Use of conventional ECG electrodes for depth of anaesthesia monitoring using the cerebral state index: a clinical study in day surgery

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Background. The cost–benefit relationship for depth of anaesthesia monitors is complicated by the high cost of specially designed EEG electrodes. The cerebral state index (CSI) monitor will accept regular ECG electrodes with snap connectors. The purpose of this study was to determine if generic ECG electrodes could replace the more expensive proprietary EEG electrodes for the CSI monitor.

Methods. Two identical cerebral state monitors were used simultaneously during sevoflurane anaesthesia for knee arthroscopy in 14 ASA I–II patients. One monitor used proprietary (Danmeter) EEG electrodes and the other used ECG electrodes (3M™ Red Dot™ Diagnostic ECG Electrodes). Paired CSI values were recorded every other minute. Anaesthetic depth was titrated clinically. Sedation depth was scored according to the Observer’s Assessment of Alertness/Sedation (OAAS) scale.

Results. The agreement between the two measures was found to be high, mean difference −0.23, and the overall repeatability mean bias was 6.6 and 153/163 pairs (94%) were located within the 95% limits of agreement. No major difference was noted in impedance, noise, or artifacts. A large overlap in CSI was noted for each level of the OAAS scale; patients with CSI values as low as 40–50 responded whereas patients not responding to surgical stimulation had CSI values as high as 75. The direct cost of disposables decreased from 4€ to 0.50€ per patient by using ordinary ECG electrodes.

Conclusions. Switching from proprietary EEG electrodes to ordinary generic ECG electrodes maintains the same accuracy at about a 10th of the cost when measuring CSI during day surgery with sevoflurane anaesthesia.


Keywords: anaesthesia, depth, monitoring; anaesthesia, general; anaesthetics volatile, sevoflurane; monitoring, CSI

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connection to any conventional disposable electrode with a snap connector.

This explorative study employed two CSI™ simultaneously to determine the degree of agreement between CSI measured using a set of generic ECG electrodes and CSI measured using the proprietary electrodes specially designed and sold for use with the CSI™.

Methods
Fourteen ASA I–II patients [mean age 53 (range 21–64), weight 80 (55–100 kg), nine males and five females] undergoing elective day surgical knee arthroscopy under general anaesthesia were studied after they gave informed consent and approval was obtained from the local ethics committee. Anaesthesia was induced with fentanyl 0.1 mg followed by propofol according to clinical needs. Anaesthesia was maintained with sevoflurane in fresh gas consisting of oxygen in air 1:1 litre min⁻¹. A laryngeal mask airway was placed in all patients, and they had spontaneous respiration with occasional assistance given when necessary. No muscle relaxants were given. Sevoflurane anaesthetic was adjusted according to clinical needs by the attending anaesthetist who was not involved in the EEG recordings.

Monitoring
Two CSI™ monitors were used for registration of the CSI. The skin of the forehead and each mastoid process was firmly rubbed with abrasive paper and one drop of sodium chloride was applied to the skin before placement of the electrodes. Two sets of three electrodes were used: proprietary composite electrodes specifically for use with the CSI™ (4€ per patient) or standard wet gel ECG electrodes with snap connectors (3M™ Red Dot™ Diagnostic ECG Electrodes, 3M Health Care; Neuss, Germany; 0.50€ per patient). These were applied according to the manufacturer’s instruction with one of each set on the forehead’s midline, one more laterally on the forehead, and one on the mastoid process behind the ear and connected to the CSI monitor. Each type of electrode was confined to the same side with the midline shared by both types. After an initial control for electrode impedance, the monitor calculates its index from the raw EEG signals using an algorithm based on power analysis of the beta, alpha, and beta–alpha ratio in conjunction with estimation of the burst suppression ratio. The index is updated every second with an averaging delay of up to 10 s.

The CSI values were manually recorded simultaneously every other minute from before induction until patients could give their name and date of birth. Patients were interviewed about awareness just before discharge. All patients were monitored during surgery according to departmental standards (ECG, non-invasive blood pressure, and pulse oximetry).

The sedation level was evaluated every minute according to the Observer’s Assessment of Alertness/Sedation (OAAS) rating scale until loss of response to stimulation:²
OAAS score 5: responds readily to name spoken in normal tone.
OAAS score 4: lethargic response to name spoken in normal tone.
OAAS score 3: responds only after name is called loudly or repeatedly.
OAAS score 2: responds only after mild prodding or shaking.
OAAS score 1: does not respond to mild prodding or shaking.
OAAS score 0: does not respond to noxious stimulus.

Statistics
Patient characteristics and results are presented as median (range). Differences in agreement between pair wise readings were visualized by Bland–Altman plot and measurement of agreement was calculated.³ ⁴ Non-parametric statistics were used, Wilcoxon signed rank test and Kruskal–Wallis when appropriate. A P-value of <0.05 was considered statistically significant. All statistics were computed on a Macintosh computer with StatView II. The ability of CSI to predict the depth of sedation was evaluated by calculating the predicted probability (PK) using a custom spreadsheet macro, PKMACRO, developed and provided by Smith and colleagues,⁵ and the jackknife method was used to compute the SE of the estimate.

Results
Anaesthesia and surgery was uneventful in all patients and no awareness or recall was reported.

There was no difference in preparation time nor was there any difference in the initial device test of impedance between the two electrode sets. During the study period, no major differences were observed in loss of signal quality or other artifacts between the two electrode sets studied. Simultaneous readings from the monitor derived via generic ECG electrodes and those derived from proprietary EEG electrodes resulted in 163 pairs of readings in the 14 ASA I–II patients.

The mean difference between pair wise readings in each individual subject was −0.28 with a mean SD of 2.9. Taking all data into account, the agreement between the two measures was −0.23 and the overall repeatability given as mean bias was 6.6. There was no obvious deviation in relation to absolute values (Fig. 1). One hundred and fifty-three of the 163 pair wise recordings (94%) were located within the 95% limits of agreement.

CSI has a high predictive probability for the OAAS (PK = 0.97 and SE = 0.01). The relationship between CSI
and OAAS sedation score for the generic ECG electrodes and the proprietary CSI electrodes showed considerable overlap (Fig. 2A and B). Patients still responding (OAAS 2) had CSI values as low as 40–50 whereas patients not responding to noxious, surgical stimulation (OAAS 0) had CSI values as high as 75.

The direct cost of disposables is decreased from 4€ to less than 0.50€ using ordinary ECG electrodes instead of proprietary CSI electrodes.

**Discussion**

This explorative study compared the use of generic ECG electrodes and Danmeter proprietary EEG electrodes when determining CSI simultaneously using two identical CSMs. The most important finding is that ordinary, inexpensive, self-adhesive ECG electrodes seem to be as reliable and effective as the almost 10-fold more expensive, proprietary EEG electrodes sold by the monitor’s manufacturer. Secondly, although the calculated probability to predict the sedation level is very good, there is nonetheless a large overlap for CSI values for each level of sedation/hypnosis. CSI indicated adequate anaesthetic depth for some patients who responded to surgical stimulation.

Development of depth of anaesthesia monitors was triggered by the persistent problem of awareness during anaesthesia. The development of these monitors, however, also has had the tendency to raise the expected standard of care before they have proved their usefulness or cost-effectiveness.

Studies of reducing awareness using depth of anaesthesia monitors have given conflicting results. Ekman and colleagues\(^6\) found a reduction in awareness incidence to 0.04% in BIS monitored, muscle-relaxed patients compared with a historical awareness incidence of 0.18%. Sebel and colleagues\(^7\) did not find any association between the use of BIS and the incidence of awareness in a huge pan-American multi-centre study. This study, however, did not have the primary aim of evaluating the effect of BIS monitoring on the incidence of awareness. Myles and colleagues\(^8\) showed a reduction in awareness in high-risk patients: with a cost per use in Australia of US$16 for routine BIS monitoring and a number needed to treat of 138, the cost of preventing one case of awareness in high-risk patients was calculated to be about US$2200.

The use of depth of anaesthesia monitors has also been suggested to have benefits by making titration of anaesthesia more individualized, ‘tailor made anaesthesia’. The cost-effectiveness of a small reduction in direct drug cost and a minute or two during emergence has to be put into the perspective of the monitoring expense. The dominant cost for most depth of anaesthesia monitors is for the single-use EEG electrodes, as shown for the cost-effectiveness of BIS. BIS monitoring decreased the consumption of anaesthetics, but the monitoring increased direct costs mainly due to the price of special EEG electrodes.\(^9\) The authors found that BIS eventually becomes
cost-effective but only for longer procedures when the decreased consumption of anaesthetic drugs covered the cost of the disposable electrodes; the break-even times were almost 5 h for sevoflurane and more than 10 h for propofol.  

This study is not the first to demonstrate that ECG electrodes can replace EEG electrodes for awareness monitors. Thogersen and Ording showed that although ECG electrodes had higher impedance, they could without problem replace the Zipprep electrodes sold with the earlier versions of the BIS monitors. Modern BIS units have connectors that no longer allow the use of ordinary ECG electrodes.  

There are of course limitations with the present study. One should bear in mind that the EEG signal indeed is much smaller than that of the ECG and that the requirements therefore are higher in order to achieve proper electrical information. We have only studied one sort of ECG electrode with a wet gel, and we are not able to describe the exact electrical performance of these electrodes. The study is entirely clinical; no specific studies were done with respect to the impedance of the ECG electrodes. No differences were seen during the initial self-check phase for the two groups and the overall results are reassuring from a clinical point of view. The indices derived showed good agreement and we could not detect any major difference with regard to artifacts, loss of signal, or other technical problems during the study. We included in the Bland–Altman analysis values during both maintenance and the induction and recovery phases. Although the data set from this study contains partially repeated measures, data were considered as being independent for both the prediction probability and Bland–Altman test. For prediction probability, no repeated measures alternative exists. For the Bland–Altman test, analysis of agreement of repeated measures are not easily handled from a statistical point of view. It may have been more accurate to focus on the intraoperative period to minimize within-subject variability. However, we are convinced our conclusion remains valid. 

The CSM has been shown to perform more or less as well as the conventional BIS during routine anaesthesia. The CSM seems an attractive alternative to the more costly BIS and Entropy monitors, both of which have a higher device cost and no option to use cheaper disposable ECG electrodes. 

This study has shown that regular ECG electrodes with snap connectors can replace the special, more expensive EEG electrodes at about a 10th of the cost when measuring CSI during day surgery with sevoflurane. 

References
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