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Research on the application of electroencephalogram-derived bispectral index in cardiac surgery

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Abstract. Monitoring the depth of anesthesia during cardiac surgery is a complex and difficult task. Alongside the conventional standard and advanced monitoring instruments, the EEG bispectral index (BIS) has proven more effective in reducing intraoperative consciousness incidents. Additionally, it offers the benefits of diminishing the requirement for anesthetic drugs and detecting cerebral ischemia. Nevertheless, pertinent evidence indicates that BIS requires improvement in various clinical scenarios. This article provides a comprehensive introduction to the principles of BIS, deliberates on the pros and cons of its clinical application, and explores methods for enhancing its efficacy. BIS fits an optimal number by fitting the mixed information from the EEG. It is widely used in drug application, depth monitoring of anesthesia and evaluation of consciousness state, but low temperature, electronic interference, and systematic error will affect it, and the standardized use and application of new technology will help to enhance its efficacy.

Keywords: bispectral index, EEG, cardiac surgery, anesthesia, consciousness.

1. Introduction

In cardiac surgery, the opening of the chest operation significantly affects the patient's blood circulation. To ensure patient safety, sophisticated hemodynamic monitoring and transesophageal echocardiography (TEE) are often employed. TEE utilizes a specialized ultrasound probe for examining heart function and evaluating parameters such as heart function, blood flow variations, blood volume status, and myocardial ischemia. Additionally, the brain is the most susceptible organ during anesthesia, necessitating monitoring for various reasons, including assessing sedation depth and consciousness, preventing intraoperative awakenings, minimizing time spent awake, and reducing overall anesthesia consumption [1]. Enhancing brain perfusion and cerebral blood flow can mitigate secondary brain damage. Research has demonstrated a connection between general anesthesia and changes in neuroelectric brain activity, primarily monitored through a raw frontal electroencephalogram (EEG) and the basic bispectral index (BIS) based on spontaneous activities [2]. This article predominantly delves into the strengths and weaknesses of EEG and BIS in the context of clinical cardiac surgery. This paper can assist anesthesiologists in improving their comprehension of BIS, better elucidating the causes of changes, analyzing and comprehending changes in patients' physiological status, decreasing the likelihood of intraoperative knowledge and avoiding too deep anesthesia, ensuring patient safety during the procedure, and decreasing the likelihood of postoperative complications.

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2. A Brief Introduction To EEG, Bis, And Anesthesia

EEG primarily monitors the combined neuronal excitability and inhibitory synaptic potentials within gray matter. It is commonly used to monitor crucial functions during anesthesia. EEG provides a real-time graphical representation of spontaneously generated electrical potentials, typically in the microvolt range, beneath a scalp electrode [3]. As consciousness transitions from wakefulness to loss, small, fast waves give way to larger, slower waves (50–300 mV). With deepening anesthesia, faster waveforms may emerge. BIS integrates aspects of the raw EEG to produce a dimensionless number ranging from 0 to 100, where 0 indicates complete cerebral suppression and 90–100 signifies wakefulness. Maintaining a BIS value between 40 and 60 is generally considered appropriate for total body anesthesia. The EEG waveform is processed to detect any signs of cerebral inhibition, with a fast Fourier transform (FFT) calculating phase coupling between dual-spectral high-frequency waves. BIS, based on spontaneous activity, is currently the most effective indicator for intraoperative awareness prevention.

3. Analysis of Pros and Cons of Bis Application

3.1. Intraoperative Awareness

Anesthesiologists should undergo appropriate training to understand the relationship between the index and the patient's anesthesia state, whether using the raw or processed EEG. In cardiac surgery involving cardiopulmonary bypass (CPB), heart rate (HR) and blood pressure (BP) can falsely indicate anesthesia depth, making it impractical to judge depth solely based on intraoperative blood pressure and heart rate [4]. Reported rates of intraoperative awareness during cardiac surgery range from 0.2% to 2%, presenting a tenfold higher risk compared to general surgeries. High-dose opioid anesthesia may lead to unpredictable maintenance of unconsciousness, as studies suggest that perception and cortical processing of auditory information may not be entirely suppressed. The Michigan Awareness Control Study, a prospective, randomized, controlled trial, may provide additional insights into the potential of BIS-guided anesthesia to reduce unintended intraoperative awareness in cardiac surgery patients. While the B- Aware trial implies that the routine use of a BIS-guided protocol during cardiac surgery could reduce awareness incidence, its applicability should be considered on a case-by-case basis. Therefore, BIS monitoring of anesthesia depth remains a crucial tool for anesthesiologists, with research indicating its potential to decrease intraoperative awareness.

3.2. Fast Track Cardiac Surgery

Experiments have demonstrated that BIS monitoring can aid in better control of systemic anesthetic dosing and anesthesia depth, which is beneficial for post-cardiac surgery recovery. This includes the time required for appropriate response to commands, tracheal extubation, eye opening, departure from the operating room, and eligibility for discharge from the post-anesthesia care unit. However, it's important to note that these studies were not randomized clinical trials, making it impossible to establish the independent contribution of pEEG monitoring to the success of a fast-track approach. In fact, these patients did not experience a shorter duration of stay in ICUs [5].

3.3. Anesthetic Dosing

In cardiac surgery, due to the surgical procedure and systemic venous anesthesia, intraoperative hypotension is common, often necessitating the use of vascular active drugs. However, the interactions between different drugs can alter pharmacokinetics, pharmacodynamics, and anesthesia depth. Nevertheless, research indicates that BIS can reduce the required dose of propofol during anesthesia and enhance the stability of blood flow dynamics in cardiac surgery . Monitoring systemic venous anesthesia depth through BIS has been proven effective. Cardiopulmonary bypass (CPB) amplifies the brain's sensitivity to anesthesia, making it more challenging to determine the patient's anesthesia depth. Interestingly, decreased sensitivity to anesthesia may persist after CPB. It's worth noting that changes in the raw EEG, which transition from slow, synchronous, large-wave activity to less synchronous patterns, can be detected towards the end of CPB. These changes, not reflected in the BIS, raise concerns

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about the accuracy of current pEEG indices as metrics of anesthetic depth. The conclusion here is that anesthesiologists may delay or reduce the administration of both volatile and IV anesthetic drugs until hemodynamic stability is achieved post-CPB. The attractiveness of using BIS to regulate anesthesia depth and reduce drug administration compensates for the delay in blood pressure changes.

3.4. Cerebral Ischemia

Can EEG or BIS serve as tools for monitoring cerebral ischemia? Studies demonstrated that, even when narcotic drug concentrations remain constant, sudden changes in EEG, such as burst suppression or continuous suppression, may point to cerebral ischemia, a serious abnormal brain-electrical phenomenon characterized by high-wave activity alternating with low-voltage or electro-suppression states. However, it's important to note that these methods lack sensitivity and are most useful for detecting acute brain damage [6]. For patients with a history of prior brain disorders, EEG and BIS are not the preferred methods, and clinical practice leans towards monitoring them using cerebral oximeters or transcranial Doppler. Patient case trials have suggested that reduced BIS may be associated with neurological deficits and cerebral ischemia, but it remains unclear whether increased BIS levels are linked to ischemia or narcotic drug concentrations in the brain. Consequently, the ability of BIS to track cerebral blood flow perfusion monitoring is uncertain. Ongoing research indicates that bilateral frontal EEG enhancements improve BIS monitoring of ischemia in the brain's frontal lobe. However, due to errors and accidents during experiments, the specificity of BIS in monitoring cerebral ischemia remains inconclusive.

3.5. Prognostic Significance: BIS and Mortality

Prolonged inhalation of narcotic drugs can lead to immunosuppression and cerebral ischemia, heightening brain sensitivity. Due to challenges like dosage instability and complex medication combinations, monitoring patient mortality solely through BIS lacks substantial meaning. Some researchers argue that cumulative durations of BIS readings below 45 are correlated with increased mortality risk, while others disagree. They believe that perioperative risk factors, variations in underlying diseases, and patients' physical resilience play a more significant role in postoperative survival [7]. Additionally, there is no definitive evidence to suggest that limiting BIS values and anesthesia depth can reduce postoperative mortality in cardiac surgery patients. Associations between anesthesia-related factors and short- and long-term survival after surgery remain a subject of debate. Nonetheless, extended cumulative durations of BIS readings below 45 can serve as markers for factors such as systemic illness, poor cardiac function, and complex intraoperative courses [8].

3.6. Special Considerations with Both BIS and Unprocessed EEG

Artifacts in EEG signals can manifest as continuous EEG suppression. In various clinical scenarios, these EEG artifacts may lead to changes and inaccuracies in BIS readings by impacting the original EEG signals, highlighting the limitations of BIS.

3.6.1. Neurological Disease. Abnormal electroencephalogram waveforms often associated with neurological disorders can significantly affect BIS numerical values. Conditions like Alzheimer's-type dementia have shown substantial cortical B energy loss, particularly in the frontal lobe region. Therefore, when patients with a history of Alzheimer's or vascular dementia undergo heart surgery, increased slow-wave activity due to their underlying conditions may necessitate cautious interpretation of the EEG and BIS values [9]. This further supports the notion that reduced BIS may be linked to neurological deficits and cerebral ischemia.

3.6.2. Muscle Activity. Electromyography (EMG) activity and the use of neuromuscular blocking drugs can indeed influence pEEG monitoring. In some instances, the BIS algorithm may struggle to distinguish between EMG signals and higher-frequency EEG activity [10]. Although the BIS algorithm has been improved to filter out EMG activity, it remains incomplete and may lead to an increased risk of

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overestimating the depth of hypnosis. Therefore, in heart surgery, the use of muscle relaxants should be approached with caution. Some anesthesiologists opt to administer only a minimal dose of muscle relaxant at the outset of the operation. Some even avoid using muscle relaxants during anesthesia induction, believing that patient consciousness can be detected through physical movements or muscle contractions. However, muscle relaxants can prevent patients from purposefully moving, potentially masking awareness. There is evidence suggesting that muscle relaxants are associated with an increased incidence of more painful conscious experiences.

3.6.3. Polypharmacy. Different narcotic drugs elicit various effects on electroencephalograms, necessitating careful attention during heart surgery monitoring. BIS often underestimates anesthesia depth in patients undergoing heart surgery, many of whom are prescribed benzodiazepines and opioids with variable effects on electroencephalograms and pEEG [11]. GABA drugs can suppress cardiomyopathy, resulting in a decline in BIS, while ketamine use increases high-frequency electroencephalogram activity, potentially misleading the BIS index.

3.6.4. Brain Region Monitored. Research dating back to 1953 suggests that narcotic drugs do not uniformly suppress all brain regions [12]. Deep brain regions like the hippocampus and amygdala, which play a role in traumatic memory, are not easily monitored through surface electroencephalograms. This underscores the potential limitations of EEG monitoring in the frontal cortex, as more valuable anesthetic information can be gleaned from monitoring different brain regions [13].

3.6.5. Electrical Interference. During heart surgery, electrical knife stimulation, cardiac pacing, and heating blankets can disrupt BIS signals. Continuous EEG suppression, coupled with the spiral deflection of EEG QRS wave groups, can result in EEG artifacts and poor signal quality, leading to inaccurate BIS results. Therefore, anesthesiologists should remain vigilant in distinguishing BIS values affected by electrical equipment interference during heart surgery.

3.6.6. Hypothermia. During heart surgery, heart protection is often achieved through cooling measures. However, research indicates that excessively low body temperatures can impact BIS values, with every one-degree centigrade drop causing a one-unit decrease in BIS. Similar low temperatures can alter the pharmacokinetics of inhaled anesthesia and propofol, affecting EEG waveforms. Studies in patients undergoing heart surgery with CPB and deep hypothermic circulatory arrest have demonstrated a strong correlation between BIS values and deep hypothermia. [14] While cold temperatures can induce vasoconstriction and accelerate blood flow, ensuring brain blood supply, it's important to note that they numerically influence BIS values. Therefore, clinical practitioners should rely on obvious abnormal EEG waveforms to assess early signs of cerebral ischemia during periods of low temperature [15].

3.6.7. Delay in Response. Like electrocardiogram and heart rate monitoring, BIS monitoring also exhibits a delay. Research indicates that the time required for the index, including BIS, to reflect state changes can range from 30 seconds to 2 minutes. This means that BIS may not respond promptly to a patient's current state. If the depth of anesthesia decreases during this delay, it can lead to heightened patient discomfort or emotional experiences, which is less than ideal for postoperative well-being. Therefore, addressing this delay in the reactivity of deep anesthesia monitoring is crucial and warrants future improvements.

4. Deficiency and Future Improvement

Furthermore, ketamine and NO-induced anesthesia cannot be detected by BIS. As anesthesia deepens, BIS values may not decrease and could even increase. BIS exhibits sensitivity and specificity similar to other anesthesia depth monitoring methods, with some overlap and potential statistical errors. Therefore, it should be used in conjunction with other monitoring techniques. Electric knives, muscle movements, ECG signals, and changes in position can all affect BIS readings.

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EEG signals are often vulnerable to electrical interference caused by electroknife procedures (such as cutting and hemostasis) and electromyography (EMG) signals. Experts have delved into improving the depth of anesthesia monitoring systems. Near-infrared spectroscopy (NIRS) hemodynamic signals are used to measure changes in cerebral blood flow (CBF) within an electrical monitoring system based on EEG signals. Additionally, experts have proposed a multimodal anesthesia depth monitoring system (SoC) using a compact and precise head patch system. This proposed SoC communicates with external devices through Bluetooth connectivity. The multimodal approach incorporates NIRS signals to compensate for electromagnetic interference, allowing anesthesiologists to assess the effects of various anesthetics. The current head patch design has been fully implemented and validated through clinical trials. It not only adheres easily to the patient's forehead but also ensures high signal quality. Furthermore, the multimodal SoC design can enhance the compact depth of anesthesia monitoring, providing more accurate monitoring even under the influence of specific drugs.

To minimize BIS delay, standardize operations and maintain intraoperative monitoring stability. First, maintain the operating room temperature between 24-26 ℃, with humidity at 50%-55%. Extreme humidity levels can affect electrode adhesion; high humidity may lead to sweating, while low humidity can hinder adhesion. Before applying electrodes, clean the skin with 75% alcohol. Position the electrodes (numbered 1-4) on the patient's head and firmly press each electrode for approximately 5 seconds, ensuring they do not touch each other. Regularly inspect the position and fixation of BIS electrodes to keep the patient's forehead dry and prevent interference from sweating and oils. Typically, BIS electrodes can be used continuously for 24 hours. If the values are not displayed during the procedure, applying a small amount of coupling agent to the electrode can enhance signaling. However, do not use BIS during defibrillation. While it is not possible to completely eliminate inherent BIS systematic errors, following standard procedures can significantly reduce BIS response delays.

5. Conclusion

BIS is widely used in clinical practice as an anesthesia depth monitoring instrument. Years of research have accumulated remarkable data, especially in cardiac surgery. BIS can be used as the gold standard of consciousness monitoring, provide new information for clinicians to help judge the effect of anesthetics and sedatives, significantly reduce the incidence of intraoperative knowledge, and at the same time, can avoid surgery patients deep anesthesia caused adverse effects. For different patients and different clinical conditions, BIS monitoring has been proven to be effective, bringing faster and more predictable recovery time to patients, greatly reducing postoperative nausea and vomiting, and achieving higher resuscitation quality. It also has a certain guiding significance for the prognosis judgment of special patients. The systematic error of BIS as well as sensitive specificity still need to be overcome in the future [16]. More importantly, only by better combining the value of the monitoring instrument response with the professional knowledge and experience of the anesthesiologist can the level of medical science and technology be improved and a new model of healthy and sustainable development can be provided for social development.

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