it also disturbs microsurgical activities in cases of smaller tumors. Furthermore, direct nerve recording in general neglects the brainstem response, that is, it does not reflect the activity of the whole auditory pathway infratentorially.

Techniques of Direct Brainstem Recording

Studies and early clinical trials of recordings obtained within the brainstem and close to the brainstem have been performed by individual investigators using the auditory brainstem implant technique (although mostly via a different approach), in which an electrode array is positioned below the flocculus pushing toward the fourth ventricle and onto the dorsal cochlear nucleus. For clinical use in CPA surgery, Møller and colleagues have positioned a monopolar electrode at the same site. In this manner, acoustic evoked responses with large amplitudes can be recorded. However, those waves show a different waveform and different latencies and thus have no reliable correlation with conventional BAEP responses. Besides, this method is limited to small- to medium-sized tumors and is more prone to electrode displacement. Using the technique presented in our current report, the surgical process is by no means altered or disturbed and there is no related lesion or morbidity. The reasons for the differences in the responses obtained using either technique are probably twofold: as the electrode is pushed farther toward the fourth ventricle, it contacts the dorsal cochlear nucleus, not the anterior nucleus as is the case with the technique presented here. The positioning of the direct electrode in relation to the wave generators and to the conventional electrode determines the similarity of the waveforms and their polarity. As the retractor electrode is placed medial to the cochlea and the eighth cranial nerve, component waves P-I and N-I are inverted, whereas the polarity is identical for all those generators that lie medial to the electrode. Component wave II may appear inverted or slightly displaced in comparing the direct to the conventional technique because the cochlear nerve lies just at the center between either recording electrodes.

Importance of Component Wave III

As pointed out previously, component wave III represents the activity of the cochlear nucleus and is the component that displays the most sensitivity to any surgical action; its diminution, delay, or even disappearance in general precedes all other significant changes in component waves I or V. This is especially relevant because over 70% of significant wave losses do not occur together and general precedes all other significant changes in component waves I or V. This is especially relevant because over 70% of significant wave losses do not occur together and acutely, but rather in a stepwise fashion. Therefore, direct recording at the component wave III generator provides optimal control of any early changes in this important wave and the chance for immediate reaction to any deterioration. Thus, successive wave losses may be prevented.

Limits of Conventional and Direct BAEP Recording

In this preliminary study all direct BAEP recordings have been reliable with regard to postoperative hearing function. Nevertheless, the total reliability of the presence or absence of BAEP responses to indicate preservation or loss of hearing must not be expected; the reasons for this are a matter of speculation. Recording of typical BAEP waveforms represents the activity of only a portion of the auditory nerve axons (a certain frequency spectrum) and it is dependent on their synchronous activity. In case of postoperative hearing preservation, the conventional BAEP response is usually preserved, although intraoperatively it

FIG. 5. Traces showing the sensitivity of direct and conventional BAEP monitoring sequences. The monitoring sequence in a 56-year-old patient with right-sided deafness and left-sided vestibular schwannoma is presented by direct recording on traces A1, B1, C1, D1, and E1 and by conventional recording on traces A2, B2, C2, D2, and E2. Upward BAEP component waves P-I, P-II, P-III, and P-V are stable at retractor fixation (A). After some drilling, P-III and P-V appear later (B). As the tumor is dissected off the nerve, direct recording shows some amplitude reduction in P-III (C1), whereas the conventional recording is stable (C2). At the time the tumor is pulled upward and dissected at the tumor–nerve border, the P-III latency appears later (D). After a short break recovery is observed. During muscle closure of the internal auditory canal, the direct recording trace signals an amplitude increase and an earlier onset of P-III (E1).
may be lost (temporarily) because of too much impulse asynchrony—at least for a certain period. However, at the moment of temporary intraoperative BAEP response loss, there may be some persistent useful electrical activity along the auditory pathway that can be detected by direct brainstem recording. So far, we have encountered two cases with absent conventional and preserved direct BAEP responses, both of which showed postoperative hearing preservation. Using direct anterior nucleus recording, it is possible that the sensitivity and the reliability of monitoring may be improved.

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References


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