Can anaesthetists be taught to interpret the effects of general anaesthesia on the electroencephalogram? Comparison of performance with the BIS and spectral entropy

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Background. Unlike the other physiological waveforms monitored in anaesthesia, the EEG lacks a regularly repeating pattern, implying that it would be very difficult for an anaesthetist to obtain any useful information from the raw EEG. There are, however, clear changes in the EEG caused by GABA-ergic anaesthetic agents. The anaesthetized EEG still looks like a random waveform, but clearly a different random waveform from that seen when conscious.

Methods. The aim of this study was to assess how 40 anaesthetists would perform at interpreting intra-operative EEGs compared with two processed EEG (pEEG) monitors, BIS and entropy, after a short educational presentation. Short segments of EEGs were used from the pre-induction phase, the intra-operative phase with adequate surgical anaesthesia, and the transition phase between these two states.

Results. While anaesthetists’ performance varied widely, most could reliably differentiate an anaesthetized from a conscious EEG. Further, both humans (41% wrong) and machines (30% wrong) made mistakes. Unlike the anaesthetists, the pEEG monitors did not make a major error (i.e. producing a number in the conscious range (>85) when analysing an anaesthetized EEG or the converse error).

Conclusion. A brief PowerPoint presentation enables anaesthetists to recognize the effects on the EEG of GABA-ergic anaesthetic agents. In the clinical context, it remains likely that the combination of a pEEG monitor that clearly presents the EEG and a clinician who has a good, basic understanding of, and a willingness to look at, the raw EEG will result in more accurate interpretation of the intra-operative EEG.

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The EEG was first described in the early 1900s. The effect of anaesthesia on the EEG was noted soon after the discovery of these drugs.\(^1\) Since the 1950s, anaesthetists have been trying to use the EEG to monitor ‘depth of anaesthesia’, but the complex and random nature of this physiological waveform has made its interpretation difficult. The development of the processed EEG (pEEG) monitors in the 1990s revolutionized the use of EEG during anaesthesia.\(^2\) They use rapid mathematical analysis of the frontal EEG to generate a ‘number’ that can be used to titrate anaesthetic delivery.\(^3–5\) pEEG monitors have been correlated with clinical indicators of anaesthesia and measured drug plasma (end-tidal) concentrations.\(^6–11\) A recent, large, randomized, controlled trial showed that the use of BIS monitoring decreased the incidence of intra-operative awareness in high-risk patients.\(^12\) Both BIS and entropy have also been shown to decrease both total anaesthetic administered and time to extubation.\(^13 14\) Clinical indices based on physiological waveforms (e.g., ECG, invasive blood pressure, and pulse oximetry) are routinely checked by validating the processed output against the raw waveform. This should be no different for pEEG monitors. However, there is an assumption that EEG interpretation is beyond all but a select few anaesthetists who spend years...
acquiring that skill. While this might be true of the full scope of EEG interpretation, we believe the basic changes seen with the transition from awake to anaesthetized states using GABA-ergic-based general anaesthesia are simple and consistent. Any anaesthetist can learn to recognize them, and this ability will add clinical value, not just academic interest. As long as the raw EEG remains a mysterious wavy line to anaesthetists, the EEG monitors will remain in a time warp of under-utilization and distrust. Anaesthetists cannot do the fast Fourier transformation or the spectral entropy calculations. However, we are quick to recognize patterns, potentially faster than the pEEG monitors.15 Most importantly, we know the clinical context. The ability of anaesthetists to learn how to interpret the effects of general anaesthesia on the raw EEG has not been studied. This study had two aims as follows:

- To teach anaesthetists about the frontal EEG and how it changes from the awake to the anaesthetized state.
- To see how anaesthetists, after our teaching session, compared with BIS and entropy at grading EEGs in terms of ‘depth of anaesthesia’.

Methods

We prepared a 15 min long educational PowerPoint presentation. This focused on the features of an awake EEG and the changes that occur as a patient becomes anaesthetized (see Appendix). The teaching presentation was repetitive, simple, focused on key themes, and had numerous examples.

Segments of EEG recordings from previous studies done at Waikato Hospital (Hamilton, New Zealand) using sevoflurane and propofol anaesthesia were used. The clinical context for each EEG was known, and this was our ‘gold standard’. The three clinical contexts were

- awake: alert and responsive to verbal commands, before the administration of any anaesthetic drugs.
- transition/sedated: within 30 s of loss of responsiveness to a verbal command after either an i.v. propofol or an inhalation sevoflurane induction.
- anaesthetized: during the course of a surgical procedure using clinical and pharmacological means (MAC or estimated plasma concentration) to ensure anaesthetic depth.

The EEG educational presentation was presented to the Waikato Hospital anaesthetic department as part of one of our routine monthly educational meetings. There were 30 specialists or trainees at the live presentation, and CD copies of the presentation (fully automated with the same commentary) were sent to the remainder of the department.

Immediately after the teaching presentation, the subjects were tested on their ability to match sample EEGs with behavioural state. Each EEG presented was 5 s long and scaled so that the tracing nearly filled the width of a PowerPoint slide. The test was divided into two parts. The first part involved ranking triplets of EEGs. Ten different triplets required ranking. Each triplet was taken from the EEG of a single patient. It was presented on a single slide and demonstrated a segment of awake EEG, a segment of EEG taken during transition from awake to anaesthetized, and a segment of EEG taken during surgical anaesthesia (Fig. 1). The vertical ordering of the segments on each slide was randomized and the subjects were asked to order the segments as awake, transition/sedated, and anaesthetized. Each ranked triplet was marked either correct (if all three EEGs were ranked appropriately) or incorrect.

The second part of the test involved interpreting 30 randomly chosen EEG segments. This was intentionally made as difficult as possible, as the segments were presented without any context whatsoever. The subjects were blinded to the fact that there were 10 from each of the awake, transition and anaesthetized states. For each EEG, we asked the following question, ‘Is this patient awake or asleep (i.e. drug-induced unresponsiveness)?’ If the anaesthetist thought the patient was asleep, there was a second part to the question: ‘Imagine that surgery is proceeding currently; on the basis of the EEG are you happy for surgery to continue?’ On the basis of the answers to these questions, the subjects’ interpretation of each EEG was categorized as either (i) awake, (ii) transitional/sedated (‘asleep but not happy for surgery to continue’), or (iii) anaesthetized (‘asleep and happy for surgery to continue’). Contingency tables were tabulated comparing ‘actual’ (the clinical context that the EEG was taken from) with subject interpretation. The performance of the ‘average anaesthetist’ was obtained by pooling the results generated by all the subjects and dividing by the number of subjects.

![Fig 1](https://academic.oup.com/bja/article-abstract/99/4/532/303941)
The EEG segments used in the second part of the test were run through both the BIS and entropy monitors. To do this, each of the 5 s long EEG strips was spliced together end-on-end 12 times to create 60 s worth of EEG. Similar contingency tables were created comparing ‘actual’ with the judgements based on the number generated by the BIS and by the entropy monitors (Table 1). In line with manufacturer recommendations,16 we used a number of 85–100 as indicating consciousness, 60–85 as indicating transition/sedation, and 0–60 as indicating anaesthesia.

Results

Forty anaesthetists or anaesthetic trainees participated in the study. They represented 66% of the anaesthetic department at Waikato Hospital.

The results from the first part of the test, which involved ranking EEGs, are shown in Figure 2. The mean percentage correct was 74%, median 80%, and SD 28%. The majority of anaesthetists achieved ≥80% correct; however, there was a long tail towards very poor performance, with 20% of anaesthetists scoring ≤20% correct.

The second part of the test involved the subjects identifying awake and anaesthetized EEGs, then making a judgement about the adequacy of anaesthesia based purely on the EEG (Fig. 2). Table 1 shows three contingency tables for the ‘average anaesthetist’, BIS and response entropy (RE). Values in bold face represent correct categorization. BIS and RE both correctly categorized 70% of the EEGs whereas the average anaesthetist correctly categorized 59%. If the transition/sedated EEG segments were removed from the analysis, then these figures improve to 93 and 70%, respectively.

A notable difference between man and machine was the rate of major errors; that is, judging that anaesthesia was adequate when the patient was conscious, or the converse, judging that the patient was conscious when they were anaesthetized (Table 1, normal face values). No major errors were made by either of the pEEG machines. Anaesthetists made these errors on 80 (10)% occasions. One or more of these errors was made by 32 (78)% anaesthetists. The major error rate [1.98 (sd 1.92)] varied much more markedly between anaesthetists than the minor error rate [10.3 (2.9)] (Fig. 3), with coefficients of variation of 0.98 and 0.28, respectively.

The BIS and entropy monitors each made nine minor errors (Table 1, italic values). The BIS errors were evenly spread among the four minor error options, whereas the entropy wrongly classified 8 (80)% of the sedated/tran-sition EEGs as anaesthetized.

The rate of major errors was unevenly distributed across the EEG tracings. Two of the tracings from awake patients accounted for 30 (59)% of the major errors when the patient was awake (Fig. 4). Similarly, two tracings from anaesthetized patients accounted for 15 (54)% of the major errors when patients were anaesthetized (Fig. 5).

Discussion

The results of our study go some way to dispelling the myth that the EEG is so complex that there is no merit in

<table>
<thead>
<tr>
<th>‘Actual’</th>
<th>Awake</th>
<th>Transition</th>
<th>Anaesthetized</th>
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<td>0.8</td>
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<tr>
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<td>3.7</td>
<td>1.2</td>
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<tr>
<td>Anaesthetized</td>
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<td>8</td>
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<tr>
<td>BIS</td>
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<tr>
<td>85–100</td>
<td>8</td>
<td>2</td>
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<td>Entropy</td>
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Fig 2 Graph showing the distribution of percentage correct categorizations made by the anaesthetists for the first (A) and the second (B) parts of the teaching quiz.
After a 15 min tutorial, the ‘average’ anaesthetist can recognize anaesthesia-related EEG patterns. A small number of anaesthetists scored very poorly. Conditions for the teaching session were less than ideal and it is likely that some of the poor marks came from anaesthetists who were interrupted by phone calls, arrived late, misunderstood instructions, or transposed question numbers.

The most worrisome errors would be for the anaesthetist to decide the EEG was consistent with adequate anaesthesia when it was in fact consistent with consciousness or the converse. The anaesthetists made one or other of these major errors on 80 (out of 800) occasions. In contrast, neither of the pEEG monitors made these errors. Most anaesthetists made few of these errors (e.g. 80% made ≤2 errors). Blink and eye movement artifacts on the EEG being mistaken for delta wave EEG activity was the main cause of falsely classifying awake patients as anaesthetized. Of the two anaesthetized EEG segments that attracted the most major errors, one in particular seemed to have a noticeable amount of low-amplitude, high-frequency activity.

There is no absolute gold standard measure of depth of anaesthesia, sedation, or both. We were confident about the accuracy of our classification of test EEG segments into ‘awake’ and ‘anaesthetized’ categories. The anaesthetized EEGs were taken during a surgical operation where careful clinical and pharmacological monitoring was being used to ensure adequate anaesthesia, and none of the patients, when screened after operation, had any evidence of intra-operative awareness. The EEG segments that we labelled ‘sedated’ in the education sessions were taken from the period during induction of anaesthesia, within 30 s of loss of response to verbal command. Sedation scores were not part of the protocol of the study from which we obtained our test EEG samples from. Further, the frontal EEG is a poor indicator of depth of sedation. For example, rousability is part of the definition of sedation, and the EEG

![Fig 3](image1.png)  
**Fig 3** Graph showing the distribution of errors made by the anaesthetists, divided into (A) ‘major’ errors and (B) ‘minor’ errors.

![Fig 4](image2.png)  
**Fig 4** Two awake EEG tracings that accounted for the majority of major errors involving misclassification of anaesthetized for awake.

![Fig 5](image3.png)  
**Fig 5** Two anaesthetized EEG tracings that accounted for the majority of major errors involving misclassification of awake for anaesthetized.
will be much more grossly affected by the patient’s state of consciousness than by graded drug-related EEG responses. As a consequence, during the write up, we have added the label ‘transition’. In the right context, these EEG patterns might be consistent with inadequate anaesthesia, occurring before consciousness and awareness. Not surprisingly, the transition/sedated EEGs proved the most difficult to categorize correctly, for both anaesthetist and machine. Anaesthetists performed more like the BIS making errors fairly evenly in both directions, whereas the entropy monitor incorrectly categorized 80% of ‘transition’ EEGs as anaesthetized.

BIS and entropy are marketed as monitors of ‘depth of anaesthesia’ with two primary functions; to decrease the incidence of awareness by detection of inadequate anaesthesia, and to reduce time to awakening and overall anaesthetic consumption by the detection of overly deep adequate anaesthesia. Using the EEG to steer, this course is made more problematic by many confounding factors, which either alter the depth of anaesthesia without changing the pEEG number, or alter this number independently of the drug-related changes in depth of anaesthesia. Such factors include opioids, ketamine, and nitrous oxide effects on depth of anaesthesia, electrolylographic activity, epileptiform activity, cerebral ischaemia, and electroconvulsive therapy, and artifact from diathermy, ECG, nerve stimulators, and bypass pumps, on the EEG. As a consequence, there is value in routinely examining the EEG before induction, and before and after significant events intra-operatively. Unlike our testing environment, the clinical setting is riddled with such important contextual information and it is here that the anaesthetist has a distinct advantage over machine. Additionally, the practising anaesthetist has the benefit of seeing progressive changes in EEG appearance with changing depth of anaesthesia.

Conclusion

After our extremely brief teaching session, anaesthetists were able to categorize EEGs as awake, sedated, or anaesthetized with comparable accuracy to the BIS and entropy monitors. The processed EEG monitors performed better with respect to major errors. As a consequence, the teaching should be modified to highlight specifically the difference between a conscious EEG with eye movement artifacts and an anaesthetized EEG with pronounced delta waves. In this study, the two monitors were not equivalent in their handling of EEGs taken during the transition from consciousness to anaesthesia. It would appear that the BIS has a more graded response than the entropy. Whether this is a help or a hindrance clinically is unknown. Regardless, having an educated eye to cast over the EEG waveform should improve the effectiveness of these monitors.

Appendix: overview of the teaching video

General principles of EEG and anaesthesia:

- GABA-ergic drugs cause predictable changes in frontal EEG.
- Natural sleep cannot be easily differentiated from anaesthesia on an EEG trace. As a corollary, when no surgery is taking place, moderately low-processed EEG values do not accurately predict response to noxious stimulation.
- Nitrous oxide, opioids, and ketamine do not cause typical GABA-ergic changes in the EEG, but do increase depth of anaesthesia.
- The utility of the processed EEG monitors is increased by the anaesthetists understanding and being able to see the real-time frontal EEG.

Awake EEG with eyes open:

- ‘Fuzzy’ baseline trace—waveform dominated by low-amplitude, >12 Hz beta activity, the high frequency and small size meant that the individual waves blurred together.
- Blinks and eye movement—seen as very large amplitude low-frequency waves coincident with eyelid or eye movement.
- Electromyography (EMG) from the ocular or extraocular facial muscles—high-frequency, higher than EEG amplitude waves which looked distinctly spiky.
- Awake but relaxed with eyes closed.
- Blinks ceased and EMG was reduced.
- The fuzzy baseline remained but at times individual waves became discernible, 8–12 Hz (alpha waves).

Transition/sedated EEG (segment taken about 30 s after loss of responsiveness):

- The presence of some slower, larger waves, <8 Hz.
- Onset of slow spindles, sporadic bursts (<1 s) of moderate amplitude, moderate frequency activity, ramping up, and ramping down in spindle shape.
- Some remaining ‘fuzziness’ to the baseline

Anaesthetized with surgery progressing:

- Absence of high-frequency ‘fuzzy’ activity.
- Presence of a slow wave background, <8 Hz.
- Sleep spindles (approximately 1 spindle per 5 s).

Deeply anaesthetized:

- Pure slow wave activity, <8 Hz, moderate amplitude.
- Burst suppression, periods of electrical silence (near flat line) interspersed in slow wave background.

Isoelectricity (constant near flat line).
References
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