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Short communication

Integration of suppression ratio in the bispectral index

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The bispectral index (BIS) is derived from the electroencephalogram (EEG) and is a specific and sensitive monitor for assessing the hypnotic component of general anesthesia and sedation. The BIS has been described in the literature as a composite index consisting of a weighted combination of four components; however, the details of the BIS algorithm have not been described in their entirety by the manufacturer of the BIS monitors. It has been reported that the four component subparameters are derived from time-domain, bispectral, and power spectral analyses of the EEG [1]. The time domain subparameter includes Quazi suppression detection and the suppression ratio (SR) [1], and these two subparameters represent the deepest anesthesia conditions. The bispectral domain subparameter is called SyncFastSlow [1]. It represents the low-frequency feature and is associated with moderate anesthetic effect. The frequency domain subparameter is called the relative beta ratio [1]. It represents the high-frequency feature and is associated with light anesthetic effect and beta activation. Therefore, the BIS is a combination of the four subparameters described above, and the individual subparameters make the BIS a precise, near-linear function across the continuum of clinical states from awake to isoelectric EEG. However, of the four subparameters, only the SR is available for recording via the processed EEG port. In this article, the author presents the relationship between the BIS and the SR at deeper anesthesia and identifies how the SR is incorporated into the BIS.

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After gaining approval by the Human Investigations Committee (Ichikawa General Hospital, Tokyo Dental College, Chiba, Japan) and obtaining informed written consent, the author enrolled 40 patients (30 men and 10 women) who underwent elective surgery under general anesthesia monitored using the BIS. Patients were excluded if any of the following conditions were met: seizure disorder; or longterm opioid, sedative, or alcohol use. Premedication consisted of 0.5 mg·kg^{-1} of atropine, with or without midazolam 1–3 mg, intramuscularly 30 min prior to the anesthetic induction. After arrival in the operating room, patients were connected to standard physiological monitors. EEG (At1-Fpzt or At2-Fpzt) was measured using a self-preparing sensor (BIS Sensor) and BIS monitor (A-1050; BIS version 3.4; Aspect Medical Systems, Newton, MA, USA). The BIS and SR were recorded continuously by a computer. Anesthesia was maintained with either propofol or sevoflurane, with or without regional anesthesia. The selection of the agents and their concentrations were at the discretion of the attending anesthesiologists. After the surgery, the author evaluated the relationship between the BIS and the SR from the obtained data.

Statistical analysis was performed using the Pearson correlation coefficient to evaluate linear regression.

The patients' average age was 42 ± 14 years. The average weight and height were 65 ± 16 kg and 160 ± 11 cm, respectively. After IV induction, all patients were endotracheally intubated with vecuronium and ventilated mechanically. End-expiratory CO_2 was maintained between 30 and 35 mmHg.

The BIS decreased in an anesthetic dose-dependent fashion in all patients and reached a plateau of 30 (Fig. 1). In all patients with BIS in the 30s, the SR value was between 0 and 40%. In seven of the 40 patients, the SR exceeded 40%. In these situations, the author observed an inverse proportional relationship between the BIS and the SR. For an SR greater than 40%, the BIS was completely determined from the SR component. The

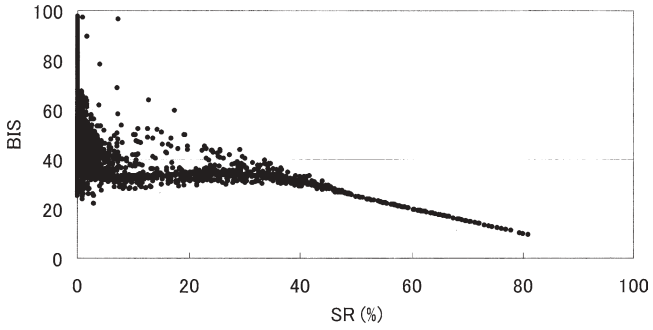

Fig. 1. The relationship between the bispectral index (*BIS*) and the suppression ratio (*SR*). The BIS decreased in an anesthetic dose-dependent fashion in all patients, and reached a plateau of 30. In all patients with BIS values in the 30s, the SR value was between 0 and 40%. For an SR greater than 40%, the BIS was completely determined from the SR component. A 1-point decrease of the BIS was observed for each 2% increase in the SR

author found a 1-point decrease of the BIS for each 2% increase of the SR for an SR greater than 40%.

This study evaluated the relationship between the BIS and the SR in various anesthetic states, especially in deep anesthesia (strong hypnotic effect). As the concentrations of the anesthetics increased, the BIS decreased in response to the hypnotic effect of the anesthetics. The BIS decreased to 40 without suppression occurring in the EEG. With an additional increase in concentration, the BIS decreased to 30 with or without suppression in the EEG. When suppression occurred more than 40% of the time (i.e., SR $>$ 40%), the BIS decreased to below 30 with increasing anesthetic concentration, in direct inverse proportion to the increase of detected suppression.

Anesthesiologists have sought a direct and reliable method of measuring anesthetic drug effects on the brain. The EEG is an obvious brain-monitoring modality, because it is a continuous, noninvasive measure of brain activity. However, until the middle 1990s, there were significant problems in using traditional EEG monitors in the operating theater. The most important problem was the difficulty of using only power spectral analysis to interpret the patients' precise hypnotic state. Anesthetic agents typically alter the low-amplitude, high-frequency EEG of the awake state to produce a high-amplitude, low-frequency signal. If this change were the sole effect of anesthetics on the EEG, the depth of the anesthesia would be easy to understand. However, there are some other effects of anesthetic agents that are more difficult to quantify, including beta activation, near suppression, burst suppression, and synchronization. Sedative-hypnotic agents, such as benzodiazepines and barbiturates, produce biphasic effects on the EEG. Low doses increase the high-frequency activity, while larger doses decrease the high-frequency activity. Very large doses of these hypnotics or inhalational agents produce near suppression and burst suppression, the latter consisting of periods of isoelectric (flat) EEG, interspersed with bursts of high-amplitude activity [2]. The BIS monitor is different from previous monitors, as it is the first one to adopt other methods of analyzing raw EEG data [3]. As described above, the combination of the four subparameters produces a single number at which each of the subparameters is chosen to have a specific range of anesthetic effect where that subparameter performs best. The BIS weights the relative beta ratio most heavily when the EEG has the characteristics of light sedation [1]. The SyncFastSlow subparameter is well correlated with behavioral responses during moderate sedation or light anesthesia [1]. The burst-suppression ratio detects deep anesthesia [1]. With regard to suppression in the current version the BIS monitor recognizes flat periods of the EEG based on a linear combination of the log of the total power between 2 and 30 Hz and the log of the total power between 31 and 40 Hz [4]. A linear combination means that there is a weighted ratio between the two frequency ranges, but the details of this ratio are not available because of proprietary concerns.

However, this study revealed that suppression was not weighted heavily until it exceeded 40%. Once suppression occurred more than 40% of the time, the BIS was completely determined by the SR. Therefore, when the BIS is in the 30s, the SR information must be ignored, and either Quazi suppression or SyncFastSlow may be the dominant subparameter expressed in the BIS. If the algorithm does not work like this; for example, if the SR information is reflected to the BIS directly in a continual fashion, sudden changes of the BIS value will occur when low levels of suppression are detected. Because this situation can often be seen at many different concentrations of anesthetics, the manufacturer of the BIS monitors established the algorithm in this way in order to reduce the possibility that there would be fluctuations in the BIS due to intermittent incorrect detection of these short episodes of suppression (personal communication from Paul J. Manberg, Ph. D., Vice President of Aspect Medical Systems). Actually, it is very difficult to correctly identify brief periods of true suppression versus low-amplitude signals or false suppression, and the transition into a burst-suppression pattern is quite variable between patients, so the author believes that the manufacturer has adopted the correct approach in not relying on the SR until it becomes significant ($>$40%). However, from this study, a BIS between 30 and 40 has the possibility of indicating a wide variety of EEG states (i.e., with or without suppression), suggesting that a modification of the algorithm will be necessary in order to make the BIS

have a more linear function, especially for BIS values in the 30s.

In conclusion, there is a zone of anesthesia in which the detection of some levels of EEG suppression does not result in a decrease in the BIS, although it was intended by the manufacturer to avoid such fluctuations in the BIS. The BIS is completely determined from the SR information when the SR exceeds 40%.

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