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Usefulness of electroencephalogramic monitoring during general anesthesia

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Introduction

Monitoring the electroencephalogram (EEG) during general anesthesia has a long history for detecting cerebral hypoperfusion or for evaluating the hypnotic effect of anesthetics. Recently, methods of processing the EEG for monitoring anesthesia have greatly expanded. Several brain-function monitors based on the processed EEG have been developed. The bispectral index (BIS) is the first scientifically validated and commercially supported monitor for determining anesthetic drug effect on the central nervous system [1]. The BIS monitor processes a single frontal EEG signal to calculate a dimensionless number that provides a measure of the patient's level of consciousness. Use of the BIS allows optimization of anesthetic drug delivery to the patient. This should speed the recovery time [2] and decrease the incidence of intraoperative awareness. Our questionnaire survey showed that 32% of anesthesiologists in Japan always use a BIS monitor during general anesthesia [3]. The usefulness of EEG monitoring and the BIS monitor is discussed in this article.

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Effect of anesthetics on EEG and BIS

When we use volatile anesthetics or propofol, the frequency of the EEG decreases and the amplitude of the EEG increases in a dose-dependent manner. During moderate anesthesia, the EEG shows a spindle wave. At a deeper anesthetic level, the EEG shows a "burst and suppression" pattern, and then it becomes silent (Fig. 1).

The BIS monitor translates these EEG changes with a number, producing a BIS scale from 0 to 100. A BIS of 100 indicates an awake and responsive subject. When hypnotics are administered, the BIS decreases, and a BIS value of 0 represents EEG silence. BIS values of 40 to 60 have been recommended for general anesthesia [1].

The BIS integrates four EEG parameters (relative beta ratio [BetaR], SynchFastSlow, QUAZI, burst suppression ratio [BSR]) into a single variable. The EEG is digitized and processed to detect and remove artifacts. The signal is then analyzed for suppression detection and also fast-Fourier transformed. The suppression is used to compute the BSR. The fast-Fourier transform is used to compute a BetaR and also to compute the bispectral analysis, from which the SynchFastSlow is derived. All of these components are combined by discriminant analysis, with the result scaled from 0 to 100.

BetaR is the logarithm of the ratio of the EEG spectral power in the 30- to 47-Hz to the 11- to 20-Hz range. Compared to the preinduction level, a decrease in spectral power between 30 and 47 Hz and an increase in spectral power between 11 and 20 Hz was observed after the induction of anesthesia. The importance of the so-called gamma band EEG has been highlighted as a

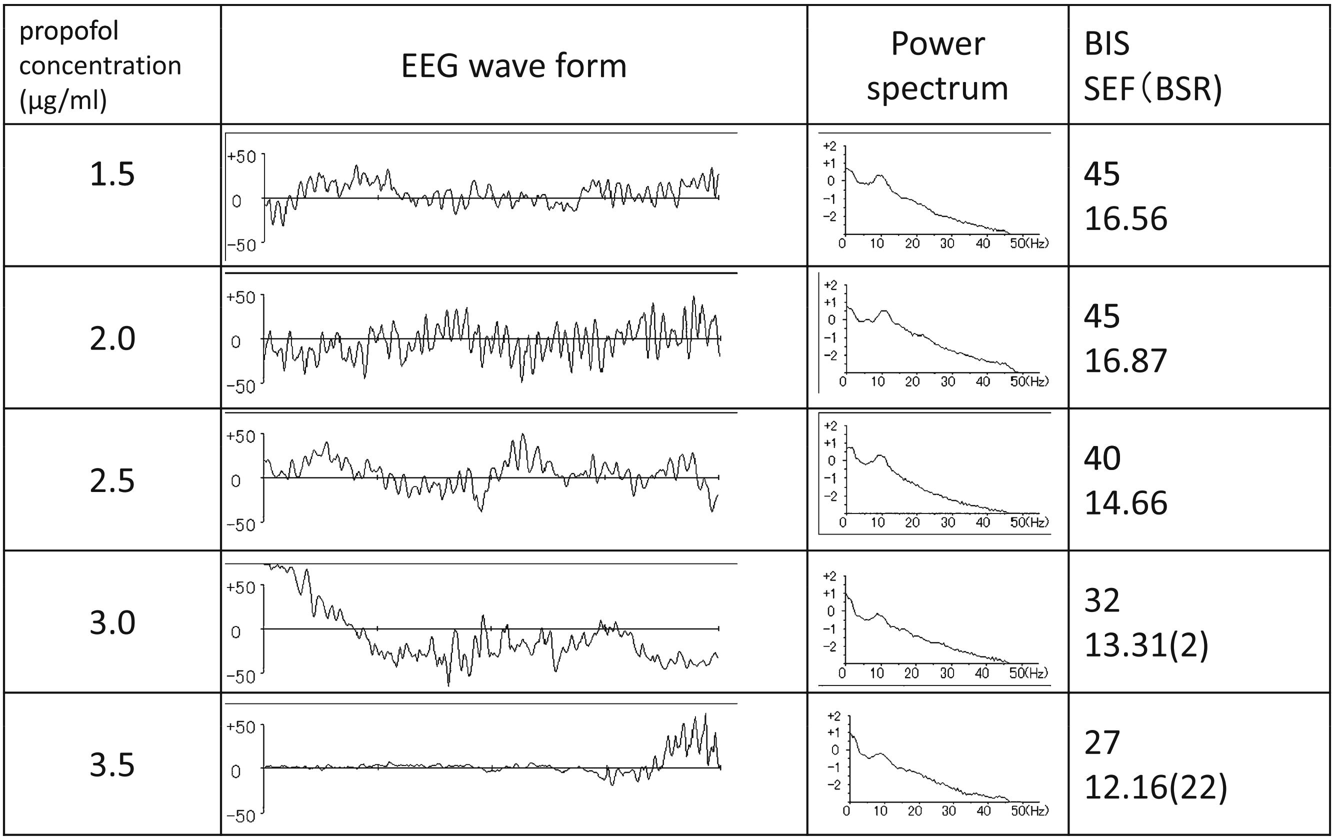

Fig. 1. Typical EEG changes during propofol anesthesia. When the propofol effect-site concentration is increased, the frequency of the EEG decreases and the amplitude of the EEG increases. During moderate anesthesia (propofol concentration from 1.5 to 2.5 µg·ml^{-1}), the EEG shows a spindle wave. At a deeper anesthetic level, the EEG shows a "burst and suppression" pattern, and then it becomes silent (3.5 µg·ml^{-1}). *BIS*, Bispectral index; *SEF*, spectral edge frequency 95%; *BSR*, burst suppression ratio

marker of the conscious state. BetaR reflects the loss of gamma band EEG and is a better indicator for tracking the patient's level of consciousness than the spectral edge frequency 95% (SEF) during the induction of anesthesia. In our study, BetaR was linearly correlated with the BIS at a BIS of more than 60 [4].

At a BIS range of 30 to 80, SynchFastSlow was linearly correlated with the BIS. Bispectral analysis is an advanced signal processing technique that quantifies phase coupling among the components of a signal. SynchFastSlow is a bispectrum-derived variable that is the logarithm of the ratio of 40 to 47 Hz and 0.5 to 47 Hz. To observe the character of SynchFastSlow, we also evaluated the relationship between BIS and SEF, that is a conventional processed EEG parameter derived from power spectral analysis. SEF was also correlated with the BIS at a BIS range of 30 to 80. Therefore we evaluated the relationship between SynchFastSlow and SEF from the data at a BIS range of 30 to 80. These two parameters correlated well. In summary, at a BIS range of 30 to 80, changes in BIS correlate well with SynchFastSlow and SEF.

BSR is the percentage of the suppression period against time. Therefore, an increase in BSR represents the isoelectricity of EEG. A BSR of more than 40 was linearly correlated with BIS in the range of 30 to 0.

Conventional power spectral analysis-derived SEF has been shown to be a good monitor to predict the depth of anesthesia. However, the SEF response is biphasic. An initial increase in SEF from the awake state is followed by a decrease in SEF. During burst suppression, SEF cannot be calculated from the EEG. The BIS uses BetaR or BSR for these two situations. Then BIS uses the novel parameter SynchFastSlow instead of SEF. Using these three parameters (BetaR, BSR, and SynchFastSlow), BIS can track the EEG changes from the awake state to electrical silence.

Pitfalls in the clinical use of BIS

When using BIS during anesthesia, we must be aware that, as with any other monitors, spurious readings are possible. In order to minimize the chance of a patient

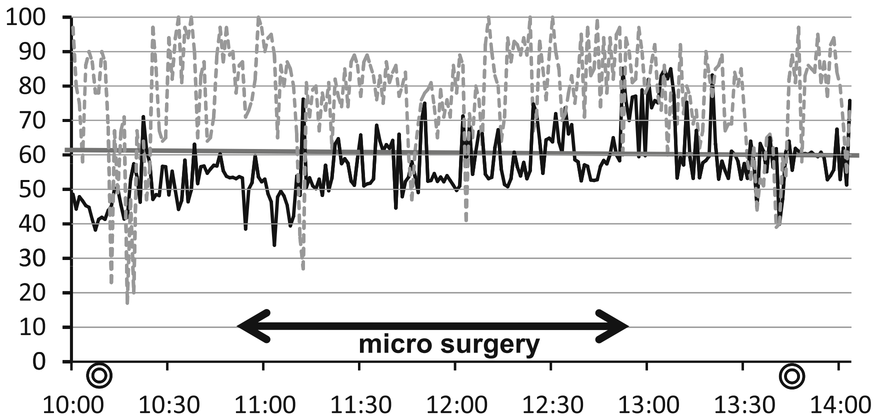

Fig. 2. Changes in BIS during surgery for aneurysmal clipping of cerebral artery. After the start of the surgery, direct vibration from the operation field and the use of electric cautery decreased the signal quality index (*SQI*) of the BIS monitor. *Continuous line*, BIS; *dotted line*, SQI

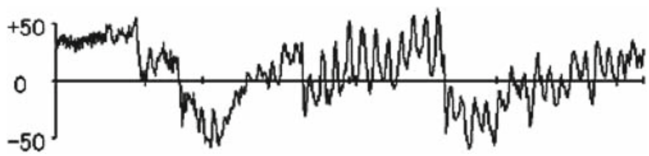

Fig. 3. Spindle-wave-like EEG shown during the drilling of a hole into the skull

being conscious, the BIS monitor is designed to "fail upward."

The most common cause of a spurious BIS value is noise contaminating the EEG signal. Contamination of the EEG signal can lead to misinterpretation and failures in monitoring. The source of contamination is electromyography (EMG) activity and direct vibration on the BIS electrode. Especially, surgery in which the surgical field is near the BIS electrode has this problem. Figure 2 shows the changes in BIS during surgery for aneurysmal clipping of cerebral artery. Anesthesia was maintained with propofol and remifentanil. After the start of the surgery, direct vibration from the operation field and the use of electric cautery decreased the signal quality index of the BIS monitor. The drilling of a hole into the skull caused a spindle-wave-like EEG (Fig. 3). During the surgery, BIS values were sometimes above 60.

Noxious stimulation can change the EEG to fast wave, and the BIS value will then increase. However, strong noxious stimulation sometimes induces a large delta wave and induces a very low BIS value. This phenomenon is called paradoxical arousal. We have noted a marked decrease in BIS value and SEF in association with the appearance of large delta waves on the EEG during abdominal surgery, especially when the peritoneal cavity was irrigated with normal saline. Therefore, we evaluated the changes in BIS during abdominal irrigation in patients anesthetized with nitrous oxide-sevoflurane [5]. BIS decreased after the start of irrigation. Pretreatment with fentanyl suppressed the decrease in BIS.

Paradoxical arousal is provoked by a strong noxious stimulus in the presence of inadequate anesthesia and analgesia; large delta waves are characteristic and dominant on the EEG. I would like to stress that adequate analgesia corresponding to the surgical procedure is required when we assess anesthetic depth by EEG monitoring.

BIS and intraoperative awareness

Awareness during anesthesia is a serious complication, with potential long-term psychological consequences. Large studies in which data were collected prospectively and reports were evaluated independently have reported an incidence of awareness of around 0.2% under general anesthesia [6]. However, the incidence is greater during high-risk surgery, including cardiac, obstetric, and major trauma surgery [6]. The incidence varies according to the dose of anesthetic administered. Since the introduction of remifentanil in Japan, the maintenance dose of anesthetics has been decreasing [3]. Therefore, the importance of the BIS monitor is increasing. A large randomized controlled trial concluded that BIS monitoring could substantially decrease the incidence of awareness in patients at high risk [7]. However, a recent trial suggests that maintaining the BIS value below 60 did not show superiority to a protocol based on maintaining end-tidal anesthetic gas at a target range between 0.7 and 1.3 minimum alveolar concentration [8]. More randomized trials in different settings are required to assess the usefulness of EEG monitoring for the prevention of awareness.

The BIS monitor as a cerebral function monitor

Although the BIS is intended to monitor the depth of anesthesia, some case reports suggest that the BIS may detect incidental ischemic brain insults. The BIS has been suggested to be an indicator of inadequate cerebral perfusion in patients with cardiac arrest [9], and those with perioperative stroke [10], and in pediatric cardiac surgery [11]. We reported a patient in whom the BIS value decreased to 0 during surgery [12]. The patient had a history of intracranial hematoma removal about 1 month before the surgery. He also had uncontrolled hypertension, although he was taking three antihypertensive drugs. After anesthesia induction, his systolic blood pressure decreased to 110 mmHg and the BIS decreased to 0. The decrease in BIS was suspected to be the result of decreased cerebral blood flow, caused by a shifting of the lower limit of autoregulation. Some case reports have suggested that BIS monitoring may not reliably indicate cerebral ischemia during carotid surgery. In our patient, regional cerebral oxygen saturation (rS_{O_2}) decreased from 61% to 49%, and the EEG showed slow waves with decreased amplitude during carotid occlusion [13]; however, the BIS did not change, or, rather, it increased. A similar paradoxical increase in BIS was reported by Bonhomme et al. [14]. They investigated the changes in BIS during carotid cross-clamping in 36 patients receiving carotid endarterectomy. During the first 3 min after carotid cross-clamping, BIS increased to more than 60 in 47% of all recruited patients, decreased to below 47 in 25%, and remained in the 40-to-60 range in 28%. A BIS increase was more frequently observed in patients with moderate or poor carotid backflow. Therefore, the paradoxical BIS increase could be related to borderline ischemia.

The BIS has some limitations as a cerebral perfusion monitor. The monitored area is the unilateral frontal cortex. The BIS might detect cerebral hypoperfusion or ischemia when general anesthesia is stable. However, cerebral hypoperfusion might change the delivery of anesthetics to the brain and change the depth of anesthesia. The interpretation of BIS changes during moderate ischemia should be considered carefully.

Conclusion

The BIS integrates some EEG parameters into a single variable. This enables tracking of the EEG changes associated with changes in the depth of anesthesia from the awake state to electrical silence. The BIS is not a magic number but a value calculated from the EEG. Checking the raw EEG is still important when using a BIS monitor.

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