Introduction: important to understand types and functions of brain monitors, and to be able to interpret different signals (signals not always as expected); analogy from aviation — pilots do not navigate using only one instrument (because ≥1 instrument may be wrong)

History of brain monitors: devices available for many years; media attention increased over last several years; after release of “infamous movie” Awake (2007), Los Angeles Times reported “every year, 30,000 people in the United States experience anesthesia awareness”; number incorrect, but quoted by Carol Ware, president of Anesthesia Awareness Campaign, who experienced awake paralysis

Terminology
Depth of anesthesia: historically, Guedel stages established objective definitions based specifically on ether anesthesia; signs of depth of anesthesia depend on type of anesthesia given (this creates difficulties for brain monitoring equipment)

Awareness: generally defined as recall of events and words in operating room; awareness possible without recall (ie, retrograde amnesia); difference between awareness and amnesia; awareness generally occurs without pain, but still traumatic experience

Awake paralysis: worst form of awareness; extremely rare; indicates practitioner error; use muscle relaxants only when necessary for specific procedure; paralytics absolutely indicated for some procedures (eg, intra-abdominal, craniotomy), but often unnecessary (for, eg, ankle procedure)

Patients at high risk for awareness: 1) those undergoing cardiac surgery, particularly with high-dose narcotic technique; 2) women having cesarean deliveries under general anesthesia (GA; “light” anesthesia used for protection of fetus); 3) hemodynamically unstable patients undergoing trauma surgery; 4) others in American Society of Anesthesiologists (ASA) classes IV and V (too unstable to tolerate anesthesia)

Characteristics of ideal brain activity monitor: would alert practitioner when plane of anesthesia too light to avoid prolonged recovery, cognitive dysfunction (in, eg, elderly patients), or death from overdose; would function equally for all patients and all anesthetic agents (eg, volatile, narcotic, total intravenous anesthesia [TIVA], ketamine); no monitors currently available meet all criteria (clinical judgment required at all times)

Non-electroencephalography (EEG) monitors: esophageal manometry — measured spontaneous and induced esophageal contractions; interpatient variability limited clinical use, so no longer available; respiratory sinus arrhythmia — misnomer referencing normal R-R variation with respiration; variation decreases with increasing depth of anesthesia and with increasing age (also no longer used); vital signs — used daily; oldest method; dependent on clinical judgment; varies with individuals and technique; has poor sensitivity (probability of positive test in presence of disease) and specificity (probability of negative test in absence of disease)

Classic EEG: 21 standard electrodes placed on shaved head; 2 different montages (unipolar measures voltage [ie, potential difference] between reference electrode and all others; bipolar measures voltage between adjacent electrodes) used; unipolar readings represent large regional or hemispheric activity; bipolar readings evaluate smaller regions (more localized); raw EEG consists of 16 channels of voltage vs time data originating in pyramidal cells of cerebral cortex (superficial layer with unidirectional axons); spontaneous EEG — activity from, eg, thoughts, dreams, metabolic activity; evoked EEG — brain responses to controlled or uncontrolled external stimuli

Processed EEG monitors: process 16 channels for easier interpretation; trends important; understanding monitor allows effective interpretation of data; Fourier’s theorem — any periodic (repeating) signal can be represented as summation of sine waves; harmonics cause fundamental frequency (eg, middle C) to sound different on different instruments; timbre determined by harmonic content (multiples of fundamental frequency with various amplitudes); brain waves broken down to sine waves

Educational Objectives
The goal of this program is to improve patient outcomes through appropriate use of brain monitoring. After hearing and assimilating this program, the clinician will be better able to:

1. Identify patients likely to experience awareness under anesthesia.
2. Describe how processed electroencephalography monitors function.
3. Use brain monitors to prevent complications from both under- and overdosing of patients.
4. Define bicoherence and burst suppression.
5. Recognize the limitations of brain monitors.

Faculty Disclosure
In adherence to ACCME Standards of Commercial Support, Audio-Digest requires all faculty and members of the planning committee to disclose relevant financial relationships within the past 12 months that might create any personal conflicts of interest. Any identified conflicts were resolved to ensure that this educational activity promotes quality in health care and not a proprietary business or commercial interest. For this program, the following has been disclosed: Dr. Barker is on the Board of Directors for Masimo Corporation. The planning committee reported nothing to disclose.
Early brain monitors: Diatiek Lifescan — developed in early to mid-1980s; used processed EEG; had separate right and left displays; 3 dimensions (power or amplitude, frequency, and time) translated into 2-dimensional display

Spectral edge frequency (SEF): first global parameter useful in determining anesthetic depth; high SEF represents high-frequency power (indicating patient more awake); low SEF represents lower-frequency energy (“tends” to indicate deeper plane of anesthesia)

Other early EEG monitors: Cerebrotrac; Neurotrac; both also no longer available

Currently available monitors: include BIS and SEDLine (use different approaches for processing data)

Bispectral index (BIS) monitor: went through several generations; initially used unilateral array (montage), but now employs bilateral measurements; rejects EMG data as artifact; computed parameters — bispectrum (bicoherence; unique to BIS), burst suppression, and beta to delta ratio (ratio of high-frequency power to low-frequency power; analogous to SEF); data integrated with proprietary algorithm to arrive at BIS index (arbitrary scale with 0 representing brain death, 100 full awareness); bicoherence — 2 different raw EEGs made up of same power spectrum (2 Hz, 3 Hz, and 5 Hz) appear different because of coherence; frequencies drift apart over time with no coherence; phase-locked frequencies (bicoherence) indicate communication between cells (ie, greater patient awareness); burst suppression — used by all monitors; periods of >500 ms of isoelectric EEG (amplitude <4 µV); suppression ratio is single number equivalent to percentage of time burst suppression occurs; deeper levels of anesthesia increase burst suppression until flat line (ie, burst suppression 100%); sign of electrical and metabolic depression that varies widely among anesthetic agents (even those in same class); 1987 study demonstrating burst suppression of 10% to 15% with 1.3 minimum alveolar concentration (MAC) of isoflurane and increase to 50% at 1.5 MAC suggested high sensitivity of index; however, high interanesthetic agent variability of burst suppression remains problematic

Summary of BIS monitor features: uses one channel sensor montage on one side of forehead; 2 channels used for identification and extraction of artifacts (now available with bilateral sensing); sensitive to global changes, with limited regional sensitivity; measures bicoherence, burst suppression, and beta to delta ratio; drawbacks — EMG, electrocautery, and differing anesthetic techniques affect data

SEDLine monitor: originally called PSA; symmetrical bilateral array that provides 2-channel data; data based on patient state index (PSI), with time trend represented; range of index values 0 to 100, with surgical anesthesia range 20 to 50 (slightly different than that with BIS); bifrontal electrodes measure 4 channels of raw EEG; displays right vs left; measures burst suppression; rather than measuring relationship between different frequencies (ie, bicoherence used by BIS), measures relationship between different spatial regions (ie, spatial coherence); display — 3 dimensions shown in 2-dimensional display; has bilateral displays; power represented by color (problem for color-blind practitioners); vertical axis represents frequency; time read left to right; SEF and burst suppression also displayed; has separate displays for EMG, artifacts (eg, electrocautery, patient motion), and burst suppression ratio; useful for assessing asymmetry (during, eg, carotid endarterectomy, warming after cardiopulmonary bypass); allows practitioner to interpret data based on techniques used

Spectral entropy monitor (Entropy): one-channel montage; measures complexity of EEG; compares 2 bands of differing frequencies; low band (0-30 Hz) and high band (response entropy; 0-50 Hz) influenced by EMG; offered as plug-in module; measures global rather than regional changes (similar to BIS); evaluates bands separately to differentiate EMG from EEG

Narcotrend monitor: popular in European Union; pattern recognition compares live EEG with stored patterns (A through F) and creates trend plot

Mid-latency auditory evoked potentials (MLAEP) monitor: only monitor that uses evoked responses; requires earphones; reflects brainstem activity rather than activity of pyramidal surface cortex; brainstem evoked potentials (BAEP) or brainstem auditory evoked responses (BAER) show higher suppression from volatile agents than from other drugs; far-field responses — detecting electrodes placed far from generating nuclei in brain (allowing small changes in electrode placement without affecting pattern); latency — time between stimulus and response; isolation of single stimulus among many differing stimuli can be difficult; uses ensemble averaging (average of responses to multiple repetitions of stimulus) to cancel noise interference; auditory responses have much shorter latency periods than somatosensory and visual evoked potentials

Outcome studies: landmark studies done in last 4 yr; prospective study (2008) — randomized 2000 high-risk patients to BIS (target 40-60) or end-tidal anesthesia gas (0.7-1.3 MAC) plus traditional monitoring of vital signs; found 2 confirmed cases of awareness in each group; author concluded that study does not prove BIS not useful, but “findings do not support routine BIS monitoring as part of standard practice”; repeat study (2011) — included 6000 patients, and had same results; studies did not assess overdose rates, delayed awakening, or recovery times (looked at awareness only); since awareness rare, study had low power, and did not prove null hypothesis (ie, did not prove absence of significant difference between study groups)

Speaker’s comments: above distinction important in evaluating outcome studies; similar situation cited with use
of pulse oximetry in operating room (ie, no prospective controlled studies prove its benefit for patient outcomes); brain monitoring devices should prevent overdose as well as awareness; limitations of brain monitors — all measure spontaneous EEG, except MLAEP; all have false-positive and false-negative readings, and interpatient and interanesthetic variability (speaker suggests potential benefit of adding ability to input type of anesthetic agent, and allowing devices to select appropriate algorithm); all have problems with artifacts and time response

Conclusions: become well familiarized with monitor; integrate output with all other available data; knowledge and experience necessary to fully evaluate depth of anesthesia

Acknowledgements

Dr. Barker was recorded at Scottsdale Anesthesia: New Developments and Controversies, held November 6-10, 2011, in Scottsdale, AZ, and sponsored by Holiday Seminars. For information on upcoming meetings sponsored by Holiday Seminars, please visit HolidaySeminars.com, or check our website, Audio-Digest.org, under “Upcoming Meetings.” The Audio-Digest Foundation thanks Dr. Barker and Holiday Seminars for their cooperation in the production of this program.

Suggested Reading


Accreditation: The Audio-Digest Foundation is accredited by the Accreditation Council for Continuing Medical Education to provide continuing medical education for physicians.

Designation: The Audio-Digest Foundation designates this enduring material for a maximum of 2 AMA PRA Category 1 Credits™. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

The American Academy of Physician Assistants (AAPA) accepts certificates of participation for educational activities designated for AMA PRA Category 1 Credit™ from organizations accredited by ACCME or a recognized state medical society. Physician assistants may receive a maximum of 2 AAPA Category 1 CE credits for each Audio-Digest activity completed successfully.

Audio-Digest Anesthesiology programs are approved by the American Association of Nurse Anesthetists (AANA) for a maximum of 24 CE credits for Volume 53 (Code Number 025902; Expiration Date 12/31/13) and 24 CE credits for Volume 52 (Code Number 33415; Expiration Date 12/31/12). CRNAs must earn a score of 80% to receive credit, and are not permitted to retest, as per the AANA.

CRNAs may earn 1 credit per issue in Volume 54 from January 1, 2012 to December 31, 2013 and in Volume 53 from January 1, 2011 to December 31, 2012.

Audio-Digest Foundation is accredited as a provider of continuing nursing education by the American Nurses Credentialing Center’s (ANCC’s) Commission on Accreditation. Audio-Digest designates each activity for 2.0 CE contact hours.

Audio-Digest Foundation is approved as a provider of nurse practitioner continuing education by the American Academy of Nurse Practitioners (AANP Approved Provider number 030904). Audio-Digest designates each activity for 2.0 CE contact hours, including 0.5 pharmacology CE contact hours.

The California State Board of Registered Nursing (CA BRN) accepts courses provided for AMA category 1 credit as meeting the continuing education requirements for license renewal.

Expiration: The CME activity qualifies for Category 1 credit for 3 years from the date of publication.

Cultural and linguistic resources: In compliance with California Assembly Bill 1195, Audio-Digest Foundation offers selected cultural and linguistic resources on its website. Please visit this site: www.audiodigest.org/CLCresources.

Estimated time to complete the educational process:

Review Educational Objectives on page 1 5 minutes
Take pretest 10 minutes
Listen to audio program 60 minutes
Take written summary and suggested readings 35 minutes
Take posttest 10 minutes
WHAT’S NEW IN BRAIN MONITORING?

1. Which of the following statements about brain monitors is true?
   (A) They are newly developed devices
   (B) They provide objective and consistent data
   (C) They are useful in preventing awareness during anesthesia
   (D) Respond similarly to all anesthetic agents

2. Which of the following about awareness during anesthesia is correct?
   (A) Generally defined as recall of events and words in the operating room
   (B) Occurs with pain
   (C) Is not possible without recall
   (D) Is a common occurrence

3. All the following statements are correct, except:
   (A) Awake paralysis is the worst form of awareness
   (B) Awareness during general anesthesia has been estimated to occur in 30,000 patients annually
   (C) Awake paralysis indicates practitioner error
   (D) Muscle relaxants should always be used during general anesthesia

4. Which of the following procedures does not present a high risk for awareness under anesthesia?
   (A) Craniotomy
   (B) Cardiac surgery
   (C) Cesarean delivery under general anesthesia
   (D) Trauma surgery

5. Which of the following non-electroencephalography forms of monitoring is still in use daily?
   (A) Esophageal manometry
   (B) Monitoring of vital signs
   (C) Monitoring of respiratory sinus arrhythmia
   (D) Electromyography

6. Bicoherence indicates increased probability of patient awareness.
   (A) True
   (B) False

7. An increase in burst suppression indicates a(n) _______ in depth of anesthesia.
   (A) Increase
   (B) Decrease

8. All the following are used to calculate the bispectral index (BIS), except:
   (A) Bicoherence
   (B) Burst suppression
   (C) Beta to delta ratio
   (D) Electromyographic data

9. Which of the following is true of the BIS monitor, but not of the SEDLine monitor?
   (A) The index is based on a 0 to 100 scale
   (B) Electromyographic data are excluded as noise
   (C) Burst suppression is measured
   (D) The data are affected by electrocautery

10. The mid-latency auditory evoked potential (MLAEP) monitor is the only monitor to measure activity of the pyramidal surface cortex.
    (A) True
    (B) False

NOTE: On Audio-Digest Anesthesiology Volume 54, Issue 19, the correct answer to question 10 is “A.”

Answers to Audio-Digest Anesthesiology Volume 55, Issue 01: 1-C, 2-B, 3-A, 4-B, 5-D, 6-B, 7-D, 8-A, 9-B, 10-B