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ORIGINAL ARTICLE

Cerebral state index versus bispectral index during propofol–fentanyl–nitrous oxide anesthesia

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Abstract
Purpose The aim of this study was to compare the cerebral state index (CSI) and bispectral index (BIS) during propofol–fentanyl–nitrous oxide anesthesia.
Methods Thirty patients scheduled for abdominal surgery, with a mean age of 30–70 years, were enrolled. Anesthesia was induced with propofol and fentanyl and was maintained with propofol, fentanyl, epidural mepivacaine, and nitrous oxide in oxygen. During surgery, the propofol infusion rate was adjusted to try to keep BIS at 40 ± 3 for 10 min and then decreased to keep the BIS at 60 ± 3 for 10 min.
Results The BIS had a larger value for the time between switching on the apparatus and starting to measure at a signal quality index >75%. The recovery time from disturbance by an electric cautery event was 41 ± 14 s for the BIS and 3 ± 1 s for the CSI ($P < 0.05$). The absolute values of the BIS and CSI were not significantly different and they showed a good correlation. The bias (mean of the differences, BIS − CSI) was negative at all measurement points, but the limits of agreement and percentage error were small.
Conclusions The absolute values of the BIS and CSI were not significantly different during propofol–fentanyl–nitrous oxide anesthesia. The start of the measurement was faster with the CSI than with the BIS after switch-on, and measurement was less disturbed by electric cautery with the CSI.

Keywords Anesthetic depth indexes · Bispectral index · Electroencephalogram · Fentanyl · Propofol

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Introduction

The bispectral index (BIS; Aspect Medical Systems, Newton, MA) is an electroencephalographic (EEG) index that is widely used to measure the hypnotic level during anesthesia. In more recent years, many other EEG indices have been developed for the same purpose. Of the many types of EEG monitors, the cerebral state monitor (CSM; Danmeter, Odense, Denmark), which shows the cerebral state index (CSI), is a low-cost and compact alternative to the BIS. According to the respective manufacturers, both the CSI and the BIS are scored as 0–100, and they have the same target value ranges for adequate sedation during general anesthesia. The BIS employs a particularly complex algorithm that was developed from data collected on 1500 patients under anesthesia [1], while the algorithm for the CSI is based on a more straightforward Fourier analysis of the EEG. The CSI is calculated from raw EEG signals using an algorithm based on power analysis of the beta, alpha, and beta–alpha ratio in conjunction with an estimation of burst suppression [2, 3]. Due to these different calculation algorithms, these indices may be different during anesthesia. Very few studies on the CSI have been published [4–9], and none of these have compared the BIS

and CSI in patients receiving propofol–fentanyl–nitrous oxide anesthesia. The aim of the study reported here was, therefore, to compare the BIS and CSM (CSI) during propofol–fentanyl–nitrous oxide anesthesia.

Materials and methods

After receiving approval of the ethics committee of the hospital and informed consent from the selected patients, we enrolled 30 patients (aged 30–70 years) with American Society of Anesthesiologists (ASA) physical status I or II who were scheduled for abdominal surgery in the study. Patients with ascertained neurological disorders, hearing disturbances, liver or renal disease, mental impairment, alcohol abuse prior to the surgery were excluded. Patients taking any drug affecting cerebral function, such as hypnotics, antidepressants, among others, were also excluded.

Without any premedication, an epidural catheter was inserted into the patient in the appropriate interspinal space. Anesthesia was induced with propofol 2–3 mg kg^{-1} and fentanyl 3–5 μg kg^{-1}, and endotracheal intubation was facilitated with vecuronium 0.15 mg kg^{-1}. Anesthesia was maintained with a propofol infusion, fentanyl, vecuronium, intermittent epidural administration of 1.5% mepivacaine, and 50% nitrous oxide in oxygen to maintain a stable hemodynamic state and a BIS between 40 and 60. During surgery, when the hemodynamic parameters were stable, the propofol infusion dose was controlled to try and keep the BIS at 40 ± 3 for 10 min; it was then decreased to keep the BIS at 60 ± 3 for 10 min. The propofol infusion was stopped at the start of skin suturing, and nitrous oxide was stopped at the end of the surgery. The endotracheal tube was extubated when the patients could protrude their tongue, and the end-tidal carbon dioxide tension was between 30 and 40 mmHg with an oxygen saturation ≧98% by spontaneous breathing under 100% oxygen.

Prior to anesthesia induction, the electrodes of both the CSM2 (Danmeter) and the BIS (ver. 3.4; A-2000; Aspect Medical Systems) were attached simultaneously on the same side. Electrode impedances were considered to be acceptable if the CSM and BIS was <3 and 10 kΩ, respectively. The smoothing rate of the BIS was 15 s. The data of both monitors were continuously sorted by the computer, and only data when signal quality index was >75% were used.

We compared the CSI and BIS for (1) time between switching on the apparatus and starting to measure each index with a signal quality index >75% (starting time); (2) duration of signal disturbance by electric cautery, which was shown as a total value of three randomly selected events of electric cautery in each patient; (3) recovery time from disturbance by electric cautery. The CSI was compared with the BIS before surgery, at a BIS around 40 and 60, and at extubation. At each measurement point, the mean value for 1 min was used for analysis.

Data are shown as the mean ± standard deviation (SD) and the range. The relation between BIS and CSI was determined by linear regression analysis. The Bland–Altman plot was used to analyze the bias (mean of the differences), limits of agreement (bias ± 2 SD of bias), and percentage error (2 SD × 100/mean). The statistical analysis was performed with the repeated measures analysis of variance (ANOVA) followed by the Student–Newman–Keuls test as a post hoc analysis for each index and by the Student t test for time and duration. A P value <0.05 was considered to be statistically significant.

Results

The mean age of the patients was 53 ± 8 (range 39–64) years and 17 were male and 13 were female. The mean body weight was 64 ± 11 (range 48–66) kg, and the mean height was 162 ± 12 (range 149–174) cm. Fifteen patients received partial gastrectomy, five received total gastrectomy, and ten received colectomy. The duration of surgery was 260 ± 115 (range 149–523) min.

Starting time was 63 ± 11 (range 50–74) s in the BIS and 38 ± 3 (range 34–42) s in the CSM ($P < 0.05$). The duration of signal disturbance by electric cautery was 9.3 ± 3.5 (5.3–13.2) min in the BIS and 2.4 ± 1.4 (1.0–3.9) min in the CSM ($P < 0.05$) for an electric cautery event lasting 8.0 ± 3.9 (4.0–12.1). The recovery time from the disturbance caused by the electric cautery event was 41 ± 14 (26–56) s in the BIS and 3 ± 1 (2–4) s in the CSM ($P < 0.05$).

The absolute values of the BIS and CSI were not significantly different (Table 1). The BIS and CSI correlated well (Fig. 1). The bias (BIS − CSI) was negative at all measurement points, while the limits of agreement and percentage error were small (Table 2; Fig. 2).

Discussion

The results of our study show that the absolute values of the BIS and CSI were not significantly different when the patients were awake and when they were under propofol–fentanyl–nitrous oxide anesthesia. However, the start of the measurement was faster with the CSM than with the BIS after switch-on, and the measurement was less disturbed by electric cautery events with the CSM.

Table 1 Bispectral index and cerebral state index

Measurement point	BIS	CSI
Before induction	89 ± 4 (83–96)	90 ± 3 (87–99)
At BIS 40 (propofol 6.1 ± 2.1 mg kg^{-1} h^{-1})	40 ± 2 (36–44)	42 ± 2 (35–47)
At BIS 60 (propofol 3.5 ± 1.7 mg kg^{-1} h^{-1})	60 ± 2 (57–64)	62 ± 2 (55–68)
Extubation	85 ± 4 (77–92)	89 ± 3 (82–97)

All values are given as the mean ± standard deviation (SD) with the range given in parenthesis

No significant differences were observed between the bispectral index (BIS) and the cerebral state index (CSI)

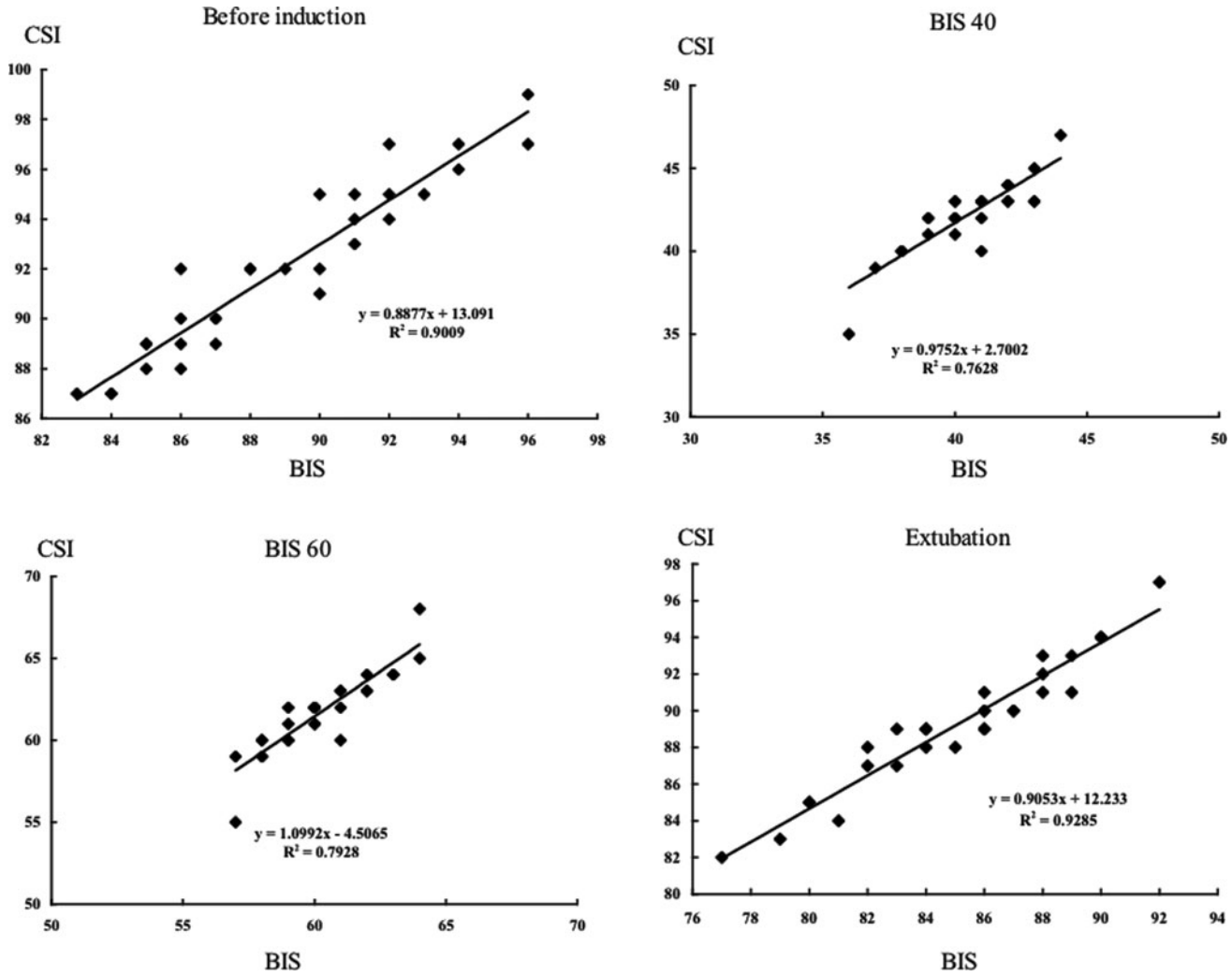

Fig. 1 Scatter plot of the simultaneously measured bispectral index (*BIS*) and cerebral state index (*CSI*). *Solid lines* Linear regression lines

We used nitrous oxide and fentanyl with propofol to make it easier to maintain the BIS at a constant level with propofol, thereby avoiding light anesthesia. Steady state nitrous oxide alone causes a slightly increase in the high-frequency and theta range activity of EEG, but it does not alter BIS or create a significant degree of hypnosis [10]. A minimal or total lack of effect of opiates and nitrous oxide has been reported on anesthetic depth monitors [5, 11]. Therefore, the effects of nitrous oxide and fentanyl may be negligible on the results of this study.

BIS and CSM have been reported to have a similar overall performance during propofol induction [12]. The CSI and BIS show similar patterns and numerical values, but large discrepancies between pair-wise readings have

occasionally been observed [4]. In one study on patients under propofol and remifentanil anesthesia, the CSI indicated that 13% of the patients were awake during parts of the course, despite being clinically sleep; these patients were correctly identified with the BIS [8]. In our study, however, the CSI and BIS showed quite similar values without large discrepancies, as indicated by small bias, limits of agreement and percentage error.

Table 2 The bias, limits of agreements, and percentage error

Measurement point	Bias	Limits of agreement	Percentage error
Before induction	−3.1	−5.37 to −0.83	2.5
BIS 40	−1.7	−3.48 to 0.38	5.0
BIS 60	−1.5	−3.58 to 0.65	3.5
Extubation	−4.2	−6.10 to −2.23	2.2

The bias is the mean of the differences; limits of agreement are the bias ± 2 SD of bias; percentage error is calculated as 2× standard deviation × 100/mean

Anderson and Jakobsson [4] reported that the median BIS for all patients when fully awake without premedication was 96 (range 91–98) and that the CSI was 92 (79–99). In a study carried out by Zhong et al. [6], the CSI had a larger baseline variability than the BIS. However, these researchers also showed that the CSI range for 90% of patients with no response was 58.3 to 72.9 and for loss of response it was 38.2 to 71.3. The corresponding ranges for the BIS values were 55.8–79.7 and 35.6–78.0, respectively [6]. As the ranges for the CSI were smaller than those of the BIS, it is possible that CSI is slightly better than the BIS in detecting loss of verbal contact and response. We did not study the fine changes of the conscious state, i.e..

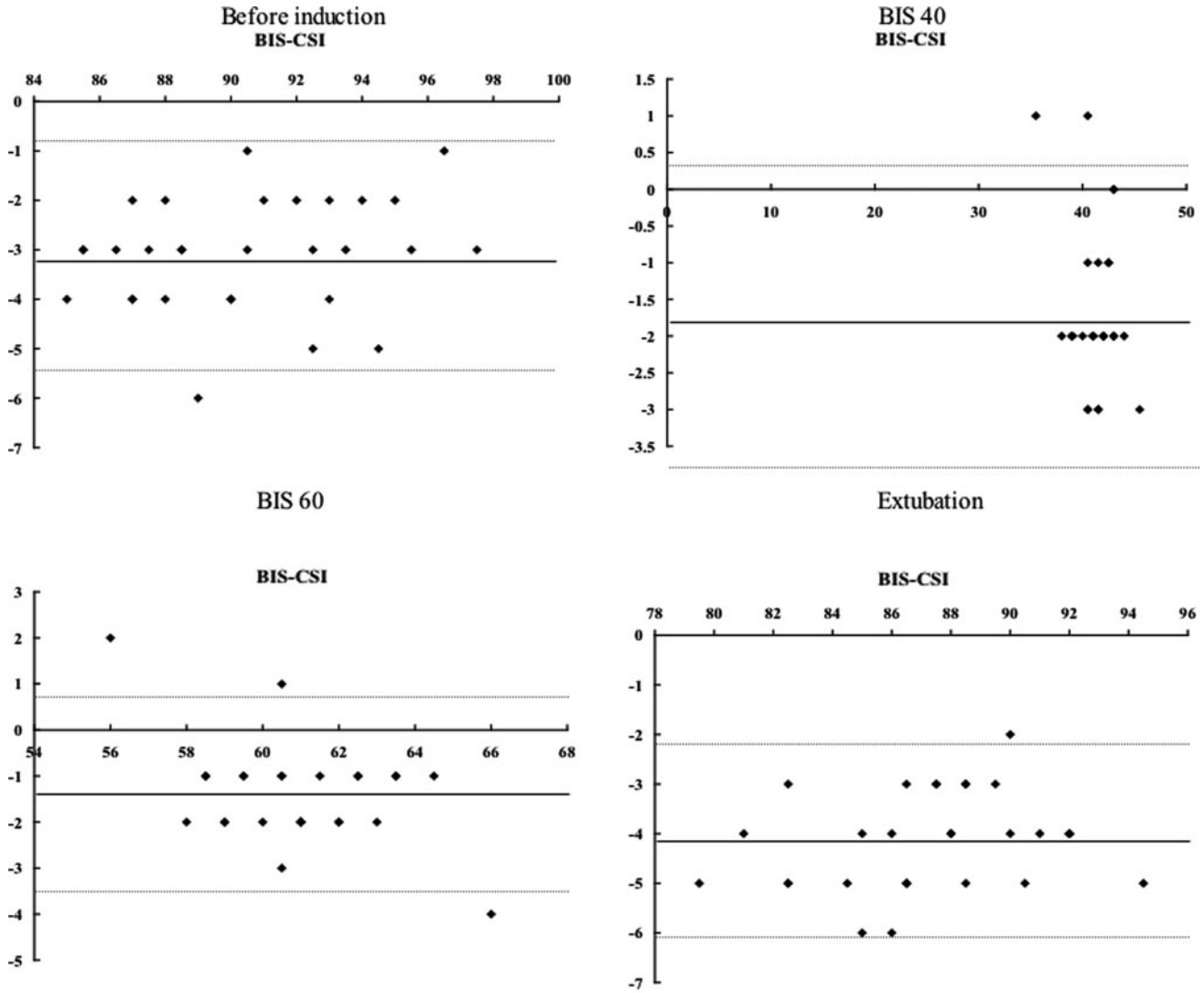

Fig. 2 Bland–Altman plot of the simultaneously measured BIS and CSI. *Solid lines* Bias (the mean of the difference BIS − CSI), *dotted lines* limits of agreement (bias ± 2 SD of bias)

the transition from consciousness to unconsciousness, but both the BIS and CSI had no overlap between awake (before induction or extubation) and anesthesia (BIS 40 or 60). Therefore, both the BIS and CSI may be able to differentiate between patients under anesthesia from those in the awake state. Our results show that the CSI and BIS had almost the same ranges in the awake state; however, larger variations in the CSI were observed at deep (BIS 40) and light (BIS 60) sedation during general anesthesia. The reason for these variations was that we tried to keep the BIS at constant levels during the study.

In the study by Nasraway et al. [13], the BIS ranged from 35 to 98 in deeply sedated patients and from 67 to 91 in mildly sedated patients. Thus, a large variability and overlap in the BIS at distinct depths of anesthesia would make it difficult to differentiate between these anesthetic depths [14, 15]. Anderson and Jakobsson [4] reported that when BIS values decreased to <40, the CSI tended to stabilize at higher levels. However, Hernandez-Gancedo et al. [16] reported that the BIS may prove useful for discriminating between deeper levels of sedation. In our study, we compared the BIS and CSI at BIS 40 and BIS 60. The BIS and CSI showed quite similar values at both anesthetic depths (BIS 40 and 60), with the CIS having a slightly higher. However, we did not study very deep sedation (BIS <30) and therefore cannot discuss the difference between the BIS and CSI in this state which, incidentally, is not so often induced in clinical anesthesia.

No overlap was seen both in the BIS and CSI among awake patients, those at BIS 40 and BIS 60, and extubation. Therefore, both BIS and CSI may be useful for detecting changes in sedation level in propofol–fentanyl–nitrous oxide anesthesia as well as distinguishing between patients under anesthesia and those awake.

Our previous study comparing the CSI and BIS in sevoflurane–nitrous oxide anesthesia [17] obtained results that are quite similar to those reported here in propofol–fentanyl–nitrous oxide anesthesia, with one exception: the bias was positive in sevoflurane–nitrous oxide anesthesia, while it was negative in propofol–fentanyl–nitrous oxide anesthesia. These two studies indicate that the BIS is higher than the CSI in sevoflurane–nitrous oxide anesthesia, while the BIS is lower than the CSI in propofol–fentanyl–nitrous oxide anesthesia.

The BIS and CSI have different time lags for reacting to a simulated change in the level of anesthesia. The CSM required between 54 and 64 s to adapt to the changed input artificial signal, and the time delay for the BIS was 60 s [18]. The fastest CSI response was measured for values increasing from general anesthesia to awake (15 s from CSI 42 to 95), while the BIS showed a time delay of 30 s [18], which may be too long because wakefulness for more than 30 s increases the risk of recall [19]. The difference in the delay may contribute to the difference in the duration of signal disturbance by electric cautery event and recovery time between the CSI and the BIS. We checked only the signal quality index when using the BIS and CSI variables and not the electromyogram. Some wrong values may have been included in the analysis by chance. However, we used muscle relaxants because of abdominal surgery. Therefore, the chance that wrong values were included is quite low.

In this study, we used the BIS (ver. 3.4, A-2000) and the CSM2 because only these monitors were available at our hospital at the time of the study. However, we now have new monitors (BIS-XP and CSM3) at our institutions. Therefore, if the newest monitors are used, the results may be different, which should be further investigated.

In conclusion, the absolute values of the BIS and CSI were identical in awake patients and during propofol–fentanyl–nitrous oxide anesthesia. However, the start of the measurement was faster with the CSM than with the BIS after switch-on, and the measurement was less disturbed by electric cautery using the CSM.

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