NEUROPHYSIOLOGIC MONITORING
CA2 Anesthesia Seminar Series
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Outline of Topics

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Raw

Processed

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> � Bispectral analysis

> � Entropy analysis

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Evoked Responses

Sensory Evoked Potentials (SEPs)

> � SSEP: somatosensory evoked potential

> � BAEP: brain stem auditory evoked potential

> � VEP: visual evoked potential

Motor Evoked Potentials (MEPs)

Anesthesia Considerations and Evoked Response Monitoring

Direct nerve stimulation with electromyography (EMG)

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Jugular Bulb venous saturation

Near-Infra Red Spectroscopy

Intracerebral electrodes

ELECTROENCEPHALOGRAPHY (EEG)

Raw EEG

The standard EEG is measured from the scalp with an array of 20 electrodes. It may also be measured directly from electrodes placed on the cortex (electrocorticography) during a craniotomy. The standard recording has 16 channels. There re 4 frequency ranges described delta (1-4 Hz), theta (4-8 Hz), alpha (8-12 Hz) and beta (12-20 Hz). Normal waking activity is mostly in the high frequency, low amplitude beta range. Closing the eyes results in a shift to the slower frequency, higher amplitude alpha range. Interpretation of the raw EEG requires considerable training and expertise and it is not within the scope of most anesthesiologists.

Figure 1: Normal Patterns of The Different EEG ranges
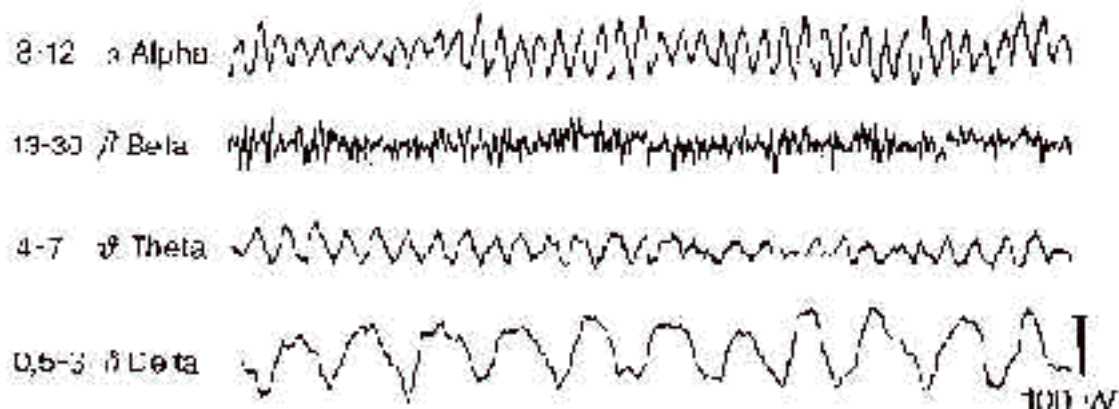
Processed EEG

The raw signal is mathematically treated to present information that can be more readily interpreted by clinicians.

Power analysis: this involves a Fourier transformation that converts the raw signal into its component sine waves. In brief this gives an expression of how much of the power in the EEG signal falls into the different frequency ranges. The information is expressed as compressed spectral array or density spectral array. Changes in both amplitude and frequency occur under anesthesia and in conditions in which the brain is compromised. Significant training and \expertise is required to interpret the data.

To make things even simpler for the clinician, some systems will produce a single number that indicates in which general direction the EEG is going. For example, spectral edge frequency is that frequency which 95% of the power of the EEG is below. If the number is decreasing, the overall EEG frequency is decreasing. Significant and especially unilateral decrease in this number for example during a carotid endarterectomy is very suggestive of diminished perfusion.

Figure 2: A Power Spectral Array
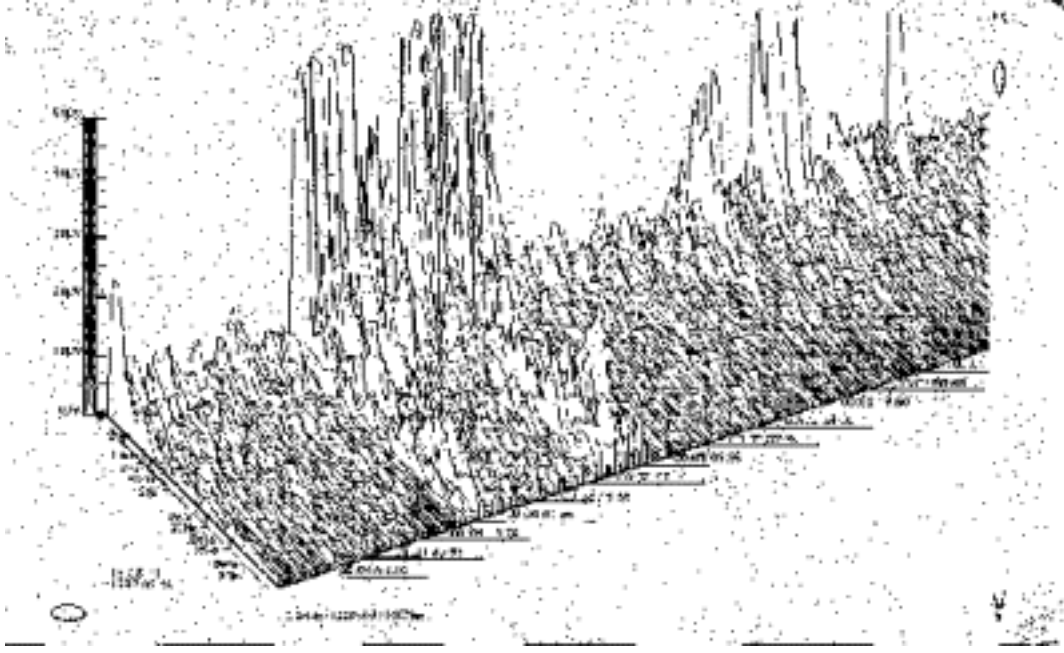
Bispectral analysis: This is a more complex analysis of the EEG that examines not just amplitude and frequency of the waveforms, but also their phase relationships. Commercially available monitors promote this technique as a monitor of anesthetic depth. It is more correct to think of it as a tool for predicting the possibility of recall. There is ample evidence that awareness can occur even when the BIS number is very low. A BIS value of 60 or below is associated with a low probability of recall of intraoperative events. However, there is clear evidence of awareness under anesthesia even at BIS numbers as low as 18.

Entropy analysis: This is a step beyond bispectral analysis. It looks at the randomness of both the EEG signal and the facial EMG. It uses changes in randomness (entropy) as a measure of anesthetic depth. In general, with deeper levels of anesthesia, randomness diminishes. The technology is interesting, but unproven.

Pathological Conditions and the EEG:

Hypoxia: causes nonspecific global slowing and the EEG may be abolished.

Hypotension: has little effect on the EEG until it becomes extreme.

Hypothermia: frequency and amplitude decrease and EEG becomes silent at 15 to 18 �C.

CO_2: hyperventilation may induce seizures; hypoventilation may produce subtle effects similar to those of a volatile anesthetic.

Anesthesia Drugs and the EEG

Subanesthetic doses of drugs initially produce an increase in beta activity. Methohexital can increase overall activity, and etomidate can produce frank seizures. With increasing anesthetic depth, waves become slower and of greater amplitude. Intravenous and volatile anesthetics in sufficient doses can completely suppress the EEG. With ketamine the EEG becomes very disorganized and complete suppression never occurs. Opioids, and benzodiazepines can slow the EEG but do not abolish it. Nitrous oxide given alone results in increased EEG frequency, sometimes > 30Hz.

Intraoperative use of the EEG

The Raw EEG

For seizure surgery electrocorticography is used to guide resection of the seizure focus. The EEG is used to map the area of excitability pre-resection, and to confirm adequate surgery post-resection.

During an awake craniotomy for resection of a tumor or vascular malformation, the cortex is electrically stimulated in order to map out areas associated with speech and motor activity. This electrical stimulation may provoke a seizure, and the electrocorticography is used to give advance warning to allow treatment before a full-blown seizure occurs.

The Processed EEG

This is most commonly used during surgical procedures in which cerebral perfusion may be compromised. For example, during a carotid endarterectomy or clipping of a cerebral aneurysm there is a significant risk of cerebral ischemia. Unilateral changes in the signal from the area at risk are likely to be clinically significant. The BIS monitor is used as a measure of anesthetic depth, and as a tool for decreasing the amount of anesthetic drugs administered.

EVOKED RESPONSES

SENSORY EVOKED POTENTIALS

These monitor the integrity of the pathway from a peripheral nerve to the cortex. They are very small amplitude signals, in the order of 0.1 � 20 �V, and need sophisticated processing and amplification techniques to pick them out from the background of the EEG, EMG and EKG activity. There are three categories, somatosensory evoked potentials (SSEPs), brainstem auditory evoked potentials (BAEPs) and visual evoked potentials (VEPs). Evoked potentials can be cortical or subcortical (spinal cord or brainstem).

SEPs are characterized by both amplitude (magnitude of response) and latency (time from stimulation until response). By convention, downward deflections are positive and upward are negative. Decreases in amplitude or increases in latency may be produced by anesthesia or factors that stress the neuraxis. It is important to try and establish a stable level of anesthesia during monitoring of SEPs.

Somatosensory Evoked Potentials (SSEPs)

Figure 3: An Outline of the Sensory and Motor Tracts

This illustration outlines the pathway for generation of short-latency SSEPs. Sensory nerves (cell bodies in the dorsal root ganglia) transmit the signal rostrally and ipsilaterally (**first order fibers**), in the posterior column to a synapse in the dorsal column nuclei at the cervicomedullary junction. Then the signal is passed via the **second order fibers** that cross to the contralateral thalamus via the medial lemniscus. Finally, the signal travels via the **third order fibers** from the thalamus to the frontoparietal sensory cortex.

Stimulating (0.2 - 2 ms, 1-2 Hz) electrodes are placed over a peripheral nerve e.g. posterior tibial, median, or ulnar. Responses are detected by needle electrodes placed in the skin over the cord (posterior columns), the brachial plexus, brain stem and cortex.
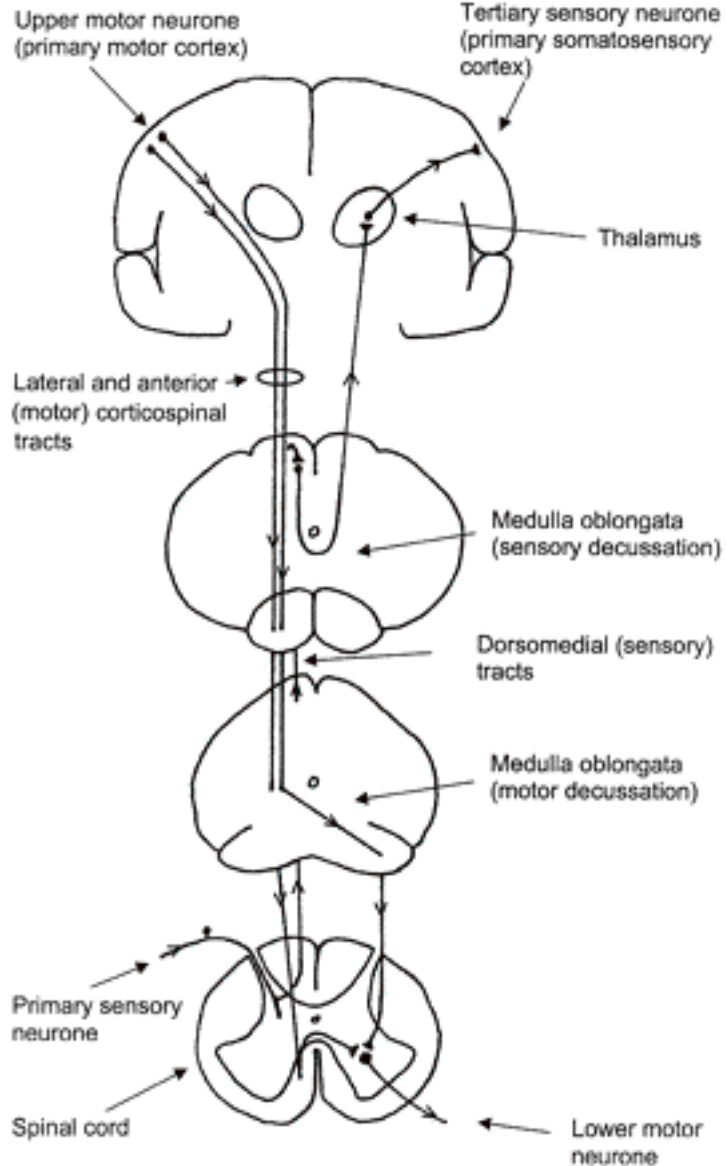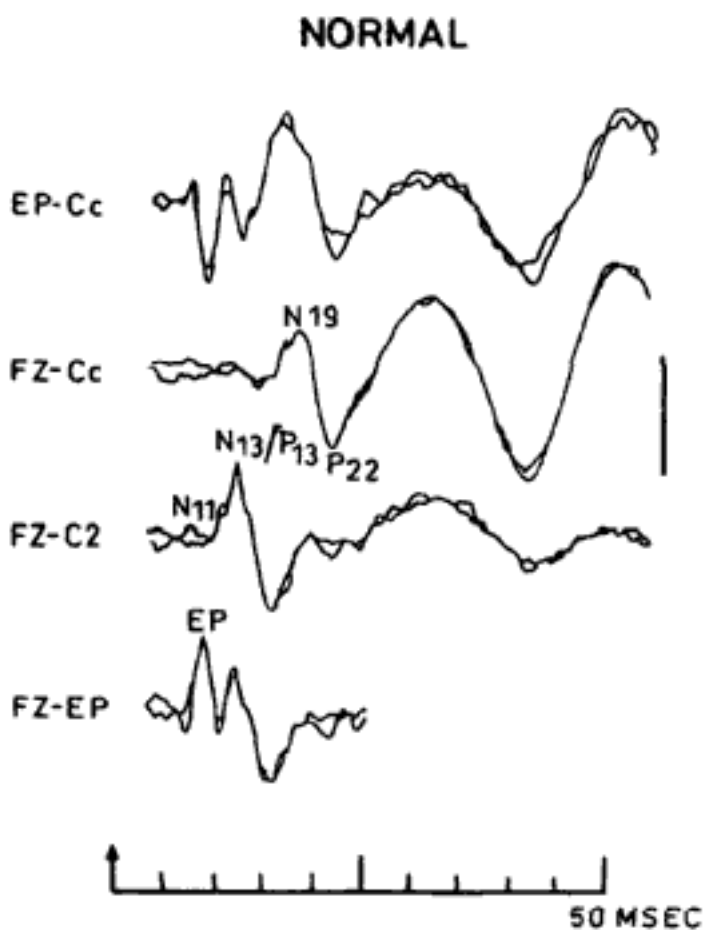
Figure 4: The Standard Short-Latency SSEP

NORMAL

EP-Cc

N 19

FZ-Cc

N13/P13 P22

N11

FZ-C2

EP

FZ-EP

50 MSEC

Signals are described in terms of the direction of the wave (N or P) and the standard time from stimulus to detection (latency) e.g. for median nerve stimulation, N19/P22 is the parietal sensory cortex. There are a variety of SSEP types produced and those used for monitoring are the short latency responses because they are the most robust.

Any interruptions in this pathway can then be detected by SSEP monitoring. SSEPs are employed in a variety of surgeries that involves these neural pathways.

Intraoperative Uses of SSEP

Spinal surgery: measures integrity of the cord during scoliosis repair, tethered cord release resection of lesions within and around the cord.

Vascular Surgery: measures integrity of cord perfusion during high cross clamping of the aorta.

Neurosurgery: measure cortical function during times of potential ischemia e.g. placing of temporary clips. SSEPs also measure brain stem function during retraction in posterior fossa procedures.

Peripheral nerve function; e.g. during hip surgery, SSEPs can monitor function of the sciatic nerve; it can

be used to monitor nerve function during exploration of the brachial plexus.

Brainstem Auditory Evoked Potentials (BAEPs)

A series of clicks (500-2000) are delivered at 100Hz by an earpiece in the auditory canal. Only the side of interest is stimulated, white noise is played in the other ear. The responses are picked up by a scalp electrode on the vertex and the peaks are labeled I through VII of which only I-V are used clinically. This modality is used anytime that brain stem function or the auditory pathway may be at risk. Examples include microvascular decompression of cranial nerves (esp. V and VII), resection of acoustic neuroma, vascular surgery in the posterior fossa, resection of CN VIII for tinnitus.

These responses are very robust, and are not influenced by anesthesia drugs. As with other SEPs, persistent changes are associated with significant risk of poor outcome.

Visual Evoked Potentials (VEPs)

Light emitting diodes deliver flashes at 3 Hz and the response is detected by scalp electrodes. VEPs are used in procedures where the optic pathway is at risk particularly for lesions around the optic chiasm. It is an unreliable technique with a high incidence of both false positives and negatives and is not a commonly used technique.

MOTOR EVOKED POTENTIALS (MEPs)

The principal drawback of SSEP monitoring is that it does not directly monitor the anterior motor pathways (figure 3). Besides being more specific for the motor tracts, motor evoked potentials (MEP) may actually be an earlier predictor of impending damage to the cord than the SSEP.

Figure 5: Outline of Spinal Tracts and Blood Supply
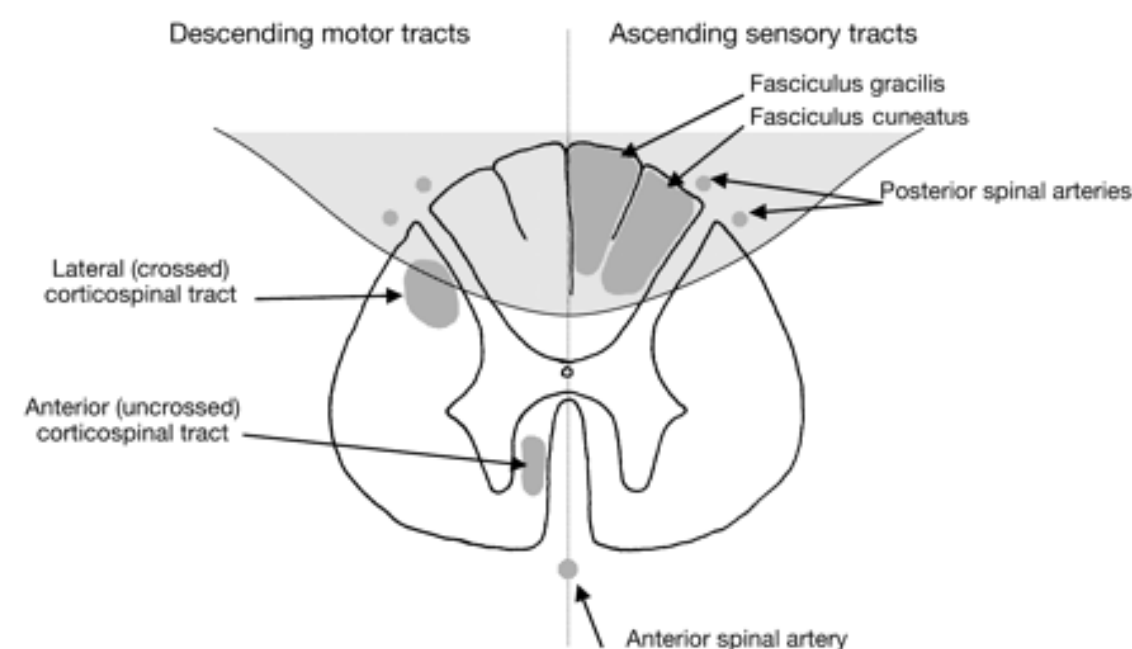
For MEP monitoring the motor cortex is stimulated transcranially and responses are detected somewhere on the resulting descending pathway (figure 3). The response can be detected in the cord, the motor nerve or the muscle itself. The stimulation is most commonly via scalp electrodes placed over the motor cortex. An older and less common technique is to use magnetic stimulation. In addition, the cord may be stimulated directly above the segment at risk and the response detected anywhere more distal.

MEPs may be more sensitive than SSEPs to the effects of anesthesia. This effect is counteracted by delivering 3-5 stimuli (200-500 Hz) and summing the EMG responses (compound muscle action potential).

Because muscle relaxants are contraindicated when the EMG is being monitored, there will be gross motor movement associated with the stimulation. A bite block should be inserted to prevent biting of the tongue. Indications for MEP monitoring are procedures where the spinal cord is at risk.

ANESTHESIA CONSIDERATIONS AND EVOKED RESPONSES

Anesthetic Drugs and Evoked Potentials

Drug	SSEPs LAT	SSEPs AMP	BAEPs LAT	BAEPs AMP	VEPs LAT	VEPs AMP	MEPs LAT	MEPs AMP
Vapors		◆		◆		◆		◆◆
N2O	◆	◆	◆	◆		◆		◆◆
Propofol		◆		◆				◆◆
Opioids		◆	◆	◆			◆	◆
Barbs		◆	◆	◆		◆		◆◆
Benzo		◆	◆	◆				◆◆
Droperidol		◆						◆◆
Etomidate				◆				◆
Ketamine	◆				◆			

SSEPs: Avoid nitrous oxide altogether and keep volatile anesthetic concentrations less than 0.5 MAC (choice of vapor doesn�t matter). Opioids, and propofol are OK. Maintain normotension, normothermia and normocapnia. Neuromuscular block enhances the signals because paralysis decreases interference from the EMG. Maintain a stable level of anesthesia, particularly around the time when the neuraxis may be under stress e.g. distraction of the spine, clipping of an aneurysm. If the signals deteriorate, talk to the surgeons and reverse the precipitating event. Consider increasing the blood pressure.

A Significant Caveat: SSEPs detect only the functional integrity of the posterior columns of spinal cord and related pathways. Injury to the anterior column of spinal cord may not be detected. This is particularly a problem in vascular surgery of the aorta. The uses of Motor EPs (EPs) or a wake up test may be needed.

MEPs: Same considerations as for SSEPs with the addition that there should be no neuromuscular block during the time of monitoring. Use of low dose ketamine might improve the signals, but whether this actually treats the problem or just makes us feel better is not known. In general the effects of anesthesia on electrically evoked MEPs are less than on magnetically MEPs.

BAEPs: these are very robust and any anesthesia technique may be used.

VEPs: very sensitive to any changes in anesthesia depth. Anesthetic considerations are the same as for SSEPs.

DIRECT NERVE STIMULATION WITH ELECTROMYOGRAPHIC (EMG) RESPONSE

General

Technique: With this modality, nerves (cranial or peripheral) are stimulated and the resultant EMG

response is detected. Multiple EMG needles are inserted into the muscles to be examined. Practically any muscle can be monitored, including face, tongue, vocal cords, and sphincters, musculature. The EMG is recorded continually, displayed visually and usually sent to a speaker to provide auditory feedback. Changes in muscle electrical activity then can be seen and heard.

Interpretation: Spontaneous or induced EMG activity is monitored. Additionally, direct electrical stimulation of the nerve can help localize the neural structure. Note that spontaneous EMG activity does not assure the integrity of the peripheral nerve. If evoked EMG activity can be elicited consistently, integrity of the distal nerve and muscle can be assured.

Clinical uses

Cranial nerve monitoring: Useful for procedures in which a cranial nerve is at risk. These include posterior fossa surgery (e.g., acoustic neuroma), vestibular neurectomy, surgery in the temporal bone, and parotid gland surgery. Trigeminal, glossopharyngeal, vagus, spinal accessory, and hypoglossal nerve functions can be monitored similarly by EMG for large tumors in the cerebello-pontine. In addition, electrical stimulation in the operative field can evaluate the integrity of peripheral nerves, e.g. exploration of a trapped or injured nerve. A sudden spontaneous increase in EMG activity suggests surgical manipulation in the vicinity of the cranial nerve.

Selective dorsal rhizotomy: **this** is a procedure that is used to reduce debilitating spasticity in conditions such as cerebral palsy by selectively transecting spinal rootlets. Overactive excitatory influence on motor nerves is reduced by removing facilitatory afferent input from muscle spindles. The procedure consists of stimulating spinal rootlets and monitoring EMG and motor function. Those rootlets that are associated with an abnormal motor response are sectioned selectively.

Tethered spinal cord release: Patients who undergo a tethered cord release procedure require dissection of scar tissue and possibly section of the filum terminale, so distinguishing functional neural elements from nonfunctioning tissue is important. Stimulation of the roots of normally functioning nerves in the cauda equina elicit EMG activity. Monitoring lower extremity musculature, as well as anal and urethral sphincters, is important if the sacral roots are involved.

Pedicle screw placement: During insertion of pedicle screws for spinal stabilization, nerve roots can be injured if the screw protrudes beyond the pedicle. EMG monitoring makes use of the fact that protrusion of the screw beyond the cortical confines of the bony pedicle or vertebral body results in low electrical impedance between the screw and the exiting nerve root. Properly placed screws that remain entirely within the bone have high impedance. If the screw is stimulated with constant voltage greater than 30 volts (V) without EMG activation, the screw is unlikely to be outside of bone. However, a response to stimulation at less than 20 V suggests screw protrusion beyond bone with risk of injury to the nerve root.

Perfusion/Oxygenation Monitoring

Transcranial Doppler

This technique uses ultrasound to measure the velocity of blood flow in a vessel, usually the middle cerebral artery. Its principal use is in detection of cerebral vasospasm following subarachnoid hemorrhage. As a vessel narrows, the velocity of blood flow increases. Mean flow velocities of greater than 120 cm per second correlate well with angiographic vasospasm. In addition, it may be used in the diagnosis of brain death where there is a characteristic pattern comprising a brief systolic inflow with flow reversal in diastole.

Near infra-red spectroscopy

Near-infrared (IR) light easily penetrates biological tissue, and near-IR light spectroscopy (NIRS) reflects cerebral oxygenation during arterial hypotension, hypoxic hypoxaemia and hypo- and hypercapnia. In the clinical setting, NIRS offers useful information in patients with both systemic and local cerebral circulatory

impairment, for example, during cranial trauma, surgery on the cerebral arteries, orthostasis and acute heart failure. It is sensitive to changes in brain volume and perfusion of the extracranial tissues.

Jugular bulb saturation

Requires placing a catheter retrograde up the internal jugular vein into the jugular bulb. It is a measure of global perfusion. It is most commonly used in patients with head injury and saturation ($SjvO_2$) less than 50% is considered to indicate cerebral ischemia. There are no outcome data to support its use.

Intracerebral electrodes

Polarographic microelectrodes have been developed in the past few years and allow continuous measurement of oxygen tension in brain tissue ($PbrO_2$). These electrodes obviously highly invasive and their use is limited to clinical studies, particularly in the area of brain injury and cerebral ischemia