Do evoked potentials have any value in anaesthesia?

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Although the generation of cerebral electrical potentials in response to stimulation of peripheral nerves (sensory evoked potentials) has been known for many years,¹ it has only found clinical applications recently. With the advancement of computer technology, this clinical diagnostic tool has now found its way into the operating room.^{2,3} This review will explain the physiological basis of monitoring sensory evoked potentials (EP) and attempt to put the application of intraoperative monitoring into perspective for the practising anaesthetist.

Electrophysiological basis of sensory EP

Sensory EP's are electrical potentials generated in response to stimulation of a peripheral nerve or cranial nerve. These potentials are thought to arise from (1) action potentials and/or (2) graded postsynaptic potentials during the propagation of the electrical impulse from the periphery to the brain and can be recorded over the scalp as well as at various sites along the anatomical pathway using surface electrodes.⁴ This differentiates the pathway and stimulus-specific event-related evoked potential from the electroencephalogram which is random in nature.⁵ The amplitude of sensory EP is small compared to the EEG, therefore necessitating the use of computer averaging or summation to extract the sensory EP signals from the background EEG. The major differences between EP and EEG are summarized in the Table.

TABLE Major differences between the electroencephalogram and evoked potentials

EEG	EP
Spontaneous random activity	Event-related activity
Non-specific function	Pathway-specific
Large amplitude	Small amplitude
Minimal equipment	Computer averaging required
Influenced by anaesthesia	Less influenced (short latency EP)

Classification and common modalities of sensory EP

Similar to electrocardiographic signals, sensory EP's are volume-conducted and can be recorded from scalp electrodes in response to stimulation of any peripheral nerve or cranial nerve. As sensory EP's are anatomically pathway-specific, a component wave or peak that appears

early reflects a neurogenerator sited distally and away from the cortex, e.g., in the brainstem. These short-latency potentials are often referred to as far-field potentials since they occur away from the recording scalp electrode. The later components (intermediate or long-latency potentials) reflect neurogenerators sited higher up on the neuraxis (e.g., the sensory cortex) and are often referred to as near-field potentials.^{2,3} By selecting the appropriate windows or latencies of the waves to be recorded, one can study specifically the brainstem or cortical components of specific anatomical pathways. The three most commonly used modes of sensory evoked potentials are: (1) brainstem auditory evoked potentials (BAEP), (2) somatosensory evoked potentials (SSEP), (3) visual evoked potentials (VEP).

All three modalities have found wide clinical applications in the neurological assessment of patients with equivocal symptoms or in patients who cannot be reliably assessed due to lack of cooperation or inability to communicate. For example, both SSEP and VEP have been used to confirm the diagnosis of multiple sclerosis and BAEP has been found to be useful in the assessment of hearing in infants.⁵ This review will restrict discussion to the last application, namely, in patients who cannot be assessed clinically due to the state of general anaesthesia. For this purpose, VEP has little or no application since the intraoperative recordings have been found to be extremely variable and therefore unreliable.⁶

SSEP are recorded over the parietal cortex in response to electrical stimulation of the contralateral median nerve or posterior tibial nerve. BAEP are recorded over the vertex in response to monaural or binaural stimulation of the auditory nerve, generally using sound clicks delivered with headphones or ear-insert transducers.

Interpretation of sensory EP

Sensory evoked potentials are characterized by specific peaks and troughs which are labelled according to their polarity (+ve or -ve and often referred to as P or N) and

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the time at which they occur following the stimuli (latency). For example, N20 in SSEP refers to a negative peak that typically occurs 20 msec following the stimulus. Assessment of changes in sensory EP is based on changes in amplitude and/or latency. Ischaemia or injury to the underlying neurological structures generally results in a decrease in amplitude and an increase in latency or total abolition of the waveforms.

Important variables in intraoperative recording of sensory EP

Recording of sensory EP in the operating room can be challenging and rewarding, but it can also be very frustrating. To record sensory EP reliably and consistently, many factors must be considered. The operating room is a very hostile electrical environment and minor current leakage from surrounding equipment or the continuous use of electrocautery may make it impossible to acquire adequate signals. Other confounding variables that may influence sensory EP include anaesthetic agents (see below), change in body temperature, and fluctuation of arterial carbon dioxide tension (PCO₂) and systemic blood pressure. Changes in PCO₂ and blood pressure within the physiological range have no significant effect on sensory EP, but this is not so with a change in body temperature. Although mild hypothermia is compatible with normal readings,⁷ a decrease in temperature below 34.5°C causes a progressive decline in amplitude and an increase in latency;⁸ neither SSEP nor BAEP can be reliably recorded below 18°C.^{9,10} The development of hypothermia does not necessarily diminish the value of SSEP monitoring since unilateral injury to the pathway at risk can be inferred from differences between bilateral recordings, but does limit its usefulness as a monitor of global cerebral function during hypothermic cardiopulmonary bypass.

Proper recording of sensory EP therefore depends not only on a meticulous technique with careful placement of electrodes and continuous attention to the acquisition of signals, but also on minimizing changes in other confounding variables.

Application of intraoperative sensory EP

There are two reasons behind the investigation of the application of intraoperative monitoring of sensory EP. The first regards an age-old question – Is my patient asleep? In other words, the desire to have an objective assessment of the depth of anaesthesia. The second, which is far more important, is concerned with the question – Can we diagnose impending neurological injury, whether to a specific cranial nerve, spinal cord, or the sensory cortex and prevent its occurrence by giving appropriate warning signals to our neurosurgical colleagues?

Depth of anaesthesia

Although the use of sensory EP as a measure of depth of anaesthesia has been suggested,¹¹ it does not appear to have any advantage over either conventional EEG or computer-processed EEG. Moreover, the effect of surgical stimulation on sensory EP has not been clarified. Nevertheless, it is important to elucidate the effects of anaesthesia, not only to allow the design of an anaesthetic regimen suitable for intraoperative monitoring, but also to enable intelligent interpretation of intraoperative sensory EP changes. Two general statements can be made about the influence of anaesthesia on sensory EP. (1) Intravenous agents have little or no effect on all modalities of sensory EP whereas all inhalational agents cause a dose-related decrease in amplitude and increase in latency.^{12–14} (2) The short-latency components (such as BAEP) are relatively resistant to anaesthetic influence and can be recorded even during deep inhalational anaesthesia, albeit with some increase in latency,^{15–17} whereas the intermediate and long-latency components are more susceptible and can be abolished by high dose inhaled anaesthetics.^{18,19} Sensory EP's are therefore best recorded during a narcotic-relaxant anaesthetic with or without low-dose inhaled anaesthetic. If higher doses of inhalational agents are to be used, nitrous oxide should be avoided because of its particularly deleterious effect on cortical evoked potentials.^{18–21} Regardless of the anaesthetic used, a useful guideline is to maintain as near steady state anaesthesia as possible during recording of intraoperative sensory EP.

Prevention of neurological injury

Intraoperative monitoring of sensory evoked potentials may be valuable when (a) a neural pathway amenable to monitoring is specifically at risk during a neurosurgical procedure (b) recording and stimulating sites are available and do not interfere with the procedure. The surgical procedures where monitoring of sensory EP's have been found to be useful are summarized below.

NEUROVASCULAR PROCEDURES

Both SSEP and BAEP have been studied during cerebral aneurysm surgery. Monitoring of SSEP, particularly the central conduction time (interpeak latency between cortex and medulla), has been found to be useful and to correlate with neurological outcome in some patients during aneurysm surgery.^{22,23} BAEP may be valuable in vascular procedures in the posterior fossa where the brainstem is at risk,^{24,25} particularly when temporary or permanent major vascular occlusion is contemplated.^{26,27} Neither modality is entirely specific, however; although good correlation with postoperative neurological outcome can be demonstrated, both false negatives and false positives

occur.²⁸ The simultaneous recording of both modalities may improve these results but further complicates the recording technique.

SSEP have been monitored during carotid endarterectomy, and are thought to be at least as good as conventional EEG, if not better, for determination of the adequacy of cerebral perfusion during cross-clamping of the carotid artery.²⁹⁻³¹ However, there was no agreement on what cortical peak should be used for monitoring purposes in these studies.^{29,30,32}

ACOUSTIC NEUROMA

Intraoperative monitoring of BAEP may help to preserve the eighth cranial nerve during this surgical procedure.³³⁻³⁵ No false negatives occur and if BAEP disappear intraoperatively and fails to return, unilateral deafness uniformly results. However, in a number of these cases the cranial nerve is knowingly sacrificed intraoperatively and the disappearance of BAEP in these situations merely confirms what is expected to occur.

CORRECTIVE SURGICAL PROCEDURE ON THE SPINE

This is perhaps the procedure where intraoperative monitoring of SSEP has gained the widest and most ready acceptance. Although scoliosis surgery carries only a low risk of neurological injury of less than one per cent, the resulting disability is so devastating that it necessitates some means of detection before permanent injury occurs. By monitoring simultaneously the cortical and spinal evoked potentials (above and below the corrective site) generated in response to stimulation of the posterior tibial nerve, injury to the spinal cord may be detected early and this frightening complication averted.^{36,37} Improved results are obtained with specially designed systems using sterile intradural and epidural electrodes.³⁷ The use of SSEP monitoring obviates the need for the "wake-up" test, which is at best unpleasant for the patient. However, even in this setting false negatives have been known to occur,^{38,39} perhaps because of the different anatomical location of the sensory and motor tracts in the spinal cord.

SSEP monitoring is also useful in procedures where the spinal cord is placed at risk due to ischaemia, as occurs in cross-clamping of the aorta during operations on the aorta.⁴⁰

MISCELLANEOUS

Both SSEP and BAEP have been used during induced hypotension for cerebral aneurysm surgery.^{41,42} SSEP have also been used during hypothermic cardiopulmonary bypass, but interpretation is rendered difficult due to the effect of low temperature on the recordings.⁴³ These indications must be considered research and experimental in nature rather than clinical.

Limitations in the use of intraoperative sensory EP

Despite the wide availability of affordable, turn-key equipment, intraoperative monitoring of sensory evoked potentials is far from being routine, with perhaps an exception in scoliosis surgery. There are many reasons for this limited use; (1) the recording of consistent and reproducible sensory EP's in the operating room, which is electrically hostile, is difficult and requires considerable experience as well as cooperation between the neurosurgeon and the anaesthetist; (2) strict criteria for interpretation of sensory EP changes have yet to be developed. Although permanent changes or disappearance of sensory EP's are generally associated with significant injury, transient changes or losses of sensory EP's are entirely compatible with an uneventful recovery. This raises the spectre of excessive false alarm and an unacceptably low specificity; (3) many confounding variables can affect the intraoperative recording, and although the influence of hypothermia and anaesthesia is known, it is not clear what the combined effects are, or indeed what additive or interactive effects ischaemia may have on this background; (4) the very basis of monitoring of sensory evoked potentials is the presence of an intact anatomical sensory pathway amenable to monitoring. A patient with a pre-existing abnormality, therefore, is difficult to monitor and the results sometimes impossible to interpret. A more distressing problem is the potential preservation of sensory-evoked potential despite loss of motor function, which has been known to occur in several cases.³⁹

What can we expect in the future?

Further improvement in technology would facilitate the recording of intraoperative sensory-evoked potentials in a consistent and reliable manner and make it possible even for the inexperienced to do so. Ongoing development of techniques to monitor motor-evoked potentials will not only improve the specificity,^{44,45} but also open new areas of utilization. However, if strict criteria for interpretation of intraoperative changes cannot be established, then interventional therapy based on these changes cannot be implemented with confidence, and the utility of this mode of monitoring will continue to be limited.

Summary

Intraoperative monitoring of sensory-evoked potential has been found to be useful in many areas, particularly during scoliosis surgery and neurovascular surgery. However, it remains a complicated technique, devoid of simple interpretation and as such cannot be considered a routine clinical monitor except in large centres with special expertise. Increase in utilization must await improvement in technique and development of strict criteria for interpretation.

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