CHAPTER

Noncardiovascular Monitoring

6

KEY CONCEPTS

1. Capnography rapidly and reliably indicates esophageal intubation—a common cause of anesthetic catastrophe—but does not detect bronchial intubation.
2. Close monitoring of neuromuscular blockade using both clinical and quantitative means can reduce the incidence of postoperative curarization.

The previous chapter reviewed routine hemodynamic monitoring used by anesthesiologists. This chapter examines the vast array of techniques and devices used perioperatively to monitor neuromuscular transmission, neurological condition, respiratory gas exchange, and body temperature.

Respiratory Gas Exchange Monitors

PRECORDIAL & ESOPHAGEAL STETHOSCOPES

Indications

Prior to the routine availability of gas exchange monitors, anesthesiologists used a precordial or esophageal stethoscope to ensure that the lungs were being ventilated in the event that the circuit became disconnected. Likewise, the heart tones could be auscultated to confirm a beating heart. Although less essential today because other modalities are available, the finger on the pulse and auscultation remain front-line monitors, especially when technology fails. Chest auscultation remains the primary method to confirm bilateral lung ventilation in the operating room, even if end tidal CO_2 detection is the primary mechanism to exclude esophageal intubation.

Contraindications

Instrumentation of the esophagus should be avoided in patients with esophageal varices or strictures.

Techniques & Complications

A precordial stethoscope (Wenger chestpiece) is a heavy, bell-shaped piece of metal placed over the chest or suprasternal notch. Although its weight tends to maintain its position, double-sided adhesive disks provide an acoustic seal to the patient's skin. Various chestpieces are available, but the child size works well for most patients. The bell is connected to the anesthesiologist by extension tubing.

The esophageal stethoscope is a soft plastic catheter (8–24F) with balloon-covered distal openings (Figure 6–1). Although the quality of breath and heart sounds is much better than with a precordial stethoscope, its use is limited to intubated patients. Temperature probes, electrocardiogram (ECG) leads, ultrasound probes, and even atrial pacemaker electrodes have been incorporated into esophageal stethoscopes. Placement through the mouth or nose can occasionally cause mucosal irritation and bleeding. Rarely, the stethoscope slides into the trachea

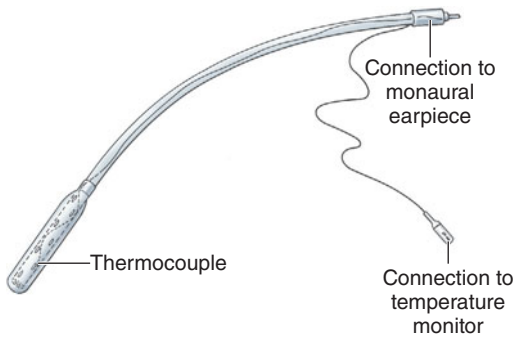

FIGURE 6–1 Esophageal stethoscope.

instead of the esophagus, resulting in a gas leak around the tracheal tube cuff.

Clinical Considerations

The information provided by a precordial or esophageal stethoscope includes confirmation of ventilation, quality of breath sounds (eg, stridor, wheezing), regularity of heart rate, and quality of heart tones (muffled tones are associated with decreased cardiac output).

The confirmation of bilateral breath sounds after tracheal intubation, however, is made with a binaural stethoscope.

PULSE OXIMETRY

Indications & Contraindications

Pulse oximeters are mandatory monitors for any anesthetic, including cases of moderate sedation. There are no contraindications.

Techniques & Complications

Pulse oximeters combine the principles of oximetry and plethysmography to noninvasively measure oxygen saturation in arterial blood. A sensor containing light sources (two or three light-emitting diodes) and a light detector (a photodiode) is placed across a finger, toe, earlobe, or any other perfused tissue that can be transilluminated. When the light source and detector are opposite one another across the perfused tissue, transmittance oximetry is used. When the light source and detector are placed on the same side of the patient (eg, the forehead), the backscatter (reflectance) of light is recorded by the detector.

Oximetry depends on the observation that oxygenated and reduced hemoglobin differ in their absorption of red and infrared light (Lambert–Beer law). Specifically, oxyhemoglobin (HbO_2) absorbs more infrared light (940 nm), whereas deoxyhemoglobin absorbs more red light (660 nm) and thus appears blue, or cyanotic, to the naked eye. The change in light absorption during arterial pulsations is the basis of oximetric determinations (Figure 6–2). The ratio of the absorptions at the red and infrared wavelengths is analyzed by a microprocessor to provide the oxygen saturation (Spo_2) of arterial blood based on established norms. The greater the ratio of red/ infrared absorption, the lower the arterial saturation. Arterial pulsations are identified by plethysmography, allowing corrections for light absorption by nonpulsating venous blood and tissue. Heat from the light source or sensor pressure may, rarely, result in tissue damage if the monitor is not periodically moved. No user calibration is required.

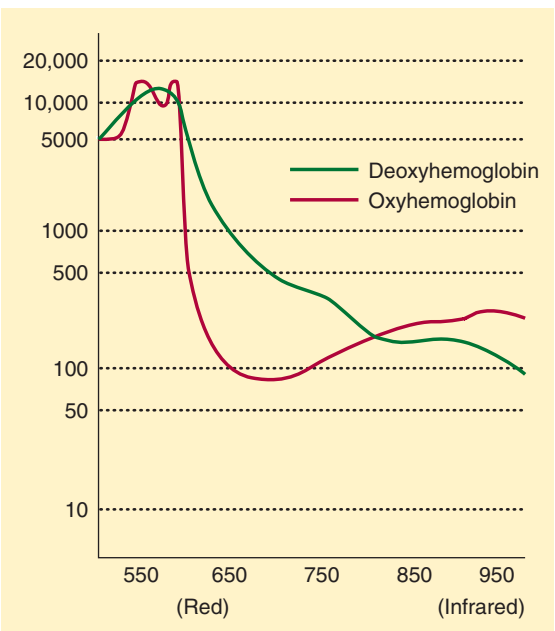

FIGURE 6–2 Oxyhemoglobin and deoxyhemoglobin differ in their absorption of red and infrared light.

Clinical Considerations

In addition to Spo_2, pulse oximeters provide an indication of tissue perfusion (pulse amplitude) and measure heart rate. Because Spo_2 is normally close to 100%, only gross abnormalities are detectable in most anesthetized patients. Depending on a particular patient's oxygen–hemoglobin dissociation curve, a 90% saturation may indicate a Pao_2 of less than 65 mm Hg. This compares with clinically detectable cyanosis, which requires 5 g of desaturated hemoglobin and usually corresponds to an Spo_2 of less than 80%. Bronchial intubation will usually go undetected by pulse oximetry in the absence of lung disease or low fraction of inspired oxygen concentrations (Fio_2).

Because carboxyhemoglobin (COHb) and HbO_2 absorb light at 660 nm identically, pulse oximeters that compare only two wavelengths of light will register a falsely high reading in patients with carbon monoxide poisoning. Methemoglobin has the same absorption coefficient at both red and infrared wavelengths. The resulting 1:1 absorption ratio corresponds to a saturation reading of 85%. **Thus, methemoglobinemia causes a falsely low saturation reading when Sao_2 is actually greater than 85% and a falsely high reading if Sao_2 is actually less than 85%**.

Most pulse oximeters are inaccurate at low Spo_2, and all demonstrate a delay between changes in Sao_2 and Spo_2. **Other causes of pulse oximetry artifact include excessive ambient light, motion, methylene blue dye, venous pulsations in a dependent limb, low perfusion (eg, low cardiac output, profound anemia, hypothermia, increased systemic vascular resistance), malpositioned sensor, and leakage of light from the light-emitting diode to the photodiode, bypassing the arterial bed (optical shunting)**. Nevertheless, pulse oximetry can be an invaluable aid to the rapid diagnosis of hypoxia, which may occur in unrecognized esophageal intubation, and it furthers the goal of monitoring oxygen delivery to vital organs. In the recovery room, pulse oximetry helps identify postoperative pulmonary problems, such as severe hypoventilation, bronchospasm, and atelectasis.

Two extensions of pulse oximetry technology are mixed venous blood oxygen saturation (Svo_2) and noninvasive brain oximetry. The former requires the placement of a pulmonary artery catheter containing fiberoptic sensors that continuously determine Svo_2 in a manner analogous to pulse oximetry. Because Svo_2 varies with changes in hemoglobin concentration, cardiac output, arterial oxygen saturation, and whole-body oxygen consumption, its interpretation is somewhat complex. A variation of this technique involves placing the fiberoptic sensor in the internal jugular vein, which provides measurements of jugular bulb oxygen saturation in an attempt to assess the adequacy of cerebral oxygen delivery.

Noninvasive brain oximetry monitors regional oxygen saturation (rSo_2) of hemoglobin in the brain. A sensor placed on the forehead emits light of specific wavelengths and measures the light reflected back to the sensor (near-infrared optical spectroscopy). Unlike pulse oximetry, brain oximetry measures venous and capillary blood oxygen saturation in addition to arterial blood saturation. Thus, its oxygen saturation readings represent the average oxygen saturation of all regional microvascular hemoglobin (approximately 70%). Cardiac arrest, cerebral embolization, deep hypothermia, or severe hypoxia cause a dramatic decrease in rSo_2. (See the section "Neurological System Monitors.")

CAPNOGRAPHY

Indications & Contraindications

Determination of end-tidal CO_2 ($Etco_2$) concentration to confirm adequate ventilation is mandatory during all anesthetic procedures, but particularly so for general anesthesia. A rapid fall of $Etco_2$ is a sensitive indicator of air embolism, a major complication of sitting craniotomies. There are no contraindications.

Techniques & Complications

Capnography is a valuable monitor of the pulmonary, cardiovascular, and anesthetic breathing systems. Capnographs in common use rely on the absorption of infrared light by CO_2 (**Figure 6–3**). As with oximetry, absorption of infrared light by CO_2 is governed by the Beer–Lambert law.

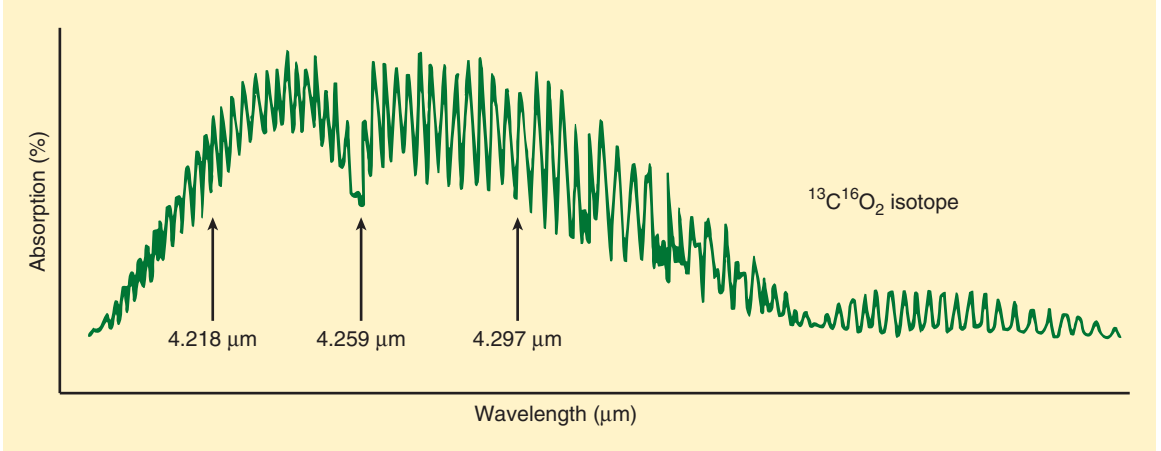

FIGURE 6–3 Absorption spectrum for CO_2. (Reproduced, with permission, from Hill DW: Methods of analysis in the gaseous and vapour phase. In: *Scientific Foundations of Anesthesia.* Scurr C, Feldman S [editors]. Year Book, 1982, p 85.)

A. Nondiverting (Flowthrough)

Nondiverting (mainstream) capnographs measure CO_2 passing through an adaptor placed in the breathing circuit (Figure 6–4). Infrared light transmission through the gas is measured and CO_2 concentration is determined by the monitor. Because of problems with drift, older flowthrough models self-zeroed during inspiration. Thus, they were incapable of detecting inspired CO_2, such as would occur with a breathing circuit malfunction (eg, absorbent exhaustion, sticking unidirectional valves). The weight of the sensor causes traction on the tracheal tube, and its generation of radiant heat can cause skin burns. Newer designs address these problems.

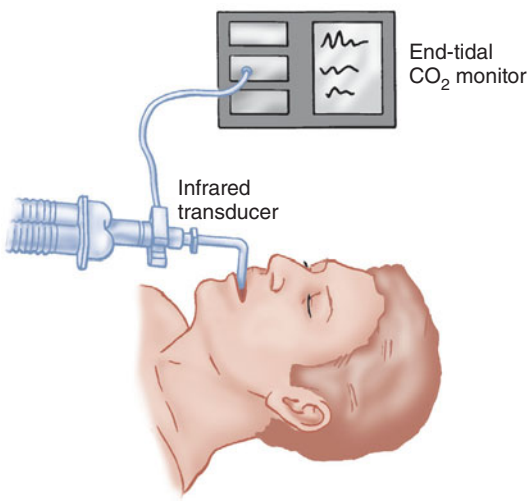

FIGURE 6–4 A nondiverting sensor placed in-line analyzes CO_2 concentration at the sampling site.

B. Diverting (Aspiration)

Diverting (sidestream) capnographs continuously suctions gas from the breathing circuit into a sample cell within the monitor. CO_2 concentration is determined by comparing infrared light absorption in the sample cell with a chamber free of CO_2. Continuous aspiration of anesthetic gas essentially represents a leak in the breathing circuit that will contaminate the operating room unless it is scavenged or returned to the breathing system. High aspiration rates (up to 250 mL/min) and low-dead-space sampling tubing usually increase sensitivity and decrease lag time. If tidal volumes (VT) are small (eg, pediatric patients), however, a high rate of aspiration may entrain fresh gas from the circuit and dilute E_TCO_2 measurement. Low aspiration rates (less than 50 mL/min) can retard E_TCO_2 measurement and underestimate it during rapid ventilation. New units autocalibrate, but older units must be zeroed to room air and against a known CO_2 concentration (usually 5%). Diverting units are prone to water precipitation in the aspiration tube and sampling cell that can cause

obstruction of the sampling line and erroneous readings. Expiratory valve malfunction is detected by the presence of CO_2 in inspired gas. Although inspiratory valve failure also results in rebreathing CO_2, this is not as readily apparent because part of the inspiratory volume will still be free of CO_2, causing the monitor to read zero during part of the inspiratory phase.

Clinical Considerations

Other gases (eg, nitrous oxide) also absorb infrared light, leading to a pressure-broadening effect. To minimize the error introduced by nitrous oxide, various modifications and filters have been incorporated into monitor design. Capnographs rapidly and reliably indicate esophageal intubation—a common cause of anesthetic catastrophe—but do not reliably detect bronchial intubation. Although there may be some CO_2 in the stomach from swallowing expired air, this should be washed out within a few breaths. Sudden cessation of CO_2 during the expiratory phase may indicate a circuit disconnection. The increased metabolic rate caused by malignant hyperthermia causes a marked rise in E_{TCO_2}.

The gradient between P_{aCO_2} and E_{TCO_2} (normally 2–5 mm Hg) reflects alveolar dead space (alveoli that are ventilated but not perfused). Any significant reduction in lung perfusion (eg, air embolism, decreased cardiac output, or decreased blood pressure) increases alveolar dead space, dilutes expired CO_2, and lessens E_{TCO_2}. True capnographs (as opposed to capnometers) display a waveform of CO_2 concentration that allows recognition of a variety of conditions (Figure 6–5).

ANESTHETIC GAS ANALYSIS

Indications

Analysis of anesthetic gases is essential during any procedure requiring inhalation anesthesia. There are no contraindications to analyzing these gases.

Techniques

Techniques for analyzing multiple anesthetic gases involve mass spectrometry, Raman spectroscopy, infrared spectrophotometry, or piezoelectric crystal (quartz) oscillation. Mass spectrometry and Raman spectroscopy are primarily of historical interest, as most anesthetic gases are now measured by infrared absorption analysis.

Infrared units use a variety of techniques similar to that described for capnography. These devices are all based on the Beer–Lambert law, which provides a formula for measuring an unknown gas within inspired gas because the absorption of infrared light passing through a solvent (inspired or expired gas) is proportional to the amount of the unknown gas. Oxygen and nitrogen do not absorb infrared light. There are a number of commercially available devices that use a single- or dual-beam infrared light source and positive or negative filtering. Because oxygen molecules do not absorb infrared light, their concentration cannot be measured with monitors that rely on infrared technology and, hence, it must be measured by other means (see below).

Clinical Considerations

A. Piezoelectric Analysis

The piezoelectric method uses oscillating quartz crystals, one of which is covered with lipid. Volatile anesthetics dissolve in the lipid layer and change the frequency of oscillation, which, when compared with the frequency of oscillation of an uncovered crystal, allows the concentration of the volatile anesthetic to be calculated. Neither these devices nor infrared photoacoustic analysis allow different anesthetic agents to be distinguished. New dual-beam infrared optical analyzers do allow gases to be separated and an improperly filled vaporizer to be detected.

B. Oxygen Analysis

To measure the F_{IO_2} of inhaled gas, manufacturers of anesthesia machines have relied on various technologies.

C. Galvanic Cell

Galvanic cell (fuel cell) contains a lead anode and gold cathode bathed in potassium chloride. At the gold terminal, hydroxyl ions are formed that react with the lead electrode (thereby gradually consuming it) to produce lead oxide, causing current, which is proportional to the amount of oxygen being

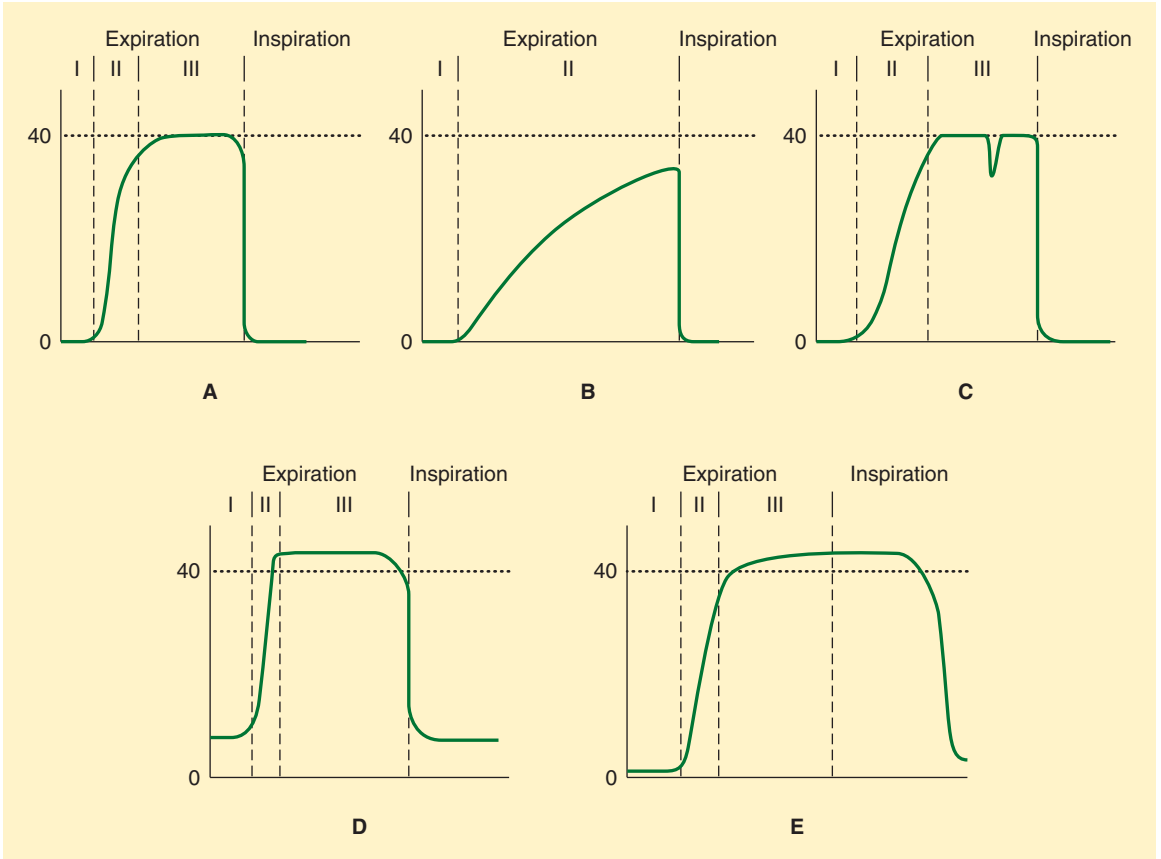

FIGURE 6–5 **A**: A normal capnograph demonstrating the three phases of expiration: phase I—dead space; phase II—mixture of dead space and alveolar gas; phase III—alveolar gas plateau. **B**: Capnograph of a patient with severe chronic obstructive pulmonary disease. No plateau is reached before the next inspiration. The gradient between end-tidal CO_2 and arterial CO_2 is increased. **C**: Depression during phase III indicates spontaneous respiratory effort. **D**: Failure of the inspired CO_2 to return to zero may represent an incompetent expiratory valve or exhausted CO_2 absorbent. **E**: The persistence of exhaled gas during part of the inspiratory cycle signals the presence of an incompetent inspiratory valve.

measured, to flow. Because the lead electrode is consumed, monitor life can be prolonged by exposing it to room air when not in use. These are the oxygen monitors used on many anesthesia machines in the inspiratory limb.

D. Paramagnetic Analysis

Oxygen is a nonpolar gas, but it is paramagnetic, and when placed in a magnetic field, the gas will expand, contracting when the magnet is turned off. By switching the field on and off and comparing the resulting change in volume (or pressure or flow) to a known standard, the amount of oxygen can be measured.

E. Polarographic Electrode

A polarographic electrode has a gold (or platinum) cathode and a silver anode, both bathed in an electrolyte, separated from the gas to be measured by a semipermeable membrane. Unlike the galvanic cell, a polarographic electrode works only if a small voltage is applied to two electrodes. When voltage

is applied to the cathode, electrons combine with oxygen to form hydroxide ions. The amount of current that flows between the anode and the cathode is proportional to the amount of oxygen present.

F. Spirometry

Newer anesthesia machines can measure (and therefore manage) airway pressures, volume, and flow to calculate resistance and compliance and to display the relationship of these variables as flow (ie, volume or pressure–volume loops). Measurements of flow and volume are made by mechanical devices that are usually fairly lightweight and are often placed in the inspiratory limb of the anesthesia circuit.

The most fundamental measurements include low peak inspiratory pressure and high peak inspiratory pressure, which indicate either a ventilator or circuit disconnect, or an airway obstruction, respectively. By measuring V_T and breathing frequency (f), exhaled minute ventilation (V_E) can be calculated, providing some sense of security that ventilation requirements are being met.

Spirometric loops and waveforms are characteristically altered by certain disease processes and events. If a normal loop is observed shortly after induction of anesthesia and a subsequent loop is different, the observant anesthesiologist is alerted to the fact that pulmonary and/or airway compliance may have changed. Spirometric loops are usually displayed as flow versus volume and volume versus pressure (Figure 6–6). There are characteristic changes with obstruction, bronchial intubation, reactive airways disease, and so forth.

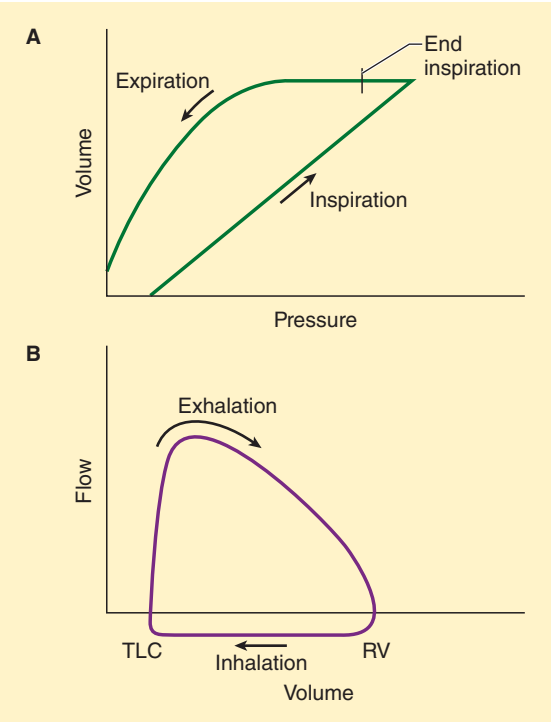

FIGURE 6–6 **A**: Normal volume–pressure loop. **B**: Normal flow–volume loop.

Neurological System Monitors

ELECTROENCEPHALOGRAPHY

Indications & Contraindications

The electroencephalogram (EEG) is occasionally used during cerebrovascular surgery to confirm the adequacy of cerebral oxygenation. Monitoring the depth of anesthesia with a full 16-lead, 8-channel EEG is not warranted, considering the availability of simpler techniques. There are no contraindications.

Techniques & Complications

The EEG is a recording of electrical potentials generated by cells in the cerebral cortex. Although standard ECG electrodes can be used, silver disks containing a conductive gel are preferred. Platinum or stainless steel needle electrodes traumatize the scalp and have high impedance (resistance); however, they can be sterilized and placed in a surgical field. Electrode position (montage) is governed by the international 10–20 system (Figure 6–7). Electric potential differences between combinations of electrodes are filtered, amplified, and displayed by an oscilloscope or pen recorder. EEG activity occurs mostly at frequencies between 1–30 cycles/sec (Hz). Alpha waves have a frequency of 8–13 Hz and are found often in a resting adult with eyes closed. Beta waves at 8–13 Hz are found in concentrating individuals, and at times, in individuals under anesthesia. Delta waves have a frequency of

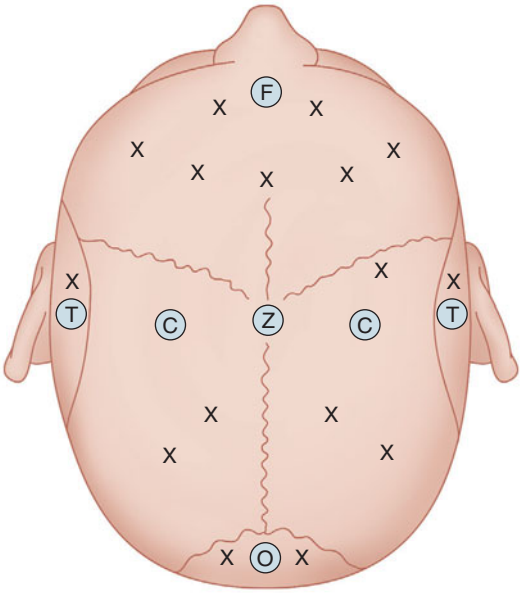

FIGURE 6–7 International 10–20 system. Montage letters refer to cranial location. F, frontal; C, coronal; T, temporal; O, occipital; Z, middle.

0.5–4 Hz and are found in brain injury, deep sleep, and anesthesia. Theta waves (4–7 Hz) are also found in sleeping individuals and during anesthesia. EEG waves are also characterized by their amplitude, which is related to their potential (high amplitude, >50 microV; medium amplitude, 20–50 microV; and low amplitude, <20 microV). Lastly, the EEG is examined as to symmetry between the left and right hemispheres.

Examination of a multichannel EEG is at times performed during surgery to detect areas of cerebral ischemia, such as during carotid endarterectomy as well as during epilepsy surgery. Likewise, it can be used to detect EEG isoelectricity and maximal cerebral protection during hypothermic arrest. The strip chart EEG is cumbersome in the operating room, and often the EEG is processed using power spectral analysis. Frequency analysis divides the EEG into a series of sine waves at different frequencies and then plots the power of the signal at each frequency, allowing for a presentation of EEG activity in a more manageable way than reviewing the raw EEG (**Figure 6–8**).

During inhalational anesthesia, initial beta activation is followed by slowing, burst suppression, and isoelectricity. Intravenous agents, depending on dose and drug used, can produce a variety of EEG patterns.

To reduce the incidence of anesthesia awareness, devices have been developed in recent years that process two-channel EEG signals and create a dimensionless variable to indicate wakefulness. Bispectral index (BIS) is most commonly used in this regard. BIS monitors examine four components within the EEG that are associated with the anesthetic state: (1) low frequency, as found during deep anesthesia; (2) high-frequency beta activation found during "light" anesthesia; (3) suppressed EEG waves; and (4) burst suppression.

Other devices attempt to include measures of spontaneous muscle activity, as influenced by the activity of subcortical structures not contributing to the EEG to further provide an assessment of anesthetic depth. Various devices, each with its own algorithm to process the EEG and/or incorporate other variables to ascertain patient wakefulness, may become available in the future (**Table 6–1**).

Controversy still exists as to the exact role of processed EEG devices in assessing anesthetic depth. Some studies have demonstrated a reduced awareness when these devices were used, whereas other studies have failed to reveal any advantage over the use of inhalational gas measurements to ensure a minimal alveolar concentration of anesthetic agent. Because individual EEG responsiveness to anesthetic agents may be variable, EEG monitors to assess anesthesia depth or to titrate anesthetic delivery might not always ensure an absence of wakefulness. Moreover, many monitors have a delay, which might only indicate a risk for the patient being aware after he or she had already become conscious (**Table 6–2**).

Clinical Considerations

To perform a bispectral analysis, data measured by EEG are taken through a number of steps (**Figure 6–9**) to calculate a single number that correlates with depth of anesthesia/hypnosis.

BIS values of 65–85 have been advocated as a measure of sedation, whereas values of 40–65

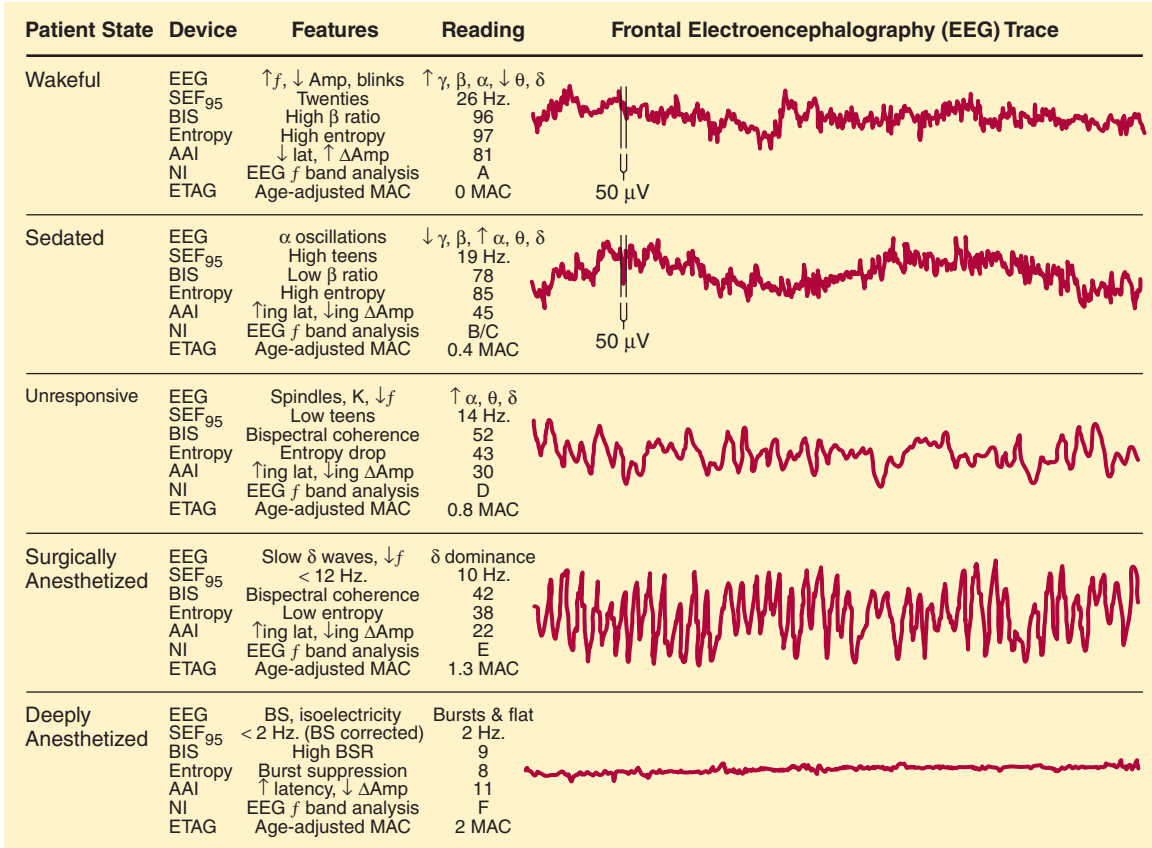

FIGURE 6–8 Patient states, candidate depth of anesthesia devices or approaches, key features of different monitoring approaches, and possible readings at different depths of anesthesia. The readings shown represent examples of possible readings that may be seen in conjunction with each frontal electroencephalography trace. The electroencephalography traces show 3-s epochs (x-axis), and the scale (y-axis) is 50 μV. AAI, A-Line Autoregressive Index (a proprietary method of extracting the mid-latency auditory evoked potential from the electroencephalogram); Amp, amplitude of an EEG wave; BIS bispectral index; blinks, eye blink artifacts; BS, burst suppression; BSR, burst suppression ratio; EEG, electroencephalography; ETAG, end-tidal anesthetic gas concentration; *f*, frequency; γ, β, α, θ, δ, EEG waves in decreasing frequencies (γ, more than 30 hertz [Hz]; β,12–30 Hz; α, 8–12 Hz; θ, 4–8 Hz; δ, 0–4 Hz); K, K complexes; Lat, latency between an auditory stimulus and an evoked EEG waveform response; MAC, minimum alveolar concentration; NI, Narcotrend index; SEF_{95}, spectral edge frequency below which 95% of the EEG frequencies reside; Spindles, sleep spindles. (Reproduced, with permission, from Mashour GA, Orser BA, Avidan MS: Intraoperative awareness: from neurobiology to clinical practice. Anesthesiology 2011;114:1218.)

have been recommended for general anesthesia (Figure 6–10). Bispectral analysis may reduce patient awareness during anesthesia, an issue that is important to the public.

Many of the initial studies of its use were not prospective, randomized, controlled trials, but were primarily observational in nature. Artifacts can be a problem. The monitor, in and of itself, costs several thousand dollars and the electrodes are approximately $10 to $15 per anesthetic and cannot be reused.

Some cases with awareness have been identified as having a BIS of less than 65. However, in other cases of awareness, either there were problems with

TABLE 6–1 Characteristics of the commercially available monitors of anesthetic depth.

Parameters	Machine/ Manufacturer	Consumable	Physiologic Signals	Recommended Range of Values for Anesthesia	Principles of Measurement
Bispectral index (BIS)	A-2000/Aspect Medical Systems, Newton, MA	BIS sensor	Single channel EEG	40–60	BIS is derived from the weighted sum of three EEG parameters: relative α/β ratio; bio-coherence of the EEG waves; and burst suppression. The relative contribution of these parameters has been tuned to correlate with the degree of sedation produced by various sedative agents. BIS ranges from 0 (asleep)–100 (awake).
Patient state index (PSI)	Patient state analyzer (PSA 400)/ Physiometrix, Inc., N. Billerica, MA	PSArray^2	4-channel EEG	25–50	PSI is derived from progressive discriminant analysis of several quantitative EEG variables that are sensitive to changes in the level of anesthesia, but insensitive to the specific agents producing such changes. It includes changes in power spectrum in various EEG frequency bands; hemispheric symmetry; and synchronization between brain regions and the inhibition of regions of the frontal cortex. PSI ranges from 0 (asleep)-100 (awake).
Narcotrend stage Narcotrend index	Nacrotrend monitor/ Monitor-Technik, Bad Bramstedt, Germany	Ordinary ECG electrode	1–2 channel EEG	Narcotrend stage D_{0-2} to C_1, which corresponds to an index of 40–60	The Narcotrend monitor classifies EEG signals into different stages of anesthesia (A = awake; B_{0-2} = sedated; C_{0-2} = light anesthesia; D_{0-2} = general anesthesia; $E_{0,1}$ = general anesthesia with deep hypnosis; $F_{0,1}$ = burst suppression). The classification algorithm is based on a discriminant analysis of entropy measures and EEG spectral variables. More recently the monitor converts the Narcotrend stages into a dimensionless number from 0 (asleep) to 100 (awake) by nonlinear regression.
Entropy	S/5 Entropy Module, M-ENTROPY/ Datex-Ohmeda, Instrumentarium Corp., Helsinki, Finland	Special entropy sensor	Single-channel EEG	40–60	Entropy described the 'irregularity' of the EEG signal. As the dose of anesthetic is increased, EEG becomes more regular and the entropy value approaches zero. M-ENTROPY calculates the entropy of the EEG spectrum (spectral entropy). In order to shorten the response time, it uses different time windows according to the corresponding EEG frequencies. Two spectral parameters are calculated: state entropy (frequency band 0–32 Hz) and response entropy (0–47 Hz), which also includes muscle activity. Both entropy variables have been re-scaled, so that 0 is asleep and 100 is awake.
Aline autore-gressive index (AAI)	AEP/2 monitor/ Danmeter A/S, Odense, Demark	Ordinary ECG electrode	AEP	10–25	AAI is derived from the middle latency AEP (20–80 ms). AAI is extracted from an autoregressive model with exogenous input (ARX model) so that only 18 sweeps are required to reproduce the AEP waveform in 2–6 s. The resultant waveform is then transformed into a numeric index (0–100) that describes the shape of the AEP. AAI > 60 is awake, AAI of 0 indicates deep anesthesia.
Cerebral state index (CSI)	Cerebral state monitor (CSM), Danmeter A/S, Odense, Demark	Ordinary ECG electrode	Single-channel EEG	40–60	CSI is a weighted sum of (1) α ratio, (2) β ratio, (3) difference between the two and (4) burst suppression. It correlates with the degree of sedation by an 'adaptive neuro-fuzzy inference system'. CSI ranges from 0 (asleep) to 100 (awake).

EEG, electroencephalogram; ECG, electrocardiogram; AEP, auditory evoked potential.

Reproduced, with permission, from Chan MTV, Gin T, Goh KYC: Interventional neurophysiologic monitoring. Curr Opin Anaesthesiol 2004;17:389.

TABLE 6–2 Checklist for preventing awareness.

- ✓ Check all equipment, drugs, and dosages; ensure that drugs are clearly labeled and that infusions are running into veins.
- ✓ Consider administering an amnesic premedication.
- ✓ Avoid or minimize the administration of muscle relaxants. Use a peripheral nerve stimulator to guide minimal required dose.
- ✓ Consider using the isolated forearm technique if intense paralysis is indicated.
- ✓ Choose potent inhalation agents rather than total intravenous anesthesia, if possible.
- ✓ Administer at least 0.5 to 0.7 minimum alveolar concentration (MAC) of the inhalation agent.
- ✓ Set an alarm for a low anesthetic gas concentration.
- ✓ Monitor anesthetic gas concentration during cardiopulmonary bypass from the bypass machine.
- ✓ Consider alternative treatments for hypotension other than decreasing anesthetic concentration.
- ✓ If it is thought that sufficient anesthesia cannot be administered because of concern about hemodynamic compromise, consider the administration of benzodiazepines or scopolamine for amnesia.
- ✓ Supplement hypnotic agents with analgesic agents such as opioids or local anesthetics, which may help decrease the experience of pain in the event of awareness.
- ✓ Consider using a brain monitor, such as a raw or processed electroencephalogram but do not try to minimize the anesthetic dose based on the brain monitor because there currently is insufficient evidence to support this practice.
- ✓ Monitor the brain routinely if using total intravenous anesthesia.
- ✓ Evaluate known risk factors for awareness, and if specific risk factors are identified consider increasing administered anesthetic concentration.
- ✓ Redose intravenous anesthesia when delivery of inhalation anesthesia is difficult, such as during a long intubation attempt or during rigid bronchoscopy.

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the recordings, or awareness could not be related to any specific time or BIS value. Whether this monitoring technique becomes a standard of care in the future remains to be seen, and studies are ongoing.

Detection of awareness often can minimize its consequences. Use of the Brice questions during postoperative visits can alert anesthesia providers

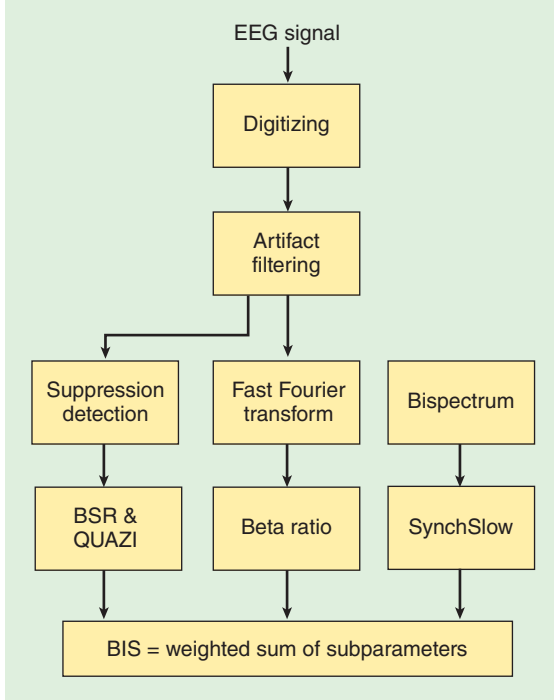

FIGURE 6–9 Calculation of the Bispectral Index. EEG, electroencephalogram; BSR, burst suppression ratio; BIS, Bispectral Index Scale. (Reproduced, with permission, from Rampil IJ: A primer for EEG signal processing in anesthesia. Anesthesiology 1998;89:980.)

of a potential awareness event. Ask patients to recall the following:

- What do you remember before going to sleep?
- What do you remember right when awakening?
- Do you remember anything in between going to sleep and awakening?
- Did you have any dreams while asleep?

Close follow-up and involvement of mental health experts may avoid the traumatic stress that can be associated with awareness events. Increasingly, patients are managed with regional anesthesia and propofol sedation. Patients undergoing such anesthetics should be made aware that they are not having general anesthesia and might recall perioperative events. Clarification of the techniques used may prevent patients so managed from the belief that they "were awake" during anesthesia.

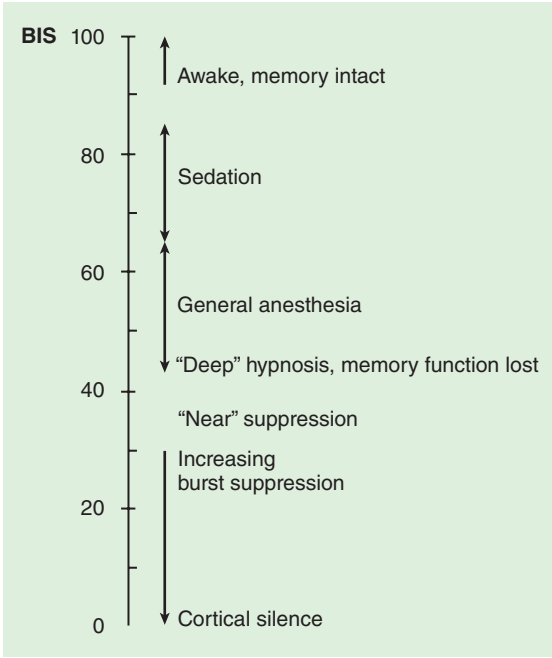

FIGURE 6–10 The Bispectral Index Scale (BIS versions 3.0 and higher) is a dimensionless scale from 0 (complete cortical electroencephalographic suppression) to 100 (awake). BIS values of 65–85 have been recommended for sedation, whereas values of 40–65 have been recommended for general anesthesia. At BIS values lower than 40, cortical suppression becomes discernible in a raw electroencephalogram as a burst suppression pattern. (Reproduced, with permission, from Johansen JW et al: Development and clinical application of electroencephalographic bispectrum monitoring. Anesthesiology 2000;93:1337.)

EVOKED POTENTIALS

Indications

Indications for intraoperative monitoring of **evoked potentials** (EPs) include surgical procedures associated with possible neurological injury: spinal fusion with instrumentation, spine and spinal cord tumor resection, brachial plexus repair, thoracoabdominal aortic aneurysm repair, epilepsy surgery, and cerebral tumor resection. Ischemia in the spinal cord or cerebral cortex can be detected by EPs. EP monitoring facilitates probe localization during stereotactic neurosurgery. Auditory EPs have also been used to assess the effects of general anesthesia on the brain. The middle latency auditory EP may be a more sensitive indicator than BIS in regard to anesthetic depth. The amplitude and latency of this signal following an auditory stimulus is influenced by anesthetics.

Contraindications

Although there are no specific contraindications for somatosensory-evoked potentials (SEPs), this modality is severely limited by the availability of monitoring sites, equipment, and trained personnel. Sensitivity to anesthetic agents can also be a limiting factor, particularly in children. Motor-evoked potentials (MEPs) are contraindicated in patients with retained intracranial metal, a skull defect, and implantable devices, as well as after seizures and any major cerebral insult. Brain injury secondary to repetitive stimulation of the cortex and inducement of seizures is a concern with MEPs.

Techniques & Complications

EP monitoring noninvasively assesses neural function by measuring electrophysiological responses to sensory or motor pathway stimulation. Commonly monitored EPs are brainstem auditory evoked responses (BAERs), SEPs, and increasingly, MEPs (Figure 6–11).

For SEPs, a brief electrical current is delivered to a sensory or mixed peripheral nerve by a pair of electrodes. If the intervening pathway is intact, a nerve action potential will be transmitted to the contralateral sensory cortex to produce an EP. This potential can be measured by cortical surface electrodes, but is usually measured by scalp electrodes. To distinguish the cortical response to a specific stimulus, multiple responses are averaged and background noise is eliminated. EPs are represented by a plot of voltage versus time. The resulting waveforms are analyzed for their poststimulus latency (the time between stimulation and potential detection) and peak amplitude. These are compared with baseline tracings. Technical and physiological causes of a change in an EP must be distinguished from changes due to neural damage. Complications of EP monitoring are rare, but include skin irritation and pressure ischemia at the sites of electrode application.

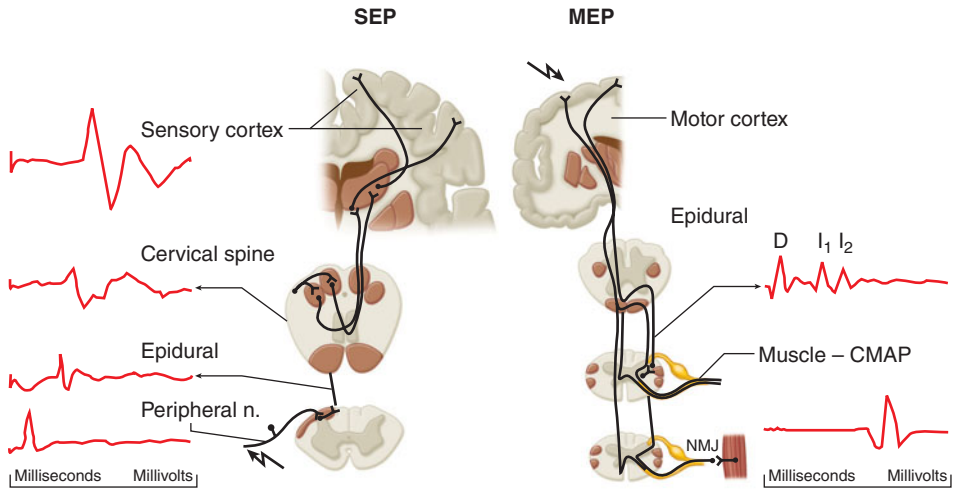

FIGURE 6–11 Neuroanatomic pathways of somatosensory-evoked potential and motor-evoked potential. The somatosensory-evoked potential (SEP) is produced by stimulation of a peripheral nerve wherein a response can be measured. The electrical volley ascends the spinal cord by the posterior columns and can be recorded in the epidural space and over the posterior cervical spine. It crosses the mid-line after synapsing at the cervicomedullary junction and ascends the lemniscal pathways having a second synapse in the thalamus. From there, it travels to the primary sensory cortex where the cortical response is measured. The motor-evoked potential (MEP) is produced by stimulation of the motor cortex leading to an electrical volley that descends to the anterior horn cells of the spinal cord via the corticospinal tract. After synapsing there it travels via a peripheral nerve and crosses the neuromuscular junction (NMJ) to produce a muscle response. The MEP can be measured in the epidural space as D and I waves produced by direct and indirect (via internuncial neurons) stimulation of the motor cortex, respectively. It can also be measured as a compound muscle action potential (CMAP) in the muscle. (Reproduced, with permission, from Sloan TB, Janik D, Jameson L: Multimodality monitoring of the central nervous system using motor-evoked potentials. Curr Opin Anaesthesiol. 2008;21:560.)

Clinical Considerations

EPs are altered by many variables other than neural damage. The effect of anesthetics is complex and not easily summarized. **In general, balanced anesthetic techniques (nitrous oxide, neuromuscular blocking agents, and opioids) cause minimal changes, whereas volatile agents (halothane, sevoflurane, desflurane, and isoflurane) are best avoided or used at a constant low dose**. Early-occurring (specific) EPs are less affected by anesthetics than are late-occurring (nonspecific) responses. Changes in BAERs may provide a measure of the depth of anesthesia. Physiological (eg, blood pressure, temperature, and oxygen saturation) and pharmacological factors should be kept as constant as possible.

Persistent obliteration of EPs is predictive of postoperative neurological deficit. Although SEPs usually identify spinal cord damage, because of their different anatomic pathways, *sensory* (dorsal spinal cord) EP preservation does not guarantee normal *motor* (ventral spinal cord) function (false negative). Furthermore, SEPs elicited from posterior tibial nerve stimulation cannot distinguish between peripheral and central ischemia (false positive). Techniques that elicit MEPs by using transcranial magnetic or electrical stimulation of the cortex allow the detection of action potentials in the muscles if the neural pathway is intact. The advantage of using MEPs as opposed to SEPs for spinal cord monitoring is that MEPs monitor the ventral spinal cord, and if sensitive and specific enough, can be used to indicate which patients might develop a postoperative motor deficit. MEPs are more sensitive to spinal cord ischemia than are SEPs. The same considerations for SEPs are applicable to MEPs in that they are affected by volatile inhalational agents, high-dose benzodiazepines, and moderate hypothermia (temperatures less than 32°C). MEPs

require monitoring of the level of neuromuscular blockade. Close communication with a neurophysiologist is essential prior to the start of any case where these monitors are used to review the optimal anesthetic technique to ensure monitoring integrity. MEPs are sensitive to volatile anesthetics. Consequently, intravenous techniques are often preferred.

CEREBRAL OXIMETRY AND OTHER MONITORS OF THE BRAIN

Cerebral oximetry uses near infrared spectroscopy (NIRS). Using reflectance spectroscopy near infrared light is emitted by a probe on the scalp (**Figure 6–12**). Receptors are likewise positioned to detect the reflected light from both deep and superficial structures. As with pulse oximetry, oxygenated and deoxygenated hemoglobin absorb light at different frequencies. Likewise, cytochrome absorbs infrared light in the mitochondria. The NIRS saturation largely reflects the absorption of venous hemoglobin, as it does not have the ability to identify the pulsatile arterial component. Regional saturations of less than 40% on NIRS measures, or changes of greater than 25% of baseline measures, may herald neurological events secondary to decreased cerebral oxygenation.

Measurements of jugular venous bulb saturation can also provide estimates of cerebral tissue oxygen extraction/decreased cerebral oxygen delivery. Reduced saturations may indicate poor outcomes. Direct tissue oxygen monitoring of the brain is accomplished by placement of a probe to determine the oxygen tension in the brain tissue. In addition to maintaining a cerebral perfusion pressure that is greater than 60 mm Hg and an intracranial pressure that is less than 20 mm Hg, neuroanesthesiologists/intensivists attempt to preserve brain tissue oxygenation by intervening when oxygen tissue tension is less than 20 mm Hg. Such interventions center upon improving oxygen delivery by increasing FIO_2, augmenting hemoglobin, adjusting cardiac output, or decreasing oxygen demand.

Other Monitors

TEMPERATURE

Indications

The temperature of patients undergoing anesthesia must be monitored. Postoperative temperature is increasingly used as a quality anesthesia indicator. Hypothermia is associated with delayed drug metabolism, increased blood glucose, vasoconstriction, impaired coagulation, and impaired resistance to surgical infections. Hyperthermia can likewise

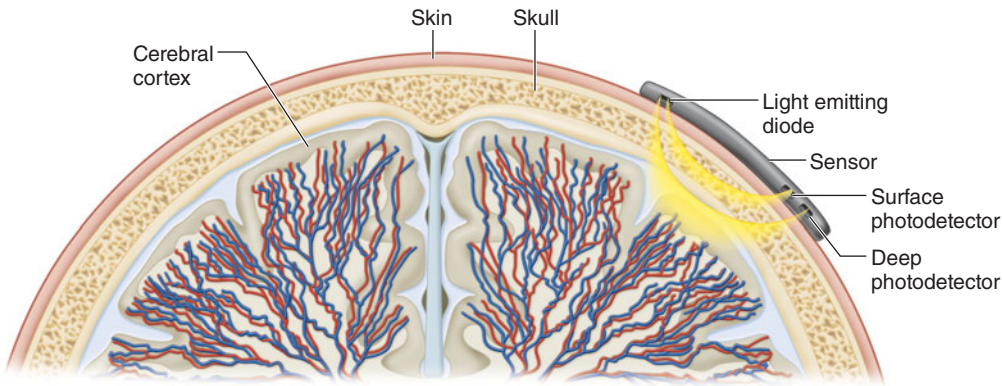

FIGURE 6–12 Principle of the INVOS® near-infrared spectroscopy technique. (Reproduced, with permission, from Rubio A, Hakami L, Münch F, Tandler R, Harig F, Weyand M: Noninvasive control of adequate cerebral oxygenation during low-flow antegrade selective cerebral perfusion on adults and infants in the aortic arch surgery. J Card Surg 2008;23:474.)

have deleterious effects perioperatively, leading to tachycardia, vasodilation, and neurological injury. Consequently, temperature must be measured and recorded perioperatively.

Contraindications

There are no contraindications, although a particular monitoring site may be unsuitable in certain patients.

Techniques & Complications

Intraoperatively, temperature is usually measured using a thermistor or thermocouple. Thermistors are semiconductors whose resistance decreases predictably with warming. A thermocouple is a circuit of two dissimilar metals joined so that a potential difference is generated when the metals are at different temperatures. Disposable thermocouple and thermistor probes are available for monitoring the temperature of the tympanic membrane, nasopharynx, esophagus, bladder, rectum, and skin. Infrared sensors estimate temperature from the infrared energy that is produced. Tympanic membrane temperatures reflect core body temperature; however, the devices used may not reliably measure the temperature at the tympanic membrane. Complications of temperature monitoring are usually related to trauma caused by the probe (eg, rectal or tympanic membrane perforation).

Each monitoring site has advantages and disadvantages. The tympanic membrane theoretically reflects brain temperature because the auditory canal's blood supply is the external carotid artery. Trauma during insertion and cerumen insulation detract from the routine use of tympanic probes. Rectal temperatures have a slow response to changes in core temperature. Nasopharyngeal probes are prone to cause epistaxis, but accurately measure core temperature if placed adjacent to the nasopharyngeal mucosa. The thermistor on a pulmonary artery catheter also measures core temperature. There is a variable correlation between axillary temperature and core temperature, depending on skin perfusion. Liquid crystal adhesive strips placed on the skin are inadequate indicators of core body temperature during surgery. Esophageal temperature sensors, often incorporated into esophageal stethoscopes, provide the best combination of economy, performance, and safety. To avoid measuring the temperature of tracheal gases, the temperature sensor should be positioned behind the heart in the lower third of the esophagus. Conveniently, heart sounds are most prominent at this location. For more on the clinical considerations of temperature control, see Chapter 52.

URINARY OUTPUT

Indications

Urinary bladder catheterization is the only reliable method of monitoring urinary output. Insertion of a urinary catheter is indicated in patients with congestive heart failure, renal failure, advanced hepatic disease, or shock. Catheterization is routine in some surgical procedures such as cardiac surgery, aortic or renal vascular surgery, craniotomy, major abdominal surgery, or procedures in which large fluid shifts are expected. Lengthy surgeries and intraoperative diuretic administration are other possible indications. Occasionally, postoperative bladder catheterization is indicated in patients having difficulty voiding in the recovery room after general or regional anesthesia.

Contraindications

Bladder catheterization should be done with utmost care in patients at high risk for infection.

Techniques & Complications

Bladder catheterization is usually performed by surgical or nursing personnel. To avoid unnecessary trauma, a urologist should catheterize patients suspected of having abnormal urethral anatomy. A soft rubber Foley catheter is inserted into the bladder transurethrally and connected to a disposable calibrated collection chamber. To avoid urine reflux and minimize the risk of infection, the chamber should remain at a level below the bladder. Complications of catheterization include urethral trauma and urinary tract infections. Rapid decompression of a distended bladder can cause hypotension. Suprapubic catheterization of the bladder with tubing inserted through a large-bore needle is an uncommon alternative.

Clinical Considerations

An additional advantage of placing a Foley catheter is the ability to include a thermistor in the catheter tip so that bladder temperature can be monitored. As long as urinary output is high, bladder temperature accurately reflects core temperature. An added value with more widespread use of urometers is the ability to electronically monitor and record urinary output and temperature.

Urinary output is a reflection of kidney perfusion and function and an indicator of renal, cardiovascular, and fluid volume status. Inadequate urinary output (oliguria) is often arbitrarily defined as urinary output of less than 0.5 mL/kg/hr, but actually is a function of the patient's concentrating ability and osmotic load. Urine electrolyte composition, osmolality, and specific gravity aid in the differential diagnosis of oliguria.

PERIPHERAL NERVE STIMULATION

Indications

Because of the variation in patient sensitivity to neuromuscular blocking agents, the neuromuscular function of all patients receiving intermediate- or long-acting neuromuscular blocking agents should be monitored. In addition, peripheral nerve stimulation is helpful in assessing paralysis during rapid-sequence inductions or during continuous infusions of short-acting agents. Furthermore, peripheral nerve stimulators can help locate nerves to be blocked by regional anesthesia.

Contraindications

There are no contraindications to neuromuscular monitoring, although certain sites may be precluded by the surgical procedure. Additionally, atrophied muscles in areas of hemiplegia or nerve damage may appear refractory to neuromuscular blockade secondary to the proliferation of receptors. Determining the degree of neuromuscular blockade using such an extremity could lead to potential overdosing of competitive neuromuscular blocking agents.

Techniques & Complications

A peripheral nerve stimulator delivers current (60-80 mA) to a pair of either ECG silver chloride pads or subcutaneous needles placed over a peripheral motor nerve. The evoked mechanical or electrical response of the innervated muscle is observed. Although electromyography provides a fast, accurate, and quantitative measure of neuromuscular transmission, visual or tactile observation of muscle contraction is usually relied upon in clinical practice. Ulnar nerve stimulation of the adductor pollicis muscle and facial nerve stimulation of the orbicularis oculi are most commonly monitored (Figure 6–13). Because it is the inhibition of the

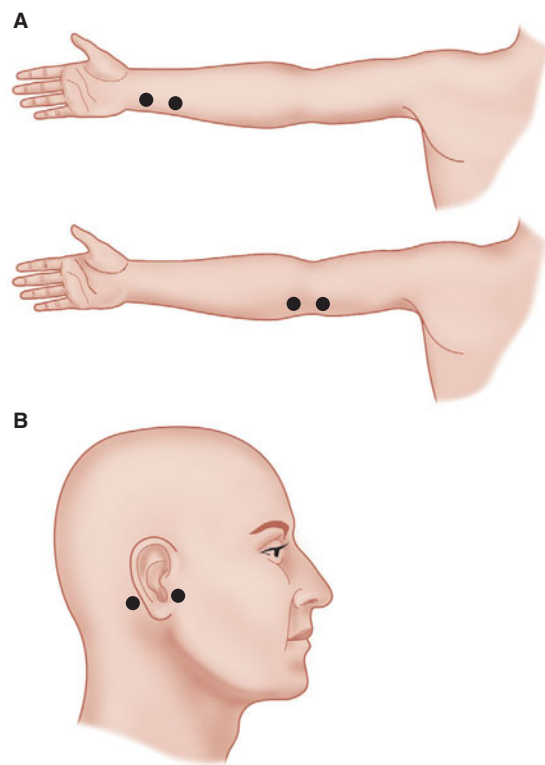

FIGURE 6–13 **A**: Stimulation of the ulnar nerve causes contraction of the adductor pollicis muscle. **B**: Stimulation of the facial nerve leads to orbicularis oculi contraction. The orbicularis oculi recovers from neuromuscular blockade before the adductor pollicis. (Reproduced, with permission, from Dorsch JA, Dorsch SE: *Understanding Anesthesia Equipment*, 4th ed. Williams & Wilkins, 1999.)

neuromuscular receptor that needs to be monitored, direct stimulation of muscle should be avoided by placing electrodes over the course of the nerve and not over the muscle itself. To deliver a supramaximal stimulation to the underlying nerve, peripheral nerve stimulators must be capable of generating at least a 50-mA current across a 1000-Ω load. This current is uncomfortable for a conscious patient. Complications of nerve stimulation are limited to skin irritation and abrasion at the site of electrode attachment.

Because of concerns of residual neuromuscular blockade, increased attention has been focused on providing quantitative measures of the degree of neuromuscular blockade perioperatively. Acceleromyography uses a piezoelectric transducer on the muscle to be stimulated. Movement of the muscle generates an electrical current that can be quantified and displayed. Indeed, acceleromyography can better predict residual paralysis, compared with routine tactile train-of-four monitoring used in most operating rooms, if calibrated from the beginning of the operative period to establish baselines prior to administration of neuromuscular blocking agents.

Clinical Considerations

The degree of neuromuscular blockade is monitored by applying various patterns of electrical stimulation (**Figure 6–14**). All stimuli are 200 μs in duration and of square-wave pattern and equal current intensity. A twitch is a single pulse that is delivered from every 1 to every 10 sec (1–0.1 Hz). Increasing block results in decreased evoked response to stimulation.

Train-of-four stimulation denotes four successive 200-μs stimuli in 2 sec (2 Hz). The twitches in a train-of-four pattern progressively fade as nondepolarizing muscle relaxant block increases. The ratio of the responses to the first and fourth twitches is a sensitive indicator of nondepolarizing muscle paralysis. Because it is difficult to estimate the train-of-four ratio, it is more convenient to visually observe the sequential disappearance of the twitches, as this also correlates with the extent of blockade. Disappearance of the fourth twitch represents a 75% block, the third twitch an 80% block, and the second twitch a 90% block. Clinical relaxation usually requires 75% to 95% neuromuscular blockade.

Tetany at 50 or 100 Hz is a sensitive test of neuromuscular function. Sustained contraction for 5 sec indicates adequate—but not necessarily complete—reversal from neuromuscular blockade. Double-burst stimulation (DBS) represents two variations of tetany that are less painful to the patient. The $DBS_{3,3}$ pattern of nerve stimulation consists of three short (200-μs) high-frequency bursts separated by 20 ms intervals (50 Hz) followed 750 ms later by another three bursts. $DBS_{3,2}$ consists of three 200-μs impulses at 50 Hz followed 750 ms later by two such impulses. DBS is more sensitive than train-of-four stimulation for the clinical (ie, visual) evaluation of fade.

Because muscle groups differ in their sensitivity to neuromuscular blocking agents, use of the peripheral nerve stimulator cannot replace direct observation of the muscles (eg, the diaphragm) that need to be relaxed for a specific surgical procedure. Furthermore, recovery of adductor pollicis function does not exactly parallel recovery of muscles required to maintain an airway. **The diaphragm, rectus abdominis, laryngeal adductors, and orbicularis oculi muscles recover from neuromuscular blockade sooner than do the adductor pollicis**. Other indicators of adequate recovery include sustained (≥5 s) head lift, the ability to generate an inspiratory pressure of at least −25 cm H_2O, and a forceful hand grip. Twitch tension is reduced by hypothermia of the monitored muscle group (6%/°C). Decisions regarding adequacy of reversal of neuromuscular blockade, as well as timing of extubation, should be made only by considering both the patient's clinical presentation and assessments determined by peripheral nerve stimulation. Postoperative residual curarization (PORC) remains a problem in postanesthesia care, producing potentially injurious airway and respiratory function compromise. Reversal of neuromuscular blocking agents is warranted, as is the use of intermediate acting neuromuscular blocking agents instead of longer acting drugs.

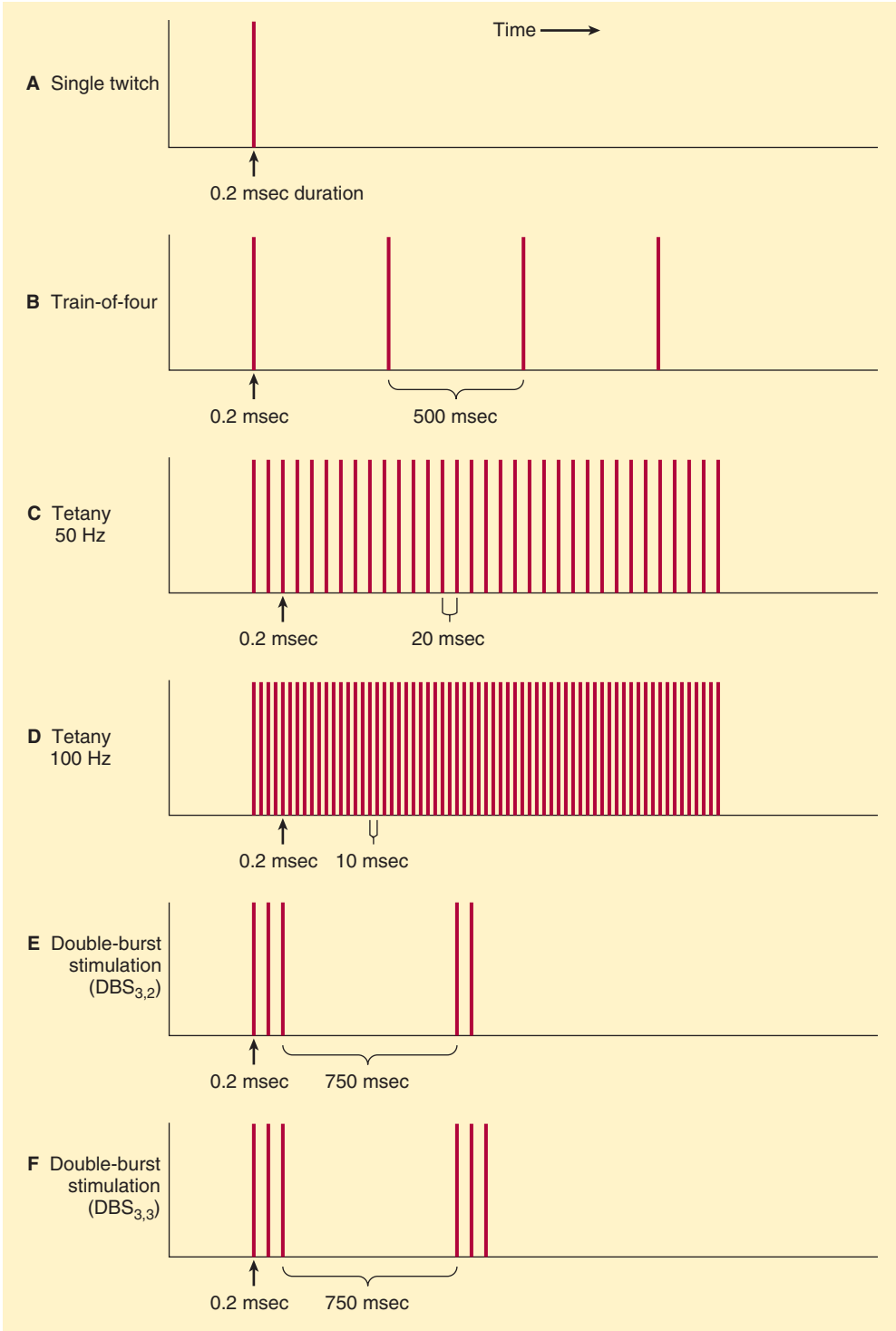

FIGURE 6–14 Peripheral nerve stimulators can generate various patterns of electrical impulses.

CASE DISCUSSION

Monitoring During Magnetic Resonance Imaging

A 50-year-old man with recent onset of seizures is scheduled for magnetic resonance imaging (MRI). A prior MRI attempt was unsuccessful because of the patient's severe claustrophobic reaction. The radiologist requests your help in providing either sedation or general anesthesia.

Why does the MRI suite pose special problems for the patient and the anesthesiologist?

MRI studies tend to be long (often more than 1 h) and many scanners totally surround the body, causing a high incidence of claustrophobia in patients already anxious about their health. Good imaging requires immobility, something that is difficult to achieve in many patients without sedation or general anesthesia.

Because the MRI uses a powerful magnet, no ferromagnetic objects can be placed near the scanner. This includes implanted prosthetic joints, artificial pacemakers, surgical clips, batteries, ordinary anesthesia machines, watches, pens, or credit cards. Ordinary metal lead wires for pulse oximeters or electrocardiography act as antennas and may attract enough radiofrequency energy to distort the MRI image or even cause patient burns. In addition, the scanner's magnetic field causes severe monitor artifact. The more powerful the scanner's magnet, as measured in Tesla units (1 T = 10,000 gauss), the greater the potential problem. Other obstacles include poor access to the patient during the imaging (particularly the patient's airway), hypothermia in pediatric patients, dim lighting within the patient tunnel, and very loud noise (up to 100 dB).

How have these monitoring and anesthesia machine problems been addressed?

Equipment manufacturers have modified monitors so that they are compatible with the MRI environment. These modifications include nonferromagnetic electrocardiographic electrodes, graphite and copper cables, extensive filtering and gating of signals, extra-long blood pressure cuff tubing, and use of fiberoptic technologies. Anesthesia machines with no ferromagnetic components (eg, aluminum gas cylinders) have been fitted with MRI-compatible ventilators and long circle systems or Mapleson D breathing circuits.

What factors influence the choice between general anesthesia and intravenous sedation?

Although most patients will tolerate an MRI study with sedation, head injured and pediatric patients present special challenges and will often require general anesthesia. Because of machine and monitoring limitations, an argument could be made that sedation, when possible, would be a safer choice. On the other hand, loss of airway control from deep sedation could prove catastrophic because of poor patient access and delayed detection. Other important considerations include the monitoring modalities available at a particular facility and the general medical condition of the patient.

Which monitors should be considered mandatory in this case?

The patient should receive at least the same level of monitoring and care in the MRI suite as in the operating room for a similarly noninvasive procedure. Thus, the American Society of Anesthesiologists Standards for Basic Anesthetic Monitoring (see Guidelines on next page) apply as they would to a patient undergoing general anesthesia.

Continuous auscultation of breath sounds with a plastic (not metal) precordial stethoscope can help to identify airway obstruction caused by excessive sedation. Palpation of a peripheral pulse or listening for Korotkoff sounds is impractical in this setting. Ensuring adequacy of circulation depends on electrocardiographic and oscillometric blood pressure monitoring. End-tidal CO_2 analyzers can be adapted to sedation cases by connecting the sampling line to a site near the patient's mouth or nose if nasal cannula with a CO_2 sampling channel are not available. Because room air entrainment precludes exact measurements, this technique provides a qualitative indicator of ventilation. Whenever sedation is planned, equipment for emergency conversion to general anesthesia (eg, tracheal tubes, resuscitation bag) must be immediately available.

Is the continuous presence of anesthesia personnel required during these cases?

Absolutely, yes. Sedated patients need to have continuous monitored anesthesia care to prevent a multitude of unforeseen complications, such as apnea or emesis.

GUIDELINES

American Society of Anesthesiologists Standards for basic anesthetic monitoring, July 2011. http://www.asahq.org/For-Members/Standards-Guidelines-and-Statements.aspx. Accessed January 9, 2013.

SUGGESTED READING

Avidan M, Zhang L, Burnside B, et al: Anesthesia awareness and bispectral index. New Eng J Med 2008;358:1097.

Ben Julian A, Mashour G, Avidan M: Processed electroencephalogram in depth of anesthesia monitoring. Curr Opin Anaesthesiol 2009;22:553.

Fenelly M: Spinal cord monitoring. Anaesthesia 1998;53:41.

Frye E, Levy J: Cerebral monitoring in the operating and the intensive care unit—an introductory for the clinician and a guide for the novice wanting to open a window to the brain. Part I: The electroencephalogram. J Clin Monit Comput 2005;19:1.

Fuchs-Binder T, Schreiber J, Meistelman C: Monitoring neuromuscular block: an update. Anaesthesia 2009;64:82.

Grocott J, Davie S, Fedorow C: Monitoring of brain function in anesthesia and intensive care. Curr Opin Anesthesiol 2010; 23:759.

Jubran A: Advances in respiratory monitoring during mechanical ventilation. Chest 1999;116:1416.

Kasman N, Brady K: Cerebral oximetry for pediatric anesthesia: why do intelligent clinicians disagree? Pediatr Anaesth 2011;21:473.

Mashour G, Orser B, Avidan M: Intraoperative awareness. Anesthiology 2011;114:1218.

Moritz S, Kasprzak P, Arit M, et al: Accuracy of cerebral monitoring in detecting cerebral ischemia during carotid endarterectomy. Anesthiology 2007;107:563.

Myles P, Leslie K, McNeil J: Bispectral function monitoring to prevent awareness during anaesthesia. The B-Aware randomized controlled trial. Lancet 2004;363:1757.

Naguib M, Koman A, Ensor J: Neuromuscular monitoring and postoperative residual curarization: a meta analysis. Br J Anaesth 2007;98:302.

Nishiyama T: Recent advance in patient monitoring. Korean J Anesthesiol 2010;59:144.

Pellicer A, Bravo Mdel C: Near infrared spectroscopy: a methodology focused review. Semin Fetal Neonatal Med 2011;16:42.

Rubio A, Hakami L, Munch F, et al: Noninvasive control of adequate cerebral oxygenation during low flow antegrade selective cerebral perfusion on adults and infants in the aortic arch surgery. J Card Surg 2008;23:474.

Saidi N, Murkin J: Applied neuromonitoring in cardiac surgery; patient specific management. Semin Cardiothorac Vasc Anesth 2005;9:17.

Schell RM, Cole DJ: Cerebral monitoring: jugular venous oximetry. Anesth Analg 2000;90:559.

Sessler D: Temperature monitoring and perioperative thermoregulation. Anesthesiology 2008;109:318.

Sloan T, Janik D, Jameson L: Multimodality monitoring of the central nervous system using motor evoked potentials. Curr Opin Anaesthesiol 2008;21:560.

Tortoriello T, Stayer S, Mott A, et al: A noninvasive estimation of mixed venous oxygen saturation using near infrared spectroscopy by cerebral oximetry in pediatric cardiac surgery patients. Pediatr Anesth 2005;15:495.