The Bispectral Index Declines During Neuromuscular Block in Fully Awake Persons

M. Messner, MD*, U. Beese, MD*, J. Romstöck, MD†, M. Dinkel, MD‡, and K. Tschaikowsky, MD*

Departments of *Anesthesiology and †Neurosurgery, Friedrich-Alexander Universität, Erlangen-Nuernberg, Germany; and ‡Department of Anesthesiology, Frankenwaldklinik, Kronach, Germany

Bispectral index (BIS) is an electroencephalographic variable promoted for measuring depth of anesthesia. Electromyographic activity influences surface electroencephalography and the calculation of BIS. In this study, we sought to determine the effect of spontaneous electromyographic activity on BIS. BIS was monitored in three volunteers by using an Aspect A-1000 monitor. The experiment was repeated in one volunteer. Electromyographic activity was recorded. Alcuronium and succinylcholine were administered. No other drugs were used. In parallel with spontaneous electromyographic activity of the facial muscles, BIS decreased in response to muscle relaxation to a minimum value of 33 and, in the repeated measurement, to a minimum value of 9 when total neuromuscular block was achieved. In two volunteers, no total block was achieved. BIS decreased to a minimal value of 64 and 57, respectively. In turn, recovery of BIS coincided with the reappearance of spontaneous electromyographic activity. During the entire experiment, the volunteers had full consciousness. BIS, assessed by software Version 3.31, correlates with spontaneous electromyographic activity of the facial muscles. BIS failed to detect awareness in completely paralyzed subjects. Thus, in paralyzed patients, BIS monitoring may not reliably indicate a decline in sedation and imminent awareness.

(Anesth Analg 2003;97:488–91)

Intraoperative awareness while paralyzed has been reported and is a dreaded scenario. It is hoped that monitoring the depth of anesthesia will detect impending intraoperative awareness, especially in paralyzed patients. When reliable indicators for the absence of intraoperative recall have been defined and validated, further goals, such as tapering drug dosage and fast-track anesthesia, can be sought.

Bispectral index (BIS) is a dimensionless variable between 0 and 100 that correlates with the degree of sedation (1–4). BIS values between 40 and 60 are proposed to indicate a sufficient depth of anesthesia excluding intraoperative awareness (5). However, the underlying algorithm of BIS calculation has never been published. BIS is determined in a multivariate regression model that depends on three variables: burst suppression ratio, relative α/β ratio, and bicoherence of the electroencephalogram (EEG) (5). High-frequency signals such as electrical devices, electrocardiogram, and electromyogram (EMG) potentially increase BIS (6). Conversely, previous reports and our own observations suggest a decrease of BIS after the administration of neuromuscular relaxants (7). The objective of this study was to elucidate whether BIS is a specific measure of hypnosis and whether spontaneous EMG activity of the facial muscles is only an artifact that causes a false BIS increase or a substantial element in the algorithm of BIS.

Methods

After approval by our local ethics board, the authors served as volunteers for this experiment in the clinical setting of an operating room. There was no form of coercion or undue influence on the volunteers to participate in this experiment. The volunteers received nothing by mouth for 6 h previously. BIS and EEG monitoring were performed with an A-1000 monitor (software Version 3.31; Aspect Medical Systems, Inc., Newton, MA) according to the guidelines of Aspect. Zip Prep® (Aspect) electrodes were placed (At_2 referenced to Fpz) on clean, dry skin. Data output at the serial connection of the A-1000 was stored on a personal computer. Three pairs of

Accepted for publication April 1, 2003.

Address correspondence and reprint requests to M. Messner, Department of Anesthesiology, University of Erlangen-Nuernberg, Krankenhausstr. 12, D-91054 Erlangen, Germany. Address e-mail to messner@gmx.li.

DOI: 10.1213/01.ANE.0000072741.78244.C0

0003-2999/03

uninsulated needle electrodes were inserted to continuously record facial muscle (frontalis muscle, nasal muscle, and orbicularis oris muscle) EMG activity, as described elsewhere (8). Impedance of EEG and EMG recording was checked and was <2 kΩ. In addition, electrocardiogram, blood pressure, and oxygen saturation were monitored. After 5 min of stable BIS recording and oxygen breathing, the arm opposite to the infusion was excluded from circulation by a blood pressure cuff inflated to 200 mm Hg for the duration of the neuromuscular block (9). Two milligrams of alcuronium and, 2 min later, 1.5 mg/kg of succinylcholine were administered. No other drugs were used. The volunteers indicated wakefulness during the entire experiment and indicated comfort or discomfort with mask ventilation by hand signals of the isolated forearm.

The experiment was performed once in the setting described previously (the volunteer was MM). The experiment was repeated twice with 1.0 mg/kg of succinylcholine (with volunteers KT and UB) and a fourth time without EMG recording and digital data storing with 1.0 mg/kg of succinylcholine (the volunteer was again MM).

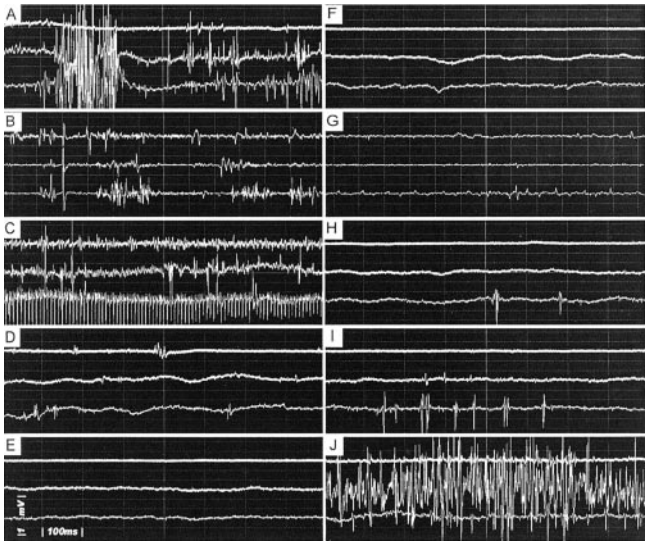

Figure 1. Electromyographic (EMG) activity corresponding to Figure 2. Upper curve = frontalis muscle; middle curve = nasal muscle; lower curve = orbicularis oris. Each strip, lasting 0.8 s, is representative for an interval of approximately 30 s. (A and J) Arbitrary contraction of the facial muscles, (B, D, G, H, and I) spontaneously arising EMG activity, (C) muscular fasciculation after succinylcholine application, and (E and F) no EMG activity.

Results

In the first experiment with MM, before muscle relaxants were administered, BIS values were measured within a range of 96 and 97. There was high-amplitude EMG activity like a typical EMG interference pattern after arbitrary contraction of the facial muscles (Fig. 1, A and J); however, there was also spontaneously arising EMG activity at rest, recorded as long-lasting trains of sporadic EMG bursts.

The alcuronium administration had no further effect. After succinylcholine injection, there was a 5-s sequence of muscular fasciculation (Fig. 1C), and then spontaneous EMG activity completely disappeared (Fig. 1, E and F). The cessation of the EMG activity was accompanied by a steep decrease in BIS (Fig. 2), to a minimum of 33. Spontaneous breathing ceased, and the volunteer was manually ventilated. The volunteer was capable of communicating by using signs of comfort and discomfort and of responding to verbal commands with the isolated hand.

As soon as spontaneous EMG activity of the frontalis muscle reappeared (Fig. 1, G, H, and J), BIS values began to recover. Five minutes after succinylcholine injection, stable values of approximately 98 were regained (Fig. 2). Spontaneous breathing reappeared. The oxygen saturation was never less than 97%. During the entire experiment, the test person had full consciousness and detailed recall and felt comfortable with mask ventilation. A few minutes later, the volunteer was able to stand up and walk.

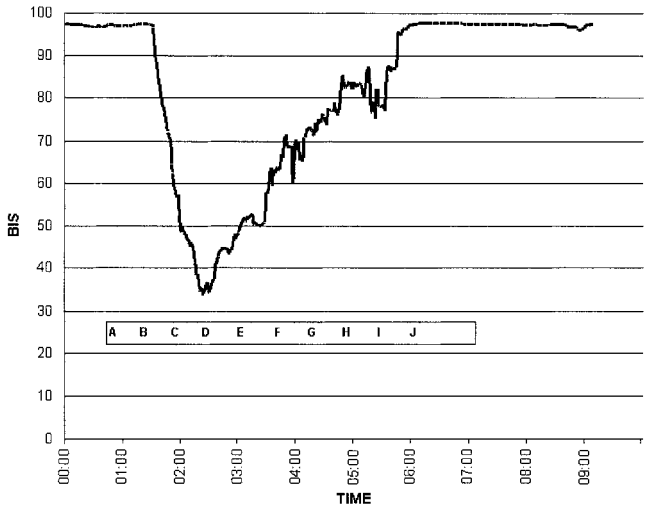

Figure 2. Time course of the bispectral index (BIS) of volunteer MM in the first experiment. The administration of succinylcholine occurred at 1:00. A–J refer to the electromyography curves shown in Figure 1.

In a second experiment with the same volunteer, the BIS value decreased after succinylcholine application to a minimal value of 9. The experiment was documented by using a screenshot of the A-1000 monitor (Fig. 3).

In volunteers UB and KT, no total neuromuscular block was achieved. Weak spontaneous EMG activity

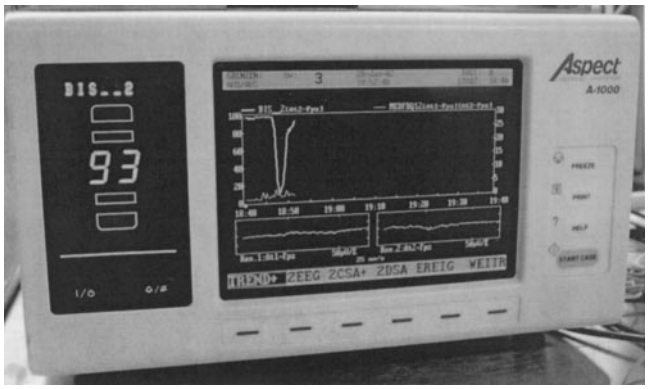

Figure 3. Time course of the bispectral index (BIS) of volunteer MM in the second experiment: a screenshot of the A-1000 monitor is shown. The minimal recorded BIS value was 9.

was still visible throughout the experiment. Both persons had some level of discomfort and stress during mask ventilation. The BIS value decreased after succinylcholine application to a minimal value of 64 (UB) and 57 (KT) (Figs. 4 and 5).

Discussion

In fully awake subjects, succinylcholine injection resulted in a profound decrease in BIS values assessed by an A-1000 monitor to values usually observed during deep anesthesia. Simultaneously, the disappearance of spontaneous facial EMG activity was monitored. Recovery of BIS coincided with the reappearance of spontaneous EMG activity of the frontalis muscle. With the isolated forearm technique, a sedative side effect associated with succinylcholine injection could be excluded. Communication with hand signs was possible throughout the experiment.

An influence of muscle relaxation on BIS has been reported. In an anesthetized subject, an injection of vecuronium further reduced an already decreased BIS value, despite constant target concentrations of propofol and remifentanil (7). In this case, the reduction in BIS after muscle relaxation was thought to result from cessation of EMG activity that artificially increased BIS. However, there is no way to discriminate the potential contributions of EMG and EEG activity to the algorithm of BIS in an anesthetized patient. Therefore, this experiment, which studied the effect of complete muscle relaxation on BIS in fully awake subjects, was necessary to elucidate whether changes in EEG or spontaneous EMG activity were responsible for the calculation of BIS. Our data show that BIS, as assessed by the A-1000 monitor with software Version 3.31, correlates with the spontaneous EMG activity of the frontalis muscle. Software Version 3.3 was released in 1998. As in Version 3.2 (1997), EMG handling should have been improved (10). Recently the A-2000 monitor

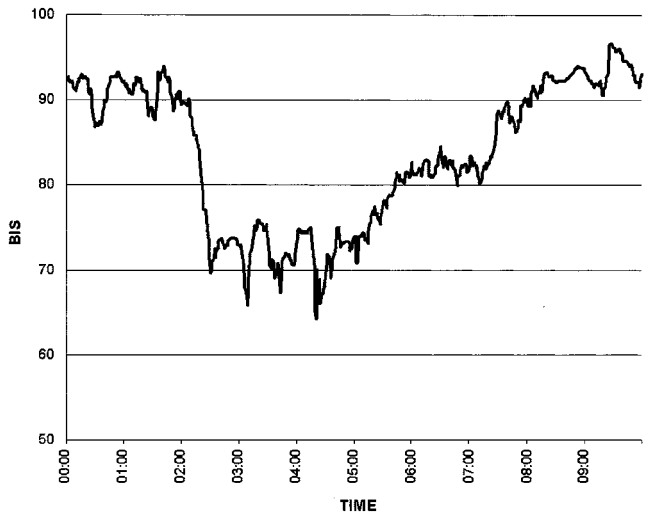

Figure 4. Time course of the bispectral index (BIS) of volunteer UB. The minimal recorded BIS value was 64.

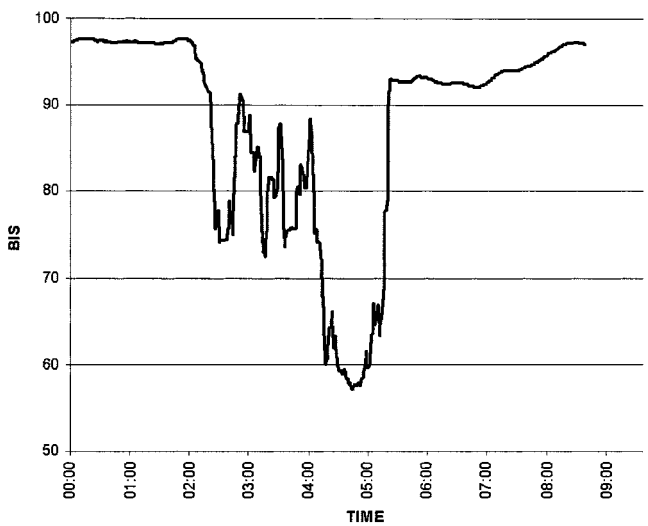

Figure 5. Time course of the bispectral index (BIS) of volunteer KT. The minimal recorded BIS value was 57.

and the BIS XP platform were introduced, and these provide an indicator for EMG activity. However, our findings do not preclude that BIS can be correlated with the degree of sedation and the likelihood of movement in anesthetized, not paralyzed, patients.

In conclusion, we have to consider that spontaneous facial muscle EMG activity is a substantial element of BIS up to software Version 3.31. Thus, BIS monitoring might be useful to detect activity in motor brainstem nuclei and their supranuclear control mechanisms, i.e., facial nerve or lower cranial nerve activity that may herald an imminent neocortical arousal reaction but can be misleading for the assessment of state of consciousness in completely paralyzed patients. Some previous studies on BIS up to software Version 3.31

and the new version of the monitor may have to be reevaluated in the light of our findings.

References

1. Glass PS, Bloom M, Kearse L, et al. Bispectral analysis measures sedation and memory effects of propofol, midazolam, isoflurane, and alfentanil in healthy volunteers. Anesthesiology 1997; 86:836–47.
2. Katoh T, Suzuki A, Ikeda K. Electroencephalographic derivatives as a tool for predicting the depth of sedation and anesthesia induced by sevoflurane. Anesthesiology 1998;88:642–50.
3. Kearse LA, Rosow C, Zaslavsky A, et al. Bispectral analysis of the electroencephalogram predicts conscious processing of information during propofol sedation and hypnosis. Anesthesiology 1998;88:25–34.
4. Sebel PS, Lang E, Rampil IJ, et al. A multicenter study of bispectral electroencephalogram analysis for monitoring anesthetic effect. Anesth Analg 1997;84:891–9.
5. Rampil IJ. A primer for EEG signal processing in anesthesia. Anesthesiology 1998;89:980–1002.
6. Hemmerling TM, Fortier JD. Falsely increased bispectral index values in a series of patients undergoing cardiac surgery using forced-air-warming therapy of the head. Anesth Analg 2002;95: 322–3.
7. Bruhn J, Bouillon TW, Shafer SL. Electromyographic activity falsely elevates the bispectral index. Anesthesiology 2000;92: 1485–7.
8. Romstöck J, Strauss C, Fahlbusch R. Continuous electromyography monitoring of cranial nerves during cerebellopontine angle surgery. J Neurosurg 2000;93:586–93.
9. Agoston S, Feldman SA, Miller RD. Plasma concentrations of pancuronium and neuromuscular blockade after injection into the isolated arm, bolus injection, and continuous infusion. Anesthesiology 1979;51:119–22.
10. Johansen JW, Sebel PS. Development and clinical application of electroencephalographic bispectrum monitoring. Anesthesiology 2000;93:1336–44.