Electroencephalogram (EEG): Changing How We Optimize Patient Safety and Comfort in Real-time

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INTRODUCTION

Brain function monitoring systems, such as the electroencephalogram (EEG), are vital tools for anesthesia providers to track brain activity and assess the depth of general anesthesia. By capturing real-time data, innovative EEG systems produce waveforms that reflect the brain's electrical activity during both awake and deep anesthetic stages. These waveforms can be interpreted by analyzing their amplitude and frequency, with different colors used to visually represent varying levels of activity. The four most common waveforms measured are alpha, beta, theta, and delta waves. These monitoring systems involve placing electrodes on both sides of the patient's forehead to capture bilateral brain electrical activity (EEG) signals. As an adjunct to vital signs and clinical assessment, the sophisticated monitor provides a quantitative value to determine the depth of general anesthesia and prevent intraoperative awareness. (Niedermeyer & da Silva, 2004)

TYPES OF ELECTROENCEPHALOGRAM (EEG) WAVE FORMS

The four primary EEG waveforms—alpha, beta, theta, and delta—represent different brain activity states and are categorized based on frequency and associated mental states **(See Figure 1)**. The waveforms are measured in Hertz (Hz), which is defined as the unit of frequency, representing the number of cycles per second of a wave. For example, Alpha waves, representing 8- 12 Hz, indicate that the brain's electrical activity cycles 8-12 times per second. Each person's brain functions differently, with brain waves operating at varying frequencies, so knowing the frequency at which a patient's brain is operating matters. Each frequency is associated with various states of brain function and consciousness. (NHA Health, n.d.)

Alpha waves are associated with a calm, relaxed, and meditative state of mind. They primarily originate from the **occipital and parietal regions** of the brain, which are responsible for sensory processing and perception (Niedermeyer & da Silva, 2004). The **occipital lobe**, located at the back of the brain, is responsible for visual processing. It interprets depth, distance, and position, and recognizes observed objects. Alpha waves are often strongest in this region, particularly when a person is awake but relaxed. The **parietal lobe**, situated behind the frontal lobes near the top and back of the brain, processes sensory information related to touch and spatial awareness. Alpha waves are also present in this region.

Beta Waves (12-30 Hz) have a higher frequency and are linked to increased alertness, anxiety, or heightened excitement (Teplan, 2002). Beta waves are primarily found in the frontal and parietal lobes of the brain.

Theta Waves (4-8 Hz) are most observed during **light sleep and deep relaxation**, and they are often associated with creativity and subconscious processing (Klimesch, 1999). In the early stages of sleep (Stage 1 & 2 non-REM sleep), theta waves are primarily found in the following brain regions: the hippocampus, frontal lobe, anterior cingulate cortex, temporal lobes, and thalamus.

Delta Waves (0.5-4 Hz) are the slowest brain waves, typically occurring during **deep sleep**, playing a critical role in physical restoration and brain recovery (Steriade & McCarley, 2005). Delta waves are found in the following brain regions: The hippocampus, frontal lobe, anterior cingulate cortex, temporal lobes, and thalamus.

Clear identification of EEG waveforms enables specialists to understand brain function more effectively and is widely utilized in both clinical and academic settings to evaluate **neurological and psychological conditions**. The brain regions observed are known as the occipital and parietal regions of the cerebral cortex. They play a crucial role in interpreting sensory information.

PATIENT STATE INDEX

A patient state index (PSI) is generated from an algorithm that processes waveform signals, providing a numerical value

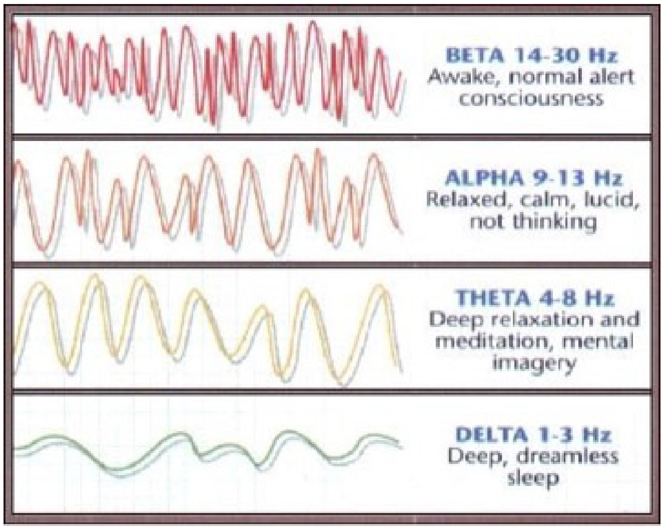

Figure 1. *An illustration of the four EEG waveforms: alpha, beta, theta, and delta waves, with labeled graphs showing their unique frequencies and amplitudes.*

between 0 and 100 **(See Figure 2)**. A PSI of zero indicates no brain activity, while a PSI of one hundred indicates full consciousness. The PSI is continuously calculated throughout the surgical procedure, providing anesthesia providers with a constant stream of information to maintain the appropriate level of sedation and ensure patient safety (Sukumar & Wright, 2020).

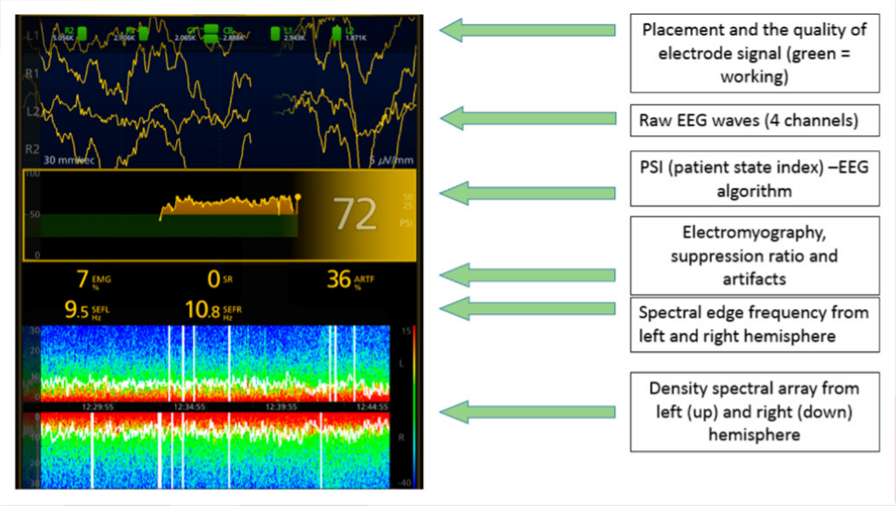

Figure 2: *Image of Patient State Index (PSI) numerical value and its relationship to EEG waveforms indicating brain activity levels.*

CLINICAL IMPLICATIONS

EEG monitoring can differ based on age and medical conditions, providing different clinical implications (Kurtz et al., 2014). However, it benefits both pediatric and adult populations, providing valuable information about brain activity in various clinical settings (Ching et al., 2013). EEG monitoring has been used to diagnose and manage neurological conditions such as epilepsy, developmental disorders, and some sleep abnormalities in children outside of the operating room (Smith, 2015). This underscores the empowering role of EEG monitoring in clinical anesthesiology (Brown et al., 2010). Due to ongoing brain development and differences in body size, pediatric readings can differ from those of mature adults (Cornelissen et al., 2015).

In contrast, interpreting the EEG of a pediatric patient can be more challenging due to their size and ongoing brain maturation (Johnson et al., 2012). For infants and children undergoing general anesthesia, EEG monitoring provides trending data to monitor sedation depth and titration of general anesthesia medications. With increasing evidence for apoptosis (cell death) of premature brain cells and metabolism of general anesthetics in infants and children, EEG monitoring can decrease opioid and benzodiazepine administration and enhance adequate intravenous titration of hypnotic and inhaled halogenated agents to reduce intraoperative awareness and morbidity. (Fink et al., 2017).

INTRAOPERATIVE AWARENESS

The incidence of intraoperative awareness under general anesthesia (GA) is reported to be between 1 and 2 per 1,000 patients, or 0.1-0.2% (Bischoff & Rundshagen, 2011). EEG monitoring is utilized primarily to assess the depth of anesthesia, prevent intraoperative awareness, and manage patients with neurological conditions. One of the primary uses of EEG in adult anesthesia is to monitor the depth of sedation. EEG-derived indices, such as the PSI, Bispectral Index (BIS), and Entropy, help anesthesia providers maintain adequate anesthesia, reducing the risks of awareness or inadequate sedation. These waveforms reflect the brain's electrical activity and guide the titration of continuous intravenous hypnotic infusions (Rampil, 1998).

Intraoperative awareness, or being conscious under general anesthesia, is preventable and can cause emotional and psychological distress for patients. Ghoneim, M. M., & Block, R. I. (2012). Patients with preexisting neurological disorders (epilepsy, traumatic brain injury, and/or stroke) are at increased risk for cognitive dysfunction. Therefore, EEG is beneficial for assessing brain activity and function.

CONCLUSION:

In conclusion, EEG monitoring during anesthesia significantly enhances patient safety monitoring in the operating room. EEG enables anesthesia providers to accurately assess sedation levels by continuously monitoring brain wave activity, thereby reducing the risk of intraoperative awareness. The different brain wave patterns recorded—alpha, beta, theta, and delta—provide supplemental data on levels of consciousness, facilitating patient-focused anesthesia management, particularly for pediatric patients. In addition to diagnosing neurological conditions, applying EEG monitoring in conjunction with the American Society of Anesthesiologists' standard of care can be a vital step forward in delivering safer and evidence-informed clinical management.

References

Bischoff, P., & Rundshagen, I. (2011). Awareness under general anesthesia. Deutsches Ärzteblatt International, 108(1-2), 1–7. https://doi.org/10.3238/arztebl.2011.0001

Ghoneim, M. M., & Block, R. I. (2012). Learning and memory during general anesthesia: An update. *Anesthesiology*, 116(3), 631–658. https://doi.org/10.1097/ALN.0b013e31823d292a

Hesse, S., James, C. J., & Ambrosy, N. (2021). *Advancements in EEG signal processing for anesthetic monitoring: Applications of machine learning techniques. Journal of Clinical Neurophysiology,* 38(4), 250–262.

Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. *Brain Research Reviews,* 29(2–3), 169–195. https://doi.org/10.1016/S0165-0173(98)00056-3

Mashour, G. A., Shanks, A., Tremper, K. K., Kheterpal, S., & Turner, C. R. (2011). Prevention of intraoperative awareness with explicit recall: A randomized controlled trial. *Anesthesiology, 115(4),* 797–805. https://doi.org/10.1097/ALN.0b013e31822e9d68

National Center for Biotechnology Information. (n.d.). *Occipital lobe.* National Library of Medicine. Retrieved from https://www.ncbi.nlm.nih.gov/books/NBK544320/

NHA Health. (n.d.). *The science of brainwaves – The language of the brain.* Retrieved from https://nhahealth.com/brainwaves-the-language/

Niedermeyer, E., & da Silva, F. L. (2004). *Electroencephalography: Basic principles, clinical applications, and related fields* (5th ed.). Lippincott Williams & Wilkins.

Queensland Brain Institute. (n.d.). *Parietal lobe.* The University of Queensland. Retrieved from https://qbi.uq.edu.au/brain/brain-anatomy/lobes-brain

Rampil, I. J. (1998). A primer on anesthetic monitoring. *The Journal of Clinical Monitoring and Computing, 14(1), 1–6.* https://doi.org/10.1023/A:1009045320768

Steriade, M., & McCarley, R. W. (2005). *Brainstem control of wakefulness and sleep.* Springer Science & Business Media.

Sukumar, S., & Wright, D. (2020). The role of electroencephalography in anesthesia monitoring. *Journal of Clinical Anesthesia, 65,* 109862. https://doi.org/10.1016/j.jclinane.2020.109862

Teplan, M. (2002). Fundamentals of EEG measurement. *Measurement Science Review, 2(2),* 1–11.

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To test your knowledge on this issue's article, provide correct answers to the following questions on the form below. Follow the instructions carefully.

1. What is the primary purpose of EEG monitoring in anesthesia?
A) To monitor heart rate
B) To assess the depth of general anesthesia
C) To control blood pressure
D) To administer medications

2. Which EEG waveform is associated with deep sleep and brain recovery?
A) Alpha waves
B) Beta waves
C) Theta waves
D) Delta waves

3. Where are alpha waves most commonly generated in the brain?
A) Occipital and parietal lobes
B) Frontal and temporal lobes
C) Hippocampus and amygdala
D) Brainstem and cerebellum

4. What PSI (Patient State Index) value indicates full consciousness?
A) 0
B) 50
C) 75
D) 100

5. Which EEG waveform is commonly seen during light sleep and deep relaxation?
A) Alpha
B) Theta
C) Beta
D) Delta

6. What is the reported incidence rate of intraoperative awareness under general anesthesia?
A) 0.1–0.2%
B) 1–2%
C) 3–4%
D) Less than 0.01%

7. What unit is used to measure EEG wave frequencies?
A) Watts
B) Volts
C) Hertz (Hz)
D) Joules

8. Which EEG monitoring index is used to assess anesthesia depth and reduce awareness risk?
A) ECG
B) MRI
C) PSI
D) CT

9. Which of the following is a benefit of EEG monitoring in pediatric patients?
A) Increases medication dosage
B) Replaces the need for anesthesia
C) Helps adjust sedation levels appropriately
D) Prevents brain development

10. According to the article, what brain areas are associated with delta wave generation?
A) Occipital lobe and cerebellum
B) Temporal lobe and brainstem
C) Hippocampus, frontal lobe, anterior cingulate cortex, temporal lobes, and thalamus
D) Visual cortex and amygdala

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4.	A	B	C	D	9.	A	B	C	D
5.	A	B	C	D	10.	A	B	C	D

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