

GUIDELINES FOR PERFORMING EEG AND EVOKED POTENTIAL MONITORING DURING SURGERY

Foreword

The 5th Congress of the International Organisation of Societies for Electrophysiological Technology (OSET) was held in August of 1995 in Washington, D. C. At this time the OSET Education Committee was charged with establishing guidelines for the performance of intraoperative EEG and evoked potential monitoring. Shortly after the meeting, a request was issued to all OSET member countries for copies of any existing guidelines developed within their boundaries. Responses were received from the United Kingdom, France, Canada, and the United States. A subcommittee of the Education Committee was then formed to review the information received and to draft a set of intraoperative guidelines that could be accepted by the OSET member countries. Working with me to draft the original guidelines were two very dedicated and enthusiastic subcommittee members: Ken Klettke, R.E.T., R. EP T. of Toronto, Ontario, Canada, and Bobby Taskey, R. EEG T., CNIM of Syracuse, New York, USA. I am very grateful to Ken and Bobby, and to the OSET Executive Committee, for their commitment to this important project.

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Introduction

EEG and evoked potential monitors can provide valuable information during intraoperative procedures that may compromise the neurological function of the anaesthetised patient. The utility of the monitors ranges from reassuring that normal activity is consistent, to detecting reversible injury, and identifying specific neural structures.

The following OSET Guidelines for EEG and Evoked Potential Monitoring during Surgery have been established to provide internationally recognised procedural outlines. The Guidelines strive to provide a working foundation for the development of individual laboratory protocols while also respecting this evolving field.

As the field of intraoperative monitoring continues to develop and mature, more methods for monitoring sensory systems have been rapidly introduced. We have elected to include only the most routinely performed procedures in this presentation, those with protocols that have been

researched and repeatedly performed. It is expected, however, that even these Guidelines will change over time.

1. RECOMMENDED STANDARDS FOR SURGICAL MONITORING PERSONNEL

Neurophysiological technologists monitoring in the operating room will be required to evaluate and discuss the acquired data, actively operate all monitoring equipment with vigilance to patient safety, and prepare a permanent record of the monitoring results and their relation to surgical events. They will also be required to interact with all operative personnel including nursing staff, surgeons, and anaesthesiologists. Intraoperative monitoring should be performed to the highest possible standards by experienced, competent technologists.

1.1 Qualifications

Neurophysiology technologists performing intraoperative monitoring must have obtained the accepted registry/certification/credential recognised within their country. They should have a minimum of three years' experience in performing routine neurodiagnostic studies and one year's experience in performing neurological monitoring under supervision. Technologists should be encouraged to attend continuing education programs in operative monitoring, as well as in other related neurodiagnostic areas.

1.2 Responsibilities

It is the responsibility of the monitoring technologist to:

- 1.2.1. Participate in establishing, before surgery, communication protocols with the surgical team to report monitoring activity;
- 1.2.2. Accurately apply all recording and stimulating electrodes;
- 1.2.3. Perform monitoring procedures and documentation according to established protocols;
- 1.2.4. Identify monitored waveforms and any variations from baseline;
- 1.2.5. Have an understanding of anaesthetic techniques and physiologic changes that can affect the waveforms being monitored; and
- 1.2.6. Be competent in the operation of monitoring equipment, including troubleshooting and electrical safety.

1.3. Data Reporting

It is recommended that an interpreting neurophysiologist be present in the operating room, or available via a real-time, remote system, to report monitoring data to the surgeon. When the neurophysiologist is not present and the technologist is providing the waveform description to the surgeon, it is the surgeon who is responsible for the interpretation of the waveform description

and any course of action taken. The interpretation of the recorded data is the responsibility of the clinical neurophysiologist.

2. SURGICAL MONITORING TECHNIQUE

2.1. Preoperative Baseline Assessment

Whenever possible the performance of preoperative baseline studies in the modality to be monitored are recommended. The baseline study can be performed in the clinical lab prior to the surgical admission or, less desirable, in the patient holding area before entering the surgical suite. The benefits of the baseline study include: identifying preoperative dysfunction that might predict operative risk, identifying additional neurological disease that might preclude normal (or useful) monitoring activity, and serving as the standard to measure subsequent postoperative changes against.

2.2. Stable Post-anaesthesia/Pre-incision Baseline

A stable monitoring trace should be secured prior to the surgeon's initiating the operative procedure. This intraoperative baseline should be obtained after the patient's desired anaesthetic state is achieved. The baseline should then be stored for review and comparison as the case progresses.

2.3. Continuous Monitoring

EEG and evoked potential monitoring should begin before the initiation of the surgical procedure and proceed continuously throughout anaesthesia. Some recording parameters in place for EEG monitoring may need adjustment to conform to the developing patterns; however, parameters and stimulation techniques should not change during EP monitoring.

2.4. Troubleshooting

Throughout monitoring, keen observation of the waveforms will reveal the presence of difficulties relating to the OR environment, instrumentation, electrodes, and patient artifacts. The rapid assessment and, if possible, elimination of artifacts and malfunctions is essential for the validity of the ongoing monitor. If a change occurs in the waveforms being monitored, and the cause is believed to be of technical origin, the surgeon must be notified if the time required to identify the source exceeds the warning time established between the surgeon and monitoring technologist.

2.5. Documentation

The monitoring technologist maintains a written record of the following (and their relationship to changes in the monitored waveforms): changes in anaesthetic levels, the surgical procedure and any manipulative events, and changes in the patient's physiological state (blood pressure, temperature, etc.). The final, summary report is the responsibility of a qualified neurophysiologist.

2.6. Alarm Criteria

It is the responsibility of the monitoring team to establish communication guidelines for relating changes that may occur in the monitored waveforms. The criteria should outline what is considered a significant change in amplitude and latency for evoked potential monitoring, and in waveform patterns and contrasting hemispheric changes for EEG monitoring.

3. STANDARDS OF SAFETY

3.1. Electrical Safety

Because the anaesthetised patient is unable to report any irritation or pain, it is essential that all electrodes, as well as monitoring and stimulating equipment, be operated within safe limits. The following standards should be met:

3.1.1. Monitoring equipment must meet the electrical safety standards established within the country. Follow-up inspections should be scheduled at a minimum of twice per year. Equipment should be mounted or housed to protect it from spills of blood and other fluids.

3.1.2. The operating room must have an installed grounding system and the integrity of all outlets checked frequently.

3.1.3. All personnel involved in operative monitoring should have thorough training in working in the electrically hostile environment of the operating room and with electrically susceptible patients.

3.2. Infection Control

Technologists must follow established infection control policies and be aware of procedures for working in the sterile field area. Particular attention should be paid to preparing instrumentation to enter the operative arena and preparing electrodes for the sterile field. (See OSET Infection Control Guidelines, 1999)

INTRAOPERATIVE MONITORING OF SOMATOSENSORY EVOKED POTENTIALS

Introduction

Somatosensory evoked potentials (SSEPs) are monitored during surgery with two primary goals in mind:

- 1) to monitor the function of neural structures at risk of iatrogenic injury, and
- 2) 2) to identify specific neural structures.

Neuromonitoring may be useful during surgery that may affect spinal cord function (deformity correction, traumatic spinal fracture repair, tethered cord release, spinal cord mass removal), brainstem function (posterior fossa mass removal), brain function (carotid endarterectomy, aneurysm repair), and peripheral nerve function (pelvic fracture surgery).

Neuroidentification may be useful during surgery for removal of cerebral masses near the sensorimotor cortex (central sulcus identification or cortical mapping) and ablation of spinal dorsal root entry zone, DREZ, for pain relief (identification of DREZ and adjacent spinal tracts).

Neuromonitoring Principles

Neuromonitoring using SSEPs requires 1) stimulation of a site caudal to the neural structure at risk, and 2) recording of evoked responses in at least one site caudal, and one site rostral, to the neural structure at risk. The caudal site will monitor the effectiveness of the stimulus, while the rostral site will monitor the passage of the evoked response through the neural structure at risk. A diminished rostral response during surgery, in view of a maintained caudal response, leads the monitoring technologist to look for possible technical reasons for the change and, if none are found, informing the surgical team of the change. This can allow surgeons to alter the surgical procedure in an effort to alleviate a dysfunction if possible. Technical reasons for a change in the rostral response include increases in anaesthetic agents or medication bolus, displacement of recording electrodes, increased electrical noise, etc.

1. STIMULATION

1.1. Electrodes

Either surface electrodes or subdermal needle electrodes can be used. Due to a more constant impedance, needle electrodes can deliver a more consistent stimulus in long cases. Although rare, electrical burns from stray capacitances have occurred when using subdermal needle electrodes. prevention is based on a well-applied ground electrode and caution when electrocautery is in use, i.e., separate the electrocautery leads from the neuromonitoring leads.

1.2. Stimulus

Rectangular, biphasic pulses using either constant current or constant voltage, duration of 100 to 200 μ s, and intensity about 1.5 times motor threshold but not to exceed 20 mA or 60 V for subdermal electrodes, and 50 mA or 150 V for surface electrodes, should be used. Since large cortical responses are obtained at low stimulation rates, optimal suggested rates for cortical recordings are between 2 and 5 per second that are not evenly divisible into the line frequency (for example, 1.3/s). Higher rates, up to 20/s, can be used for subcortical monitoring because subcortical responses are less affected by higher stimulation rates than cortical responses.

1.3. Sites

1.3.1. Median: The cathode should be placed about 4 cm proximal to the distal wrist crease between the tendons of the palmaris longus and flexor carpi radialis muscles; the anode should be placed 2--3 cm distal to the cathode.

1.3.2. Ulnar: The cathode should be placed about 4 cm proximal to the distal wrist crease on either side of the tendon of the flexor carpi ulnaris muscle, and the anode should be placed 2--3 cm distal to the cathode.

1.3.3. Posterior tibial: The cathode should be placed between the medial malleolus of the ankle and the Achilles tendon just proximal to the malleolus, and the anode should be placed 2--3 cm distal to the cathode.

1.3.4. Peroneal: The cathode should be placed in the lateral popliteal fossa just medial to the tendons for the biceps femoris muscles, and the anode should be placed 2--3 cm distal to the cathode.

1.4. Technique

Both sides should be monitored independently and, if the equipment is able, responses from both sides should be displayed on the same screen by alternating left and right stimuli with a short delay between them. The analysis time (sweep length) for upper limbs is 50--75 ms per limb, and for lower limbs, 100--125 ms per limb. If cortical response amplitudes are insufficient to begin with, synchronous bilateral stimulation will result in a larger cortical response allowing monitoring to proceed. With bilateral stimulation, however, it is possible to miss unilateral SSEP deterioration. If only one stimulator is available, responses must be recorded independently in an alternating fashion.

2. REGISTRATION/RECORDING

The monitoring technologist should endeavour to optimally record evoked responses with respect to time, amplitude, and stability. An evoked response change is easier to interpret when starting with a large, stable response that can be recorded quickly. The following parameters are intended to provide an optimally large, stable response.

2.1. Bandpass

The suggested general bandpass of 30 Hz--1 kHz is relatively narrow to provide a stable response. If the initial cortical response is too small for neuromonitoring, the low-frequency filter can be lowered. If spinal potentials have an unstable baseline, the low-frequency filter may be raised to 100 Hz.

2.2. Gain

The gain should be set at 100,000 or a sensitivity of 10 μ V/division, while the display gain can be adjusted to optimally display the waveforms (about 0.5--1 μ V/division). If noise is activating the automatic reject function, the next less sensitive gain may be used.

2.3. Electrodes

Subdermal needle or surface electrodes can be used for recording. Needle electrodes are convenient due to their ease of application. Surface electrodes applied using collodion and conductive gel are less invasive and carry a smaller risk of electrical burn because of the larger surface area contacting the skin.

2.4. Montages

2.4.1. For upper limb SSEPs, suggested 4-channel montages include:

- a) Channel 1: EP_{Left} EP_{Right} Channel 2: CS2-Fpz Channel 3: C₃'-Fpz Channel 4: C₄'-Fpz
- b) Channel 1: C₃' or C₄' to F_z Channel 2: C₃' or C₄' to Erb's point contralateral to the scalp Channel 3: Erb's point ipsilateral to the side of stimulation to F_z Channel 4: CS2 to F_z

A 2-channel system can be effective using; Channel 1: EP_{Left} -EP_{Right} Channel 2: C₃'-C₄' EP refers to Erb's point, which is generally located just above the clavicle and just lateral to the insertion of the sternocleidomastoid muscle. CS2 is the second level of the cervical spine. This site can be placed roughly in the midline of the upper, posterior neck. C₃' and C₄' are 2 cm posterior to C₃ and C₄ of the International 10:20 System for Electrode Placement.

2.4.2. For posterior tibial nerve stimulation, suggested montages include:

- a) Channel 1: Left popliteal fossa (PF)-medial knee Channel 2: Right popliteal fossa (PF)-medial knee Channel 3: CS2-Fpz Channel 4: Cz'-Fpz (or C₃'-C₄')

b) Channel 1: Cz' - Fpz' Channel 2: C₃' or Cz' - Fpz' (or C₃' to C₄') Channel 3: Interspinous ligament (IsL) or epidural space (ES) to reference electrode (R) on the spinous process at the same level proximal to the surgical site. Channel 4: IsL or ES caudal to R. The caudal electrode is placed below the level of spinal manipulation, thus monitoring the stimulus input

A 2-channel system can be effective using:

Channel 1: PF_{Left} PF_{Right} Channel 2: Cz'-Fpz (or C₃'-C₄') Occasionally, a coronal scalp derivation (C₃'-C₄') may have larger cortical responses than the sagittal derivation (Cz'-Fpz). The monitoring technologist may wish to record both initially then use the best one for the remainder of the monitoring. The popliteal fossa (PF) is the posterior aspect of the knee between the tendons of the biceps femoris muscles on the lateral side and the tendons of the semimembranosus and semitendinosus muscles on the medial side. Cz' is 2 cm posterior to Cz.

In the special case of monitoring sciatic nerve function during pelvic surgery, the peroneal is the primary nerve to be monitored. This is because its division in the sciatic nerve is more easily affected than the posterior tibial nerve division during the sciatic nerve compression that occurs during pelvic surgery. Unfortunately, it is difficult to monitor a caudal site to determine stimulation effectiveness. The lumbar response is best used as a rostral monitor instead of the cortical response because of the stability it offers.

2.5. Analysis Time

When one stimulator is being used, upper limb analysis time should be 50--75 ms, and lower limb analysis time should be 100--150 ms. If two stimulators are available and one can be delayed, then both sides can be evaluated on one screen by alternating stimulation during averaging. This method has been called simultaneous asynchronous stimulation.

2.6. Averaging

The number of transient responses required per average depends upon the clarity of the averaged response and the comfort of the monitoring technologist when evaluating the waveforms. As soon as the averaged response is clear (50--500 stimuli) then another can be started. Minimising artifacts will decrease the time taken per average.

2.7. Artifact

A ground electrode (plate, disk, cup, band, or subdermal needle) should be placed between the most distal stimulus site and the first recording site, to minimise line frequency Artifact and some stimulus Artifact. Recording leads should be grouped together as tightly as possible and electrode-skin impedances be similar to minimise line

frequency Artifact and stimulus Artifact. If the operating table is electrical, unplugging it may decrease excessive line frequency Artifact. Electrically operated equipment near the recording electrodes, such as infusion pumps and fluid warmers, may be located elsewhere if they are causing line frequency Artifact. EMG Artifact can be eliminated by requesting the patient receive a neuromuscular block if this is compatible with surgery and anesthesiology.

2.8. Safety

2.8.1. Infection control: Electrodes should be properly cleaned, and sterilised (when indicated) prior to use on each patient. Electrodes that are intended for the sterile field should preferably be gas autoclaved, double wrapped if multiple items are packaged, and tagged with an expiration date.

2.8.2. Electrical safety: If monopolar electrocautery is used during surgery, ensure that the neuromonitoring leads are distant from the cautery return lead. This will help minimise the chance of stray capacitances from the radio-frequency electrocautery unit, which could cause current flow in neuromonitoring leads. Make sure the evoked potential equipment used is electrically isolated from the patient contact parts, and that it has an isolation transformer. Make sure that leakage current testing is performed routinely on all pieces of equipment.

3. ALARM CRITERIA

Alarm criteria for standard spinal cord monitoring using SSEPs have often been suggested as a 50% decrease in cortical baseline amplitude, or 10% increase in cortical baseline latency when using the post-anaesthesia/preincision baseline as a comparison. The accepted criteria, however, should be agreed upon within the monitoring team in each institution. Other events that may result from neural compromise are unilateral changes and especially sudden changes that correlate to surgical manoeuvres or decreases in perfusion. The monitoring technologist should be aware of the effect of medications and anaesthetic agents and communicate effectively with anesthesiology, especially when a change in responses occurs, to determine the cause of the change.

4. TROUBLESHOOTING

4.1. Small Amplitude of the Baseline Cortical Response

4.1.1. Check anaesthetic level. If it is high, discuss lowering it with the anaesthesiologist.

4.1.2. Lower the low-frequency filter.

4.1.3. Lower the stimulation rate.

4.1.4. Increase the stimulus intensity (use the peripheral response amplitude to titer).

4.1.5. Decrease the electrical noise (see section B below).

4.1.6. If underlying neural pathology exists, when monitoring spinal cord function, stimulate both sides together (two stimulators are needed).

4.2. High Background Noise

4.2.1. Discuss using a neuromuscular block with the anaesthesiologist if EMG is the source.

4.2.2. Move powered devices and power cords away from the recording leads.

4.2.3. Make sure recording leads, especially pairs, are wound together.

4.2.4. Unplug the operating room table.

4.2.5. Make recording pair electrode impedances match.

4.3. High Stimulus Artifact

4.3.1. Match the impedances of the recording electrode pair (especially if Artifact is only affecting a few channels or one channel).

4.3.2. Reapply the ground electrode.

4.3.3. Reapply stimulating electrodes and make sure they are connected properly. Replace the stimulating electrode if you suspect it is broken.

4.3.4. Move the recording electrode pairs closer together if possible.

4.4. Good Motor Twitch but No Evoked Responses

4.4.1. This could relate to an underlying pathology and thus is a limitation when monitoring.

4.4.2. Check for constriction of the nerve in the proximal limb (poor positioning, intermittent blood pressure cuff, tourniquet).

5. APPENDIX

The following two surgical scenarios employ SSEP techniques under special circumstances for neuroidentification and are briefly described here.

5.1. Central Sulcus Identification The monitoring technologist should prepare the patient for a median nerve SSEP and record a scalp cortical response after induction of anaesthesia but prior to surgical preparation, to determine if a response exists. If, as a result of the underlying pathology, the response is absent or very low amplitude, subsequent cortical surface recording may be difficult. Once the cortex has been exposed, the surgeon places a sterile subdural electrode strip containing at least four electrodes across the suspected central sulcus. Responses are recorded using a common reference on the scalp ipsilateral to the stimulated side (either a surface or

subdermal needle electrode applied prior to draping). A polarity reversal occurs across the central sulcus following median nerve stimulation at the wrist. Precentrally, the response is initially positive (P20), and postcentrally it is initially negative (N20). Once the central sulcus is identified the surgeon can better avoid working near the sensorimotor cortex, which will minimise postoperative neurological deficits.

5.2. Dorsal Root Entry Zone Identification

This special case requires direct stimulation of, and recording from, the spinal cord. The purpose of this surgical procedure is to electrically ablate an

area of the dorsal root entry zone (DREZ) of the spinal cord that is presumed to be generating pain signals that cannot be controlled. A complication of this procedure is extending ablation too far laterally, thus affecting the dorsolateral tract fibres and leg motor function. Since visual identification of

the exposed DREZ during surgery may be impossible in cases of long-standing complete root avulsion, spinal cord conduction techniques are used to precisely identify the DREZ.

Briefly, the rostral end of the exposed cord is stimulated with very low current (0.2--0.5 mA) at the known dorsolateral tract, and a silver ball electrode records the spinal cord evoked response from the caudal, exposed cord using a subdermal needle reference electrode in the wound. The baseline response amplitude should be no greater than 20 μ V. The stimulating electrode is then moved to the dorsal column tract and a second recording is made. The dorsal column response is smaller and slower for the same stimulus intensity. Stimulation at the DREZ results in no response because longitudinal tracts do not exist at this point. This identifies the DREZ.

Table. Use of SSEP in surgical area, neural structure at risk, nerve stimulated, and brief comments.

REFERENCES

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INTRAOPERATIVE MONITORING OF BRAINSTEM AUDITORY EVOKED POTENTIALS

Introduction

Brainstem auditory evoked potentials (BAEP) can be utilized during neurosurgical procedures that involve the pons and the lower midbrain. The intent is to protect these areas from damage that could lead to serious, permanent, neurologic deficits. The recording of direct nerve action potentials from the exposed 8th cranial nerve and cochlear structures in cases such as microvascular decompressions and acoustic nerve tumour resections also can help preserve hearing.

1. ELECTRODES

1.1. Type

Standard EEG electrodes, adhered to the scalp with collodion and filled with a conductive gel, are recommended in most cases. During some surgical procedures, however, the scalp site for electrode placement is within the area of the sterile field. In these cases, subdermal (needle) electrodes may be preferred since they are sterile and insert quickly. In the cases of direct 8th nerve recording, a wick or wire electrode is applied by the surgeon directly to the exposed 8th nerve or through the tympanic membrane cochlear promitory.

1.2. Placement

1.2.1. Over the left and right earlobes (A1 and A2 position of the International 10/20 System of Electrode Placement); or over the left and right mastoid processes (M1 and M2).

1.2.2. At the vertex location on the scalp (designated as Cz in the 10/20 System). The Cz electrode can be moved anterior to avoid the surgical field.

1.2.3. The ground electrode can be placed at Fz or Fpz of the International 10/20 System.

2. INSTRUMENTATION PARAMETERS

2.1. Low Filter Setting: 10 Hz to 30 Hz (-3 dB) with a filter rolloff not exceeding 12 dB/octave.

2.2. High Filter Setting: 2.5 to 3 kHz (-3 dB) with a filter rolloff not exceeding 24 dB/octave.

Whenever possible, filters should be kept constant throughout the monitoring to eliminate filter-related phase shifts, which alter latencies and can lead to erroneous interpretations. When recording in the operating room, it may become necessary to change filter settings in response to

an electrically hostile environment and changes in the patient's physiologic state. Changes made to any instrument setting must be noted on the tracing and on the technologist's work sheet.

2.3. Analysis Time: 10 to 15 milliseconds from stimulus onset.

2.4. Number of Trials: 1000--4000 individual trials.

3. STIMULATION

3.1. Stimulators: Sponge or foam ear inserts are suggested for use in the operating room because of their small size and placement away from the surgical field. The inserts should be placed before surgical draping, then covered with waterproof tape or bone wax to secure them and protect them from fluids. The inserts are connected to the transducer by a plastic tube (approximately ten centimetres in length), which should be checked for kinks or compression that could obstruct delivery of the stimulus to the moulded insert.

3.2. Stimulus: Otoscopic visualisation of the canal and tympanic membrane must be carried out (by a qualified practitioner) to ensure a clear stimulus pathway. Excessive waxy secretions must be cleared from the external auditory canal before inserts or headphones are applied.

3.2.1. Click type: Broadband clicks are preferred and should be generated by a 100gms rectangular pulse (single, monophasic, square wave).

3.2.2. Click polarity: Clicks of alternating positive and negative polarity are recommended to diminish stimulus Artifact.

3.2.3. Intensity: Stimulus intensity suggested is 100 decibels peak equivalent sound pressure level (dB pe SPL) or, alternately 60 to 70 dB HL (with HL referring to hearing level as defined as the mean hearing threshold established through a group of normal subjects using the same monitoring equipment).

3.2.4. Rate: Stimulus rate is variable at 5 to 50 stimuli per second. Rapid assessment in the OR is essential and can be performed at high rates when Waves I and V are being monitored.

3.2.5. Masking: Clicks should be delivered to only one ear at a time and a masking noise delivered to the non-stimulated ear.

4. MONTAGES

A minimum of two channels is recommended for recording, with three channels being desirable.

4.1. Recommended Two-channel Montage

Channel 1: vertex to ipsilateral ear lobe or mastoid (Cz-Ai or Cz-Mi)

Channel 2: vertex to contralateral ear lobe or mastoid (Cz-Ac or Cz-Mc)

4.2. Recommended Three-channel Montage:

Channel 1: vertex to ipsilateral ear lobe or mastoid

Channel 2: vertex to contralateral ear lobe or mastoid

Channel 3: left ear lobe to right ear lobe (A1-A2)

5. BASELINE RECORDING

A preoperative baseline BAEP should be recorded from the patient prior to the day of surgery to verify the patient has a reproducible brainstem auditory evoked response. The patient's post-anaesthesia/pre-incision BAEP recording will act as the baseline tracing to which all intraoperative recordings will be compared. Latencies with ear inserts will include the extra time for the stimulus to reach the eardrum via the plastic tube.

INTRAOPERATIVE MONITORING OF THE ELECTROENCEPHALOGRAM

Introduction

The electroencephalogram can be a useful tool for monitoring the brain when surgical procedures may potentially compromise blood perfusion to the brain or involve the cerebral cortex. Computer processed EEG provides frequency analysis and data reduction of the scalp EEG, and is often used during vascular procedures. The continuous EEG, however, remains the standard for recording when pattern recognition is required, such as during electrocorticography. In either case, it is essential that the monitoring technologist be very familiar with anaesthetic agents and their effects on the EEG.

1. ELECTRODES

1.1. Placement

The full head should be measured according to the International 10/20 System of Electrode Placement. No fewer than 21 electrodes should be applied.

1.2. Impedances

All inter-electrode impedances should be between 500 and 5000 ohms. High electrode impedances or poorly matched impedances can increase line frequency interference.

1.3. Types

Collodion application of scalp electrodes is preferred. Sterile subdermal needle electrodes may be used when the placement of electrodes would impinge on the operative field.

Modified Electrode Placements

Surgical procedures involving a craniotomy may require modification of the standard 10/20 placement. Alternative placements should be documented and well illustrated on the technologist's work sheet. Modified placements may also reduce the number of electrodes that can be applied.

2. RECORDING CHANNELS

Eight-channel recordings can give adequate information for generalised abnormalities. To detect more localised ischaemia events, however, it is recommended that 16-channel recordings be used whenever possible, with 21 channels optimal. The additional channels provide the opportunity to monitor other physiological activity such as EKG, movement, blood pressure, etc.

3. RECORDING PARAMETERS

3.1. High-Frequency Filter

A high-frequency filter of 70 Hz is preferable although lowering this to 50 or 35 Hz may be necessary due to the electrically hostile environment of the operating room.

3.2. Line-Frequency Filter

Line-frequency filters may be necessary, again due to the electrically hostile environment. It may be necessary to re-evaluate the application of electrodes to eliminate unwanted line-frequency (50 or 60 Hz) interference. The line-frequency filter should be used judiciously and only after all other methods of reducing 60 Hz interference have been exhausted.

3.3. Low-Frequency Filter

A low-frequency filter of 0.3--0.5 Hz is recommended to best record the slow EEG activity from anaesthetic agents and ischaemia. Although a low-frequency filter of 1 Hz is reasonable at times, a filter of 5 Hz should be restricted to brief periods of viewing low amplitude beta activity or spikes. During procedures that can disrupt or reduce cerebral blood flow, it is important to maintain a lower (.3--.5 Hz) filter setting in order to record the physiological effects of cerebral ischaemia.

3.4. Chart/Paper Speed

The baseline recording of the EEG should be performed with a standard paper speed of 30 mm/sec. The paper speed can then be slowed to 5 to 15 mm/sec to emphasise beta asymmetries and slow activity, as well as to conserve paper.

4. BASELINE RECORDING

It is recommended that preoperative and baseline recordings be performed on all patients to rule out any EEG abnormalities that may complicate interpretation during surgical or radiological procedures.

5. EEG MONITORING DURING SURGICAL AND RADIOLOGIC PROCEDURES

5.1. Carotid Endarterectomy

This procedure is performed to remove atherosclerotic plaque from the carotid artery, which can become dislodged and result in a stroke. The carotid endarterectomy includes clamping the branches of the carotid artery above and below the plaque or stenosed area so that the material can be surgically removed. Because the clamping can produce significant cerebral ischaemia, the EEG is used to evaluate collateral perfusion of the brain.

The EEG monitoring should begin with the start of the surgical procedure. Once anaesthesia levels are stabilised, the baseline EEG activity should be noted for reference throughout the

procedure. Changes in the EEG will typically occur 30 seconds to 2 minutes after clamping of the carotid artery. The first EEG change is usually a decrease in background alpha and beta activity. Anaesthetic agents that enhance fast activity actually improve the detection of this first change. The diminished fast activity should be compared to the baseline recording, and can appear over one or both hemispheres. A second indication of ischaemia EEG change is increased slow activity, again with the change as compared to the preclamped baseline. Both decreased amplitude of fast activity and increased slow activity may be seen at the same time. The degree of resulting ischaemia is greatest when there is a significant reduction in both fast and slow activity unilaterally or bilaterally or there is a total suppression of the EEG. The amount of disruption in the cortical activity displayed on the EEG determines the window of time for correcting the ischaemia before irreversible damage occurs. Anaesthetic agents can mimic some of the EEG changes described above; therefore, communication with the anaesthesiologist is essential and any changes in anaesthetic levels should be clearly noted on the EEG record. Alarm criteria for the technologist to alert the surgeon to significant changes should be determined by the surgical/technical staff at each hospital and established prior to surgery. (Some have established a drop of 50% in amplitude of the fast frequencies, as compared to the baseline recording, as significant.) It is of the utmost importance that the technologist be aware that both diffuse and subtle, focal change may occur caused by embolic events, which may lead to permanent neurologic deficit. A physician with training in the interpretation of EEGs should be present during any procedure that requires cross clamping of an artery.

5.2. Intracranial Aneurysm Surgery

The large craniotomy necessary to expose most intracranial aneurysms limits the scalp area available for electrode placement. Silicone electrode strips, placed by the surgeon, can be used to record directly from the cortical surface. Disruption of middle cerebral artery blood flow will cause EEG changes similar to those seen during carotid endarterectomies. It may be necessary to “trap” aneurysms of the intracranial portion of the internal carotid artery with temporary clips. Placing the clip across the neck of an aneurysm can cause a pinching effect that reduces the amount of flow in that artery or causes a complete blockage. The EEG changes are very quick to appear and can guide the surgeon in repositioning the clip. Aneurysms of the more distal middle cerebral artery and the anterior circulating arteries may produce more focal EEG changes, depending on how distal they are. A physician with training in the interpretation of EEGs should be present during any procedure that requires clipping of any aneurysm.

When the involved arteries also perfuse the brainstem, the BAEP may be monitored along with the EEG.

5.3. Cardiac Bypass Surgery

Cardiac bypass procedures have been known to produce cerebral ischaemia causing postoperative stroke. The monitored EEG has been used as an indicator of cerebral ischaemia; however, EEG features are suppressed by the profound hypothermia often used to protect the brain. The EEG is used to identify the suppression of all brain activity to determine when hypothermia has been established, and can also be used to monitor deliberate, drug-induced burst suppression.

5.4. Electrocorticography (ECoG)

Following craniotomy, electrodes are placed directly on the surface of the brain to localise epileptiform activity in patients with epilepsy, or to isolate abnormal activity related to tumour growth or other invasive events. The cortical recordings are obtained by using strips or a grid of EEG electrodes embedded in narrow bands or rectangular sheets of silicone with an inter-electrode spacing of one centimetre. These arrays can be sterilised and applied on the cortical surface with saline-soaked cotton strips to weigh the array down. Another type of ECoG electrode system employs a metal or plastic frame that holds a series of spring-loaded, cotton-tipped electrodes that touch the surface of the cortex. The spring mechanism absorbs the pulsations from the surface of the brain. This type of electrode array is more flexible for random placement of the electrodes around an area of suspected abnormality. During such monitoring, a physician with training and experience in the interpretation of ECoG must be present during the recording.

5.5. Sodium Amytal Testing (Wada Test)

The Wada test is performed prior to epilepsy surgery to determine the patient's hemisphere dominance for language and memory. The EEG is used to record the slow activity induced by sodium amytal, thus giving an electrical estimate of the duration of the amytal effects and the hemispheric recovery from the drug. The EEG will also reveal any seizure activity that could compromise the test results. The Wada test is classified as an intraoperative procedure in some institutions around the world.

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