Guideline 11B: RECOMMENDED STANDARDS FOR INTRAOPERATIVE MONITORING OF SOMATOSENSORY EVOKED POTENTIALS

Somatosensory evoked potentials (SSEPs) can be used intraoperatively to assess the function of the somatosensory pathways during surgical procedures in which the spinal cord, brainstem, or cerebrum is at risk and to localize the sensorimotor cortex.(Jones, Edgar et al. 1983; Lueders, Lesser et al. 1983; Emerson and Adams 2003)

A. General Requirements

1. Terminology

Waveforms should be named as described in Guideline 9D.(ACNS 2006)

2. Stimulus and Safety

A constant current stimulator is recommended for use in the operating room. Care should be exercised to prevent blood or other fluid from contaminating the stimulating site. Either standard disk electroencephalography (EEG) electrodes or sterile subdermal needle electrodes may be used. Disk EEG electrodes should be applied to the scalp with collodion and sealed with plastic tape or sheet to prevent drying and to protect them from blood or other fluids. Contact impedance for disk electrodes should be less than 5 Kohms. Subdermal needle electrodes should be similarly secured; it is important that OR personnel be made aware of the use of locations of needle electrodes, so that they may observe necessary caution to avoid needle sticks.

a. Stimulus Isolation and Subject Grounding

The stimulation unit must be isolated from the main portion of the stimulator circuitry to avoid a large current flow to the patient in the case of stimulator malfunction. Commercial somatosensory stimulators designed for human use contain appropriate isolation circuitry. The ground may be placed on the limb that is stimulated to minimize the stimulus artifact.

b. Stimulus Parameters

Monophasic rectangular pulses of 100-300 μs duration and 30-40 mA intensity are recommended for stimulation of peripheral nerves. Failure of stimulation may occur when there is a significant increase in contact impedance or due to the development of a salt bridge, such as when excessive electrode paste short circuits the two stimulating electrodes. However, at times stimulation may fail due to patient related factors such as limb edema, peripheral neuropathy, or variant anatomy. Before increasing current levels to intensity above 30-40 mA, stimulating electrodes should be carefully evaluated.

B. Neurophysiologic Intraoperative Monitoring of the Spinal Cord

The risk of neurologic deficit resulting from spinal cord damage is 0.5-1.6% in cases of instrumentation for scoliosis.(MacEwen, Bunnell et al. 1975; Nuwer, Dawson et al. 1995; Coe, Arlet et al. 2006) In cases of surgical decompression for spinal cord tumors or trauma, the risk increases to about 20%. Surgery on the descending thoracic aorta exposes patients to the highest risk of injury to the spinal cord, with the incidence of paraplegia approaching 40%.(Husain, Ashton et al. 2008)

Monitoring of SSEPs directly assesses the function of the dorsal columns and may serve as a surrogate marker for "global" spinal cord function. Although there is good correlation between preservation of SSEPs and normal motor function, there are reported cases of postoperative paraplegia with preserved intraoperative SSEPs.(Ben-David, Haller et al. 1987; Nuwer, Dawson et al. 1995; Minahan, Sepkuty et al. 2001) Preservation of SSEPs does not guarantee preservation of motor function. For this reason, motor evoked potential (MEP) monitoring, which assesses the motor pathways in the ventral aspect of the spinal cord, may be conducted simultaneously with SSEP monitoring.

The selection of the nerve to be stimulated to obtain the SSEP is determined by the segmental level of the surgical procedure. Spinal cord surgery above the C6 level can be monitored by SSEPs to median nerve stimulation. Ulnar nerve SSEP monitoring can be used when the surgery involves the lower cervical segments (above C8). Surgery involving levels below the C8 segment requires monitoring of SSEPs to stimulation of the posterior tibial or common peroneal nerve. Other smaller nerves are used less often as their SSEPs are smaller in amplitude and harder to reproduce.

1. Monitoring of Cervical Spinal Cord

NIOM for surgeries during which the cervical spinal cord is at risk involve SSEP monitoring with stimulation of the ulnar or median nerve. The median nerve is utilized if the surgery is above the level of C6. For surgeries below this level and above C8, the ulnar nerve can be used.

a. Stimulation

1. Placement of stimulating electrodes

When the median nerve is stimulated for SSEP monitoring, the cathode should be placed between the tendons of the palmaris longus and the flexor carpi radialis muscles, 2 cm proximal to the wrist crease. The anode should be placed 2-3 cm distal to the cathode or on the dorsal surface of the wrist. Either surface disk electrodes or subdermal needle electrodes may be used.

2. Subject grounding

A plate electrode on the palmar surface of the forearm or a band electrode around the forearm should be used as the ground electrode.

3. Stimulation rate

A repetition rate of 2-8/s is suggested when obtaining SSEP for NIOM. A higher stimulation rate, up to 20/s, may be useful in certain instances to increase the speed monitoring. However, high stimulation rates can also result in lower amplitudes of the responses, thus increasing the amount of time needed to obtain a reproducible response. Stimulus rates must be optimized to obtain reliable responses in the shortest time possible. Stimulus rates that are multiples of the line current frequency (60 Hz in the North America) should be avoided, and fine adjustments of stimulus frequency often helps to eliminate line noise artifact from recordings.

4. Side of stimulation

SSEPs are obtained following unilateral median or ulnar nerve stimulation. Most current equipment permits right and left stimulation to be interleaved, with independent right and left SSEP recording being obtained currently. This helps in obtaining responses quicker.

b. Recording

The recording technique is the same whether median or the ulnar nerves are stimulated. A multi-channel recording is suggested. In the operating room environment, technical problems may occur in one or more channels. If problems occur with some channels, it is important to have additional channels for backup to allow monitoring to continue. Recording both subcortical and cortical SSEPs increases reliability. (Emerson and Adams 2003) Cortical SSEPs are near-field, short latency EPs recorded from the scalp over the underlying sensory cortex using bipolar "scalp-to-scalp" electrode derivations. Subcortical SSEPs are near-field EPs recorded using "scalp-to-noncephalic" electrode derivations.(ACNS 2006)

1. System bandpass

System bandpass of 30 – 1 kHz (-3db) is used most often. A lower low pass filter does not usually meaningfully enhance the recorded waveforms and often adds to recorded noise. A higher high pass filter may be useful if one is relying primarily of the P14 subcortical component for monitoring. Filter settings should generally be kept constant during a monitored procedure. Changes in filter settings will cause changes in the responses that can erroneously be attributed to pharmacologic or surgical factors. If filter setting are changed, it is important that baselines be reestablished.

2. Analysis time

An analysis time of 50 ms is typical. The analysis time should be at least twice the usual latency of the last waveform of interest. Thus, in a median or ulnar nerve SSEP, the last waveform of interest is the N20; consequently the analysis for an upper limb study should be at least 40-50 ms.

3. Number of repetitions to be averaged

A sufficient number of repetitions must be averaged to produce an interpretable and reproducible SSEP. Generally 250 – 1000 repetitions are needed; the number of repetitions depends on the amount of noise present and the amplitude of the SSEP signal itself (signal to noise ratio). In general, it is not desirable to average more than the number of necessary repetitions as this may delay feedback to the surgeon.

4. Electrode type and placement for cortical scalp SSEPs

Either standard disk EEG electrodes or sterile subdermal needle electrodes may be used. Disk EEG electrodes should be applied to the scalp with collodion and sealed with plastic tape or sheet to prevent drying and to protect them from blood or other fluids. If disk electrodes are used, impedance should be < 5 Kohms. Subdermal needle electrodes can also be used but are more likely to be dislodged. They should be secured in a manner similar to that described above. Recording electrodes are placed at CP3 and CP4 scalp locations (intermediate between C3 and C4, and P3 and P4, respectively), and at right and left Erb's points.

5. Montage

A multichannel montage that includes cortical near-field as well as subcortical far-field and Erb's point signals is recommended. For example:

Channel 1: CPc – Cpi
Channel 2: CPc – EPc
Channel 3: CPi – EPc
Channel 4, EPi – EPc

CPc and CPi refer to the CP3 or CP4 electrode positions respectively contralateral and ipsilateral to the stimulated nerve. EP refers to Erbs Point. Subcortical derivations may not be necessary if total intravenous anesthesia (TIVA) is used, as with this anesthetic paradigm, the cortical responses are typically robust and have a higher signal to noise ratio than the subcortical responses. Consequently cortical responses can be obtained more rapidly, reducing the time needed for each average. However, whenever possible, obtaining subcortical channels should be considered for redundancy.

c. Analysis of Results and Criteria for Abnormalities

Assessment of amplitude, morphology and latency of Erb's potential, P14, N18 and N20 are recommended.(ACNS 2006) The waveforms which are most robust and rapidly obtained should be analyzed more closely. Analysis of interpeak latencies is not relevant in the operating room as comparisons are made to normative data, rather each patient serves as his or her own control. Alterations of SSEPs are reported immediately to the surgical team and the anesthesiologist as warning that neural function may be compromised. Typically, a 50% drop in amplitude and a 10% prolongation in latency is considered a significant change in SSEPs. However, smaller but clearly distinct changes may also be significant.(Nuwer and Packwood 2008)

2. Intraoperative Monitoring of Thoracolumbar Spinal Cord

SSEPs obtained from stimulation of the posterior tibial or common peroneal nerve are used for NIOM during surgeries in which the spinal cord below the C8 level is at risk. Stimulation of the posterior tibial nerve at the ankle is often preferred because of its easy accessibility. Stimulation of the common peroneal nerve at the knee is technically more difficult, but it can be useful when the posterior tibial nerve cannot be stimulated, such as with a peripheral neuropathy or below knee amputation. The technique is essentially the same irrespective of the nerve stimulated. The description that follows will be limited to posterior tibial nerve SSEPs.

a. Stimulation

1. Placement of stimulating electrodes

The cathode should be placed over the posterior portion of the medial surface of the ankle, 1-2 cm distal and posterior to the medial malleolus. The anode should be placed 2-3 cm distal to the cathode. Either surface disk electrode of subdermal needle electrode may be used.

2. Subject grounding

A plate or band electrode over the calf should be used as a ground electrode.

3. Stimulus intensity

Stimulation of the posterior tibial nerve produces either a plantar flexion of the great toe or cupping of the sole of the foot. Caution should be exercised in increasing stimulus intensity in a pharmacologically paralyzed patient. Often a stimulus intensity of 20 mA is sufficient to activate the tibial nerve. However, in patients in whom the nerve is diseased, higher stimulus intensity is needed.

4. Stimulus rate

A stimulation rate of 2-10/s is recommended. Stimulus rates that are multiples of the line current frequency (60 Hz in the North America) should be avoided, and fine adjustments of stimulus rate often helps to eliminate line noise artifact from recordings.

5. Side of stimulation

The lower extremities should be stimulated unilaterally, with SSEPs obtained independently from right and left sides. Most current equipment permits right and left stimulation to be interleaved, with independent right and left SSEP recording being obtained currently. This helps in obtaining responses quicker. In rare instances, where SSEPs are of very low amplitude, bilateral stimulation may be may be useful; in these cases, unilateral injuries of the cord may go undetected.

b. Recording

Recording protocols for posterior tibial and peroneal nerve SSEPs are the same. Multiple-channel recording is suggested, allowing recording a combination of subcortical and cortical SSEPs. However, as noted above for upper limb SSEPs, when TIVA is used, obtaining subcortical responses may not be necessary. With TIVA, the cortical waveforms have a high signal to noise ratio and can be averaged more quickly, allowing more rapid feedback to the surgeon. Whenever possible, obtaining subcortical channels should be considered for redundancy.

1. System bandpass

The recording bandpass is typically 30 – 1 kHz (-3db). The same considerations apply as for upper extremity SSEPs.

2. Analysis time

An analysis time of 75-150 ms is typical. As noted above, the analysis time should be at least twice the usual latency of the last waveform of interest. Thus, in a posterior tibial nerve SSEP, the last waveform of interest is the P37; consequently the analysis for an upper limb study should be at least 75-150 ms.

3. Number of repetitions to be averaged

A sufficient number of repetitions must be averaged to produce an interpretable and reproducible SSEP. Generally 250 – 1000 trials are needed; the number of trials depends on the amount of noise present and the amplitude of the SSEP signal itself (signal to noise ratio). In general, it is not desirable to average more than the number of necessary trials, as this may delay feedback to the surgeon. Modification of the recording montage (see below) may result in a higher signal to noise ratio of the cortical waveform and may help reduce the number of repetitions need to obtain a reliable response.

4. Electrode placement

Either standard disk EEG electrodes or sterile subdermal needle electrodes may be used. Disk EEG electrodes should be applied to the scalp with collodion and sealed with plastic tape or sheet to prevent drying and to protect them from blood or other fluids. If disk electrodes are used, impedance should be < 5 Kohms. Subdermal needle electrodes can also be used but are more likely to be dislodged. They should be secured in a manner similar to that described above.

Recording electrodes are typically placed at CPz, CP3 and CP4 scalp locations. Additional scalp electrodes in or behind the midsagittal plane may be useful to allow selection of the electrode derivation that produces the highest amplitude cortical response, as well as to provide redundancy.(Emerson and Adams 2003; MacDonald, Al Zayed et al. 2005) At the start of surgery, it may be useful to try different derivations to determine the one with the highest amplitude. Determining the best montage will facilitate NIOM and allow acquisition of reliable responses with fewer repetitions. Non-cephalic electrodes are often placed on the chin or at Erb's points. Electrodes are placed in the popliteal fossa to record the nerve action potential following posterior tibial nerve stimulation.

5. Montage

A multichannel montage that includes cortical near-field as well as subcortical far-field and Erb's point signals is recommended. For example:

Channel 1: CPi – Cpc
Channel 2: CPz – CPc
Channel 3: CPz – Chin/EPc
Channel 4: PF1 – PF2

Where EPc is contralateral Erb's point and PF1 and PF2 are ipsilateral popliteal fossa electrodes. As noted above, other derivations may result in higher amplitude cortical waveforms and should be considered as well. Examples of such derivations include Cz – CPc and Cz – Fpz. When NIOM with tibial SSEP is started, it may be useful to obtain SSEPs from CPi, CPc, Cz, Fpz, Pz referenced to either the chin or EPc electrode.(MacDonald, Al Zayed et al. 2005; MacDonald, Al-Enazi et al. 2008) This can allow selection of the best montage.

c. Analysis of Results and Criteria for Abnormalities

Assessment of amplitude, morphology and latency of popliteal fossa, P31 and P37 potentials are recommended.(ACNS 2006) The waveforms which are most robust and rapidly obtained should be analyzed more closely. Analysis of interpeak latencies is not relevant in the operating room as comparisons are made to normative data, rather each patient serves as his or her own control. Alterations of SSEPs are reported immediately to the surgical team and the anesthesiologist as warning that neural function may be compromised. Typically, a 50% drop in amplitude and a 10% prolongation in latency is considered a significant change in SSEPs. However, smaller but clearly distinct changes may also be significant.(Nuwer and Packwood 2008)

d. Utility of Upper Extremity SSEPs

Monitoring upper extremity SSEPs may detect peripheral nerve and brachial plexus ischemia or compression. During surgery in which the thoracolumbar spinal cord is at risk, the patient may

be positioned in a manner that causes excessive stretching or compression of the brachial plexus. If upper extremity SSEPs are monitored, such stretching and compression will result in loss of amplitude and prolongation of latency of the EP potential.(O'Brien, Lenke et al. 1994; Jones, Fernau et al. 2004) Repositioning of the limb often results in improvement of the waveforms and reduces postoperative morbidity. Monitoring of the ulnar nerve SSEP is preferable to median nerve SSEP for this purpose since the former assess the lower brachial plexus, which is most susceptible to stretch injury.

C. Localization of Sensorimotor Cortex

SSEPs can be recorded directly from the cortical surface to localize the central sulcus and the precentral and postcentral gyri.(Lueders, Lesser et al. 1983; Kombos 2008; Tatum, Vale et al. 2008)

1. Stimulus

The same parameters described for the stimulation of the median nerve for cervical spinal cord monitoring are recommended. The median nerve contralateral to the exposed cortex should be stimulated.

2. Recording

a. System bandpass

The recommended system bandpass is 1-30 Hz to 250-1,500 Hz (-3 dB). A bandpass similar to that used for cervical spinal cord monitoring can be used.

b. Analysis time

An analysis time of 50 ms is recommended.

c. Number of trials to be averaged

SSEPs recorded from the cortical surface are large (20-500 µV) and consequently have a higher signal to noise ratio than SSEPs recorded off the scalp. Often 25-50 repetitions are adequate to obtain a reproducible response. At least two trials should be obtained to ensure reproducibility.

d. Electrode type and placement

A standard subdural electrode strip or grid comprised of stainless steel or platinum disk electrodes embedded in a flexible silicone or similar material is placed on the cortical surface. Care should be taken that electrodes are not floating in a pool of blood, cerebrospinal fluid (CSF), or irrigating solution. Since SSEPs recorded from the cortical surface are highly localized and the initial estimate of the hand area may be incorrect, recording from a minimum of 16 electrode locations is desirable (i.e. recording from 4 adjacent placements of a 4 x 1 electrode strip).

e. Montage

A minimum of 4-channel recording is recommended, however an 8, 16, or 32 channel averager greatly facilitates the localization of the central sulcus and pre and postcentral gyri. A contralateral (i.e. on the side of the stimulated nerve) scalp or ear electrode may serve as a reference. A referential montage with points on the strip or grid electrode referenced to the

contralateral scalp or ear electrode is used most often.(Robertson, Traynelis et al. 1994) A bipolar montage with sequential electrodes can be used as well.(Kombos 2008) A photograph or a drawing depicting numbered electrode positions in the operating field is helpful.

3. Analysis of Results and Criteria for Cortical Localization

The N20/P30 waveforms are recorded over the somatosensory cortex whereas waveforms of the opposite polarity, P20/N30, are recorded over the primary motor cortex. The P20 is sometimes also referred to as the P22. Referential recordings from adjacent electrodes over the pre and postcentral gyri produce a "phase reversal" between the N20 and the P20. The phase reversal marks the site of the central sulcus. If a clear phase reversal is not identified, the site of the highest amplitude of the N20 and P20 waveforms marks the vicinity of the central sulcus. The central sulcus is localized directly underneath or a few millimeters anterior to the area of highest amplitude. The point at which the N20 and P20 waveforms are the highest amplitude also marks the hand area of the sensory and motor cortices. SSEPs should be obtained from multiple sites on the exposed cortex to map the central sulces as it is often not linear, especially in the presence of lesions.(Legatt and Kader 2000)

D. Conclusions

SSEPs are a vital part of NIOM. They assess the functional integrity of the dorsal spinal cord, but can also be used to warn of peripheral nerve/brachial plexus injury from patient positioning. Median SSEPs can be used to localize the central sulcus and pre and postcentral gyri. Even as other types of NIOM, namely motor evoked potentials, gain popularity because of their ability to monitor the anterior spinal cord, the use of SSEP has not diminished. In fact, SSEPs continue to be used, and they greatly enhance and supplement other types of NIOM.

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