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Prediction of movement at laryngeal mask airway insertion: comparison of auditory evoked potential index, bispectral index, spectral edge frequency and median frequency

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We have studied 46 patients to compare the efficacy of the auditory evoked potential (AEP) index, bispectral index (BIS), 95% spectral edge frequency (SEF) and median frequency (MF) in predicting movement in response to insertion of the laryngeal mask airway (LMA). Anaesthesia was induced with target-controlled infusions of propofol and alfentanil. After loss of eyelash reflex and adequate jaw relaxation, the LMA was inserted without the assistance of a laryngoscope or neuromuscular blocker. Patients who showed any visible spontaneous muscle movement within 1 min of LMA insertion were defined as movers. Values in movers and non-movers at 30 s before LMA insertion were analysed. Only AEP index discriminated between movers and non-movers with a prediction probability of 0.872. BIS, SEF and MF could not predict movement at LMA insertion. AEP index was the most reliable predictor of movement in response to LMA insertion.

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Several electroencephalographic variables have been studied as a monitor of depth of anaesthesia, including spectral edge frequency (SEF),[1–3] median frequency (MF)[4] and bispectral index (BIS).[5–10] The auditory evoked potential (AEP) is another possible monitor of depth of anaesthesia. Middle latency auditory evoked potentials (MLAEP) have been reported to correlate well with depth of anaesthesia[11] and to demonstrate potential awareness.[12 13] However, MLAEP are usually obtained intermittently and the waveforms can be difficult to interpret in the clinical situation. More recently, the auditory evoked potential (AEP) index, which is derived from the AEP, has been proposed as a single numerical value for monitoring depth of anaesthesia.[14–17] AEP index reflects the shape of AEP waveforms and is calculated from the amplitude difference between successive 0.56-ms segments of the curve.[16 17]

A major requirement of a monitor of depth of anaesthesia is to predict movement caused by stimuli. Because no neuromuscular blocker is used for insertion of the laryngeal mask airway (LMA) in most cases, monitors of depth of anaesthesia should be able to predict if anaesthesia is deep enough to prevent movement in response to this manoeuvre. There is no published study which has assessed how well the AEP can predict movement in response to any noxious stimuli or the ability of BIS, MF or SEF to predict movement on insertion of the LMA.

We recorded simultaneously the four variables, AEP index, BIS, SEF and MF, in patients undergoing general anaesthesia in whom a LMA was to be placed. In this study, we wished to assess if the four variables could predict movement in response to insertion of the LMA.

Patients and methods

After obtaining approval from the Ethics Committee and informed patient consent, we studied 46 patients (16 males) undergoing elective surgery. Mean age and weight were 51 (range 16–86) yr and 69 (SD 15) kg, respectively.

Anaesthesia was induced with target-controlled infusions of propofol and alfentanil.[18 19] The target plasma concentration of alfentanil was set at 25 ng ml^{-1} throughout induction of anaesthesia using a TCI system described previously.[19]

The initial blood target concentration of propofol was set at 2 μg ml^{-1} using a Diprifusor TCI system. The anaesthetist in charge of the patient then increased progressively the target blood concentration of propofol until there was loss of eyelash reflex and adequate jaw relaxation for insertion of the LMA. The LMA was inserted without the assistance of a laryngoscope or neuromuscular blocker. The anaesthetist was blinded to the electroencephalographic variables. Monitoring during anaesthesia included non-invasive arterial pressure, ECG, capnography and pulse oximetry.

Definitions of movers and non-movers

Movers were defined as patients who showed any visible spontaneous muscle movement, such as withdrawal or flexor movement of the arms and legs, frowning of the forehead muscles or coughing, within 1 min of LMA insertion. The examiner evaluating the patient's response to LMA insertion was not blinded to the target concentration of propofol.

Surface EEG analyses

The EEG was obtained from four disposable silver–silver chloride electrodes (Zipprep, Aspect Medical Systems, MA, USA) placed bilaterally on the outer malar bone (At1 and At2), with Fpz as the reference and Fp1 as the ground. Impedance of the electrodes was confirmed to be less than 2000 Ω. BIS, MF and 95% SEF were measured using an EEG monitor (A-1000, BIS 3.1 algorithm, rev. 3.12 software, Aspect Medical Systems, MA, USA). BIS, MF and 95% SEF required at least 30 s to be fully updated. Values were stored automatically on a microcomputer (T2130CT, Toshiba, Japan) at intervals of 5 s. The EEG before induction of anaesthesia was obtained with the patient's eyes closed.

Auditory evoked potentials acquisition

The AEP were obtained using a similar system to that described in our previous studies[12 16 17] from three electrodes (Zipprep) placed on the right mastoid (+), middle forehead (–) and Fp2 as the reference. The amplifier was custom-built with a 5 kV medical grade isolation. It had a common mode rejection ratio of 170 dB with balanced source impedance, input voltage noise of 0.3 mV (10 Hz to 1 kHz rms) and current input noise of 4 pA (0.05 Hz to 1 kHz rms). A third-order Butterworth analogue band-pass filter with a bandwidth of 1–220 Hz was used. The clicks were 70 dB above the normal hearing level with a duration of 1 ms. They were presented at a rate of 6.9 Hz to both ears. The amplified EEG was sampled at a frequency of 1778 Hz by a 12-bit analogue-to-digital converter (PCM-DAS08, Computer Boards Inc., MA, USA) and was processed in real-time by the microcomputer. AEP were produced by averaging 256 sweeps of 144 ms duration. The time required for a full update of the signal was 36.9 s, but a moving time averaging technique allowed a faster response time to any change in the signal. The AEP were obtained at intervals of 3 s. AEP index is a mathematical derivative that indicates the shape of the AEP. The value was calculated as the sum of the square root of the absolute difference between every two successive 0.56-ms segment of the AEP waveform.[16]

Table 1 Difference in heart rate and systolic arterial pressure at 30 s before insertion of the LMA, time elapsed after start of the propofol infusion until insertion of the LMA, amount of propofol infused until insertion of the LMA and target blood propofol concentration at insertion of the LMA in movers and non-movers (mean (SD)). No significant differences between groups

	Movers ($n = 14$)	**Non-movers ($n = 32$)**
Heart rate (beat min^{-1})	77.4 (10.7)	70.9 (12.5)
Systolic arterial pressure (mm Hg)	123.7 (17.4)	134.3 (22.7)
Time elapsed (s)	258 (110)	286 (165)
Propofol infused (mg kg^{-1})	3.0 (1.2)	2.8 (0.9)
Propofol target concentration (μg ml^{-1})	6.6 (2.8)	5.9 (2.3)

Data analysis

Each variable was recorded simultaneously and averaged values for 15 s were obtained at five times: before induction of anaesthesia, 60 and 30 s before insertion of the LMA, 40 s after insertion of the LMA and 30 s before surgical incision. Values at these five times were analysed using the Kruskal–Wallis test with Dunnett's test. Averaged values in movers and non-movers at the five times were analysed using the Mann–Whitney test.

The efficacy of each variable to predict movement in response to insertion of the LMA was evaluated using prediction probability (Pk), which compares the performance of indicators with different units of measurement. The mathematical basis of Pk was described by Smith and colleagues.[20] A Pk value of 1 means that the values of the predicting variables, for example an anaesthetic depth indicator, always correctly predicts the value of the variable to be predicted, in this example, the true observed anaesthetic depth. A Pk value of 0.5 means that the values of the indicator predict no better than a 50–50 chance, as would be obtained by flipping a coin. The jacknife method was used to compute Pk values and the standard error of the estimate. A paired-data jacknife analysis[20] was used to determine if the Pk value for one indicator differed from that of another. For multiple comparisons, Bonferroni's correction to the paired-data jacknife analysis was used. The prediction probability was calculated using a custom spreadsheet macro, PKMACRO.[20] Probability values <0.05 were considered significant.

When a variable had a Pk value significantly larger than 0.5, the relationships between movement in response to LMA insertion and the variables were defined using logistic regression (SPSS, Chicago, USA). The values for predicting movement in 50% or 5% of patients at LMA insertion were calculated directly from the best-fitting logistic curve.

Results

Table 1 shows the differences between movers and non-movers in heart rate, systolic arterial pressure at 30 s before

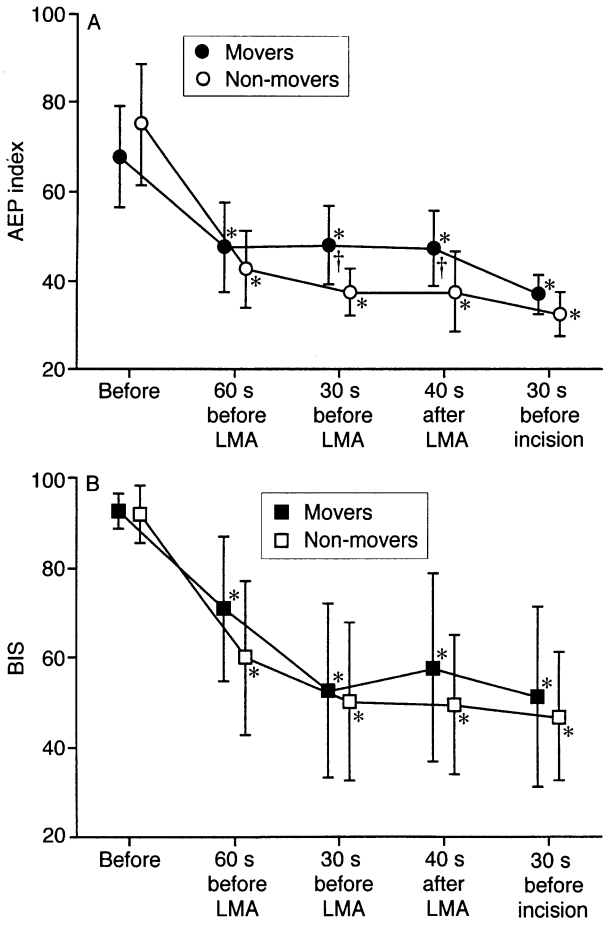

Fig 1 A: Auditory evoked potential (AEP) index at five times: before induction of anaesthesia (Before), 60 s and 30 s before insertion of the LMA (60 s and 30 s before LMA, respectively), 40 s after insertion of the LMA (40 s after LMA) and 30 s before incision, in movers (n=14) and non-movers (n=32) (mean (SD)). *P<0.05 compared with values before anaesthesia; †P<0.05 compared with non-movers. B: Bispectral index (BIS) at the same five times in movers (n=14) and non-movers (n=32) (mean (SD)). *P<0. 05 compared with values before anaesthesia.

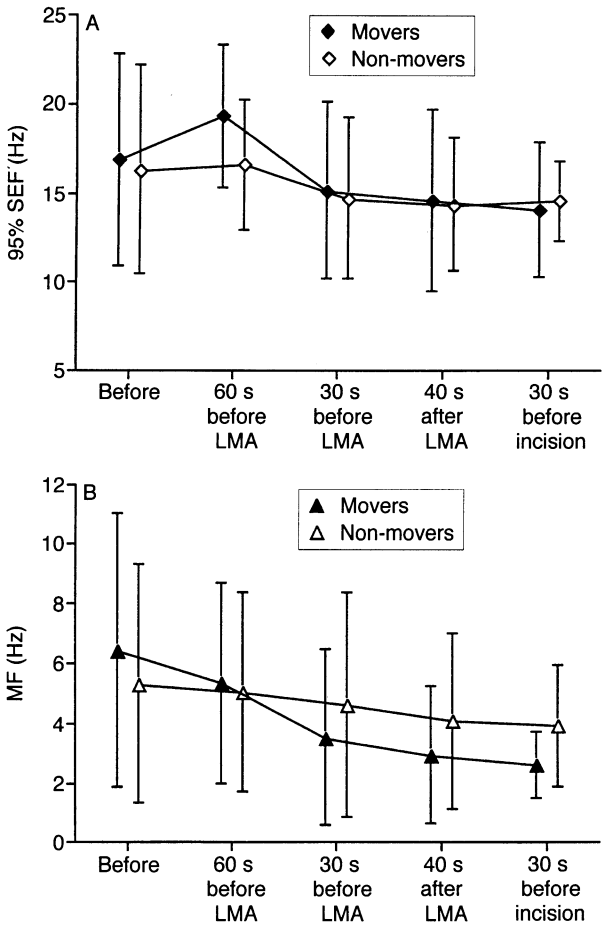

Fig 2 A: 95% spectral edge frequency (SEF) at five times: before induction of anaesthesia (Before), 60 s and 30 s before insertion of the LMA (60 s and 30 s before LMA, respectively), 40 s after insertion of the LMA (40 s after LMA) and 30 s before incision, in movers (n=14) and non-movers (n=32) (mean (SD)). B: Median frequency (MF) at the same five times in movers (n=14) and non-movers (n=32) (mean (SD)).

insertion of the LMA, time elapsed after the start of infusion of propofol until insertion of the LMA, amount of propofol infused until insertion of the LMA and the target blood concentration of propofol at LMA insertion. There were no differences between groups for any of these variables.

Induction of anaesthesia decreased values for AEP index and BIS (Fig. 1). Although those before and after insertion of the LMA were significantly smaller than those before anaesthesia, there was no difference between the values before and after LMA insertion. Non-movers had significantly smaller AEP index values at 30 s before and 40 s after insertion of the LMA than movers. However, there was no difference in BIS between movers and non-movers at any time.

SEF and MF values did not differ between the three periods or between movers and non-movers (Fig. 2).

Pk values of the four variables at 30 s before insertion of the LMA are shown in Table 2. The Pk value for AEP index, which indicates the probability of correctly predicting if a patient will move in response to LMA insertion, was significantly higher than 0.5. However, Pk values for BIS, 95% SEF and MF were not significantly different from 0.5. The Pk value for AEP index differed significantly from those for BIS, 95% SEF and MF. Because only AEP index was shown to be a reliable indicator for predicting movement, the AEP index value predicting movement in 50% or 5% of patients was determined to be 45.4 or 33.1.

Table 2 Prediction probability (Pk) values of the four electroencephalographic variables (auditory evoked potential (AEP) index, bispectral index (BIS), 95% spectral edge frequency (SEF) and median frequency (MF)) at 30 s before insertion of the LMA (mean (SEM)). *P<0.05 indicates Pk value was significantly larger than 0.5; †P<0.05 indicates the Pk value was significantly different from that of AEP index

	Pk
AEP index	0.872 (0.073)*
BIS	0.547 (0.102)†
SEF	0.549 (0.103)†
MF	0.587 (0.094)†

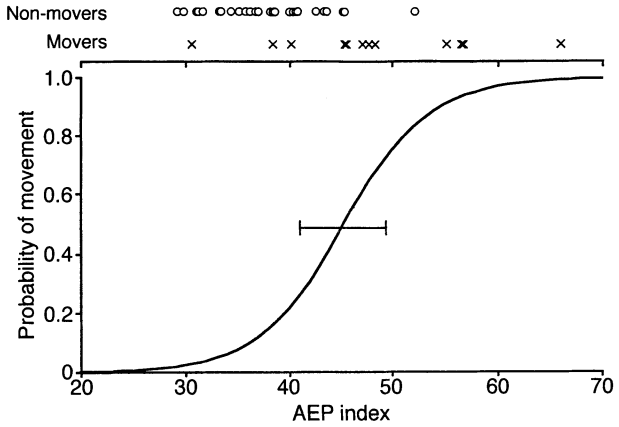

Fig 3 Probability of movement in response to insertion of the LMA as a function of auditory evoked potential (AEP) index at 30 s before LMA insertion. In the upper part of the figure, individual observations are presented. The lower part shows the relationship between AEP index and probability of movement (with 95% confidence limits for the probability of 50%).

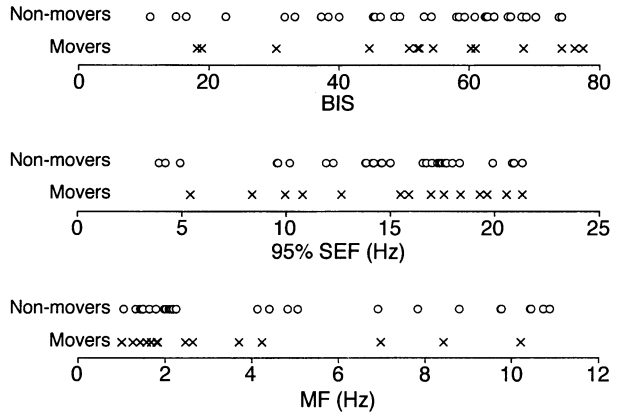

Fig 4 Bispectral index (BIS), 95% spectral edge frequency (SEF) and median frequency (MF) at 30 s before insertion of the LMA. Each symbol represents one patient. None of the BIS, 95% SEF or MF values predicted movement in response to LMA insertion.

Figure 3 shows the relationship between AEP index and the probability that movement at LMA insertion will occur. It was not possible to relate BIS, 95% SEF or MF and the probability of movement using logistic regression analysis (Fig. 4).

Discussion

We have shown that the AEP index predicted movement on LMA insertion. Although Schwender and colleagues[21] and Thornton and colleagues[22] reported that surgical stimuli increased the amplitude of midlatency auditory evoked potentials, no study has evaluated the ability of AEP to predict movement in response to any stimulus. Thus our study is the first report of AEP as a predictor of movement. Our results suggested that, during propofol and alfentanil anaesthesia, an AEP index of less than 33 indicates that the level of anaesthesia is deep enough for the probability of movement in response to LMA insertion to be less than 5%.

Although previous studies[5–8] reported that BIS could predict movement in response to skin incision, we did not find any difference in BIS values between movers and non-movers. Our finding is consistent with that of Katoh, Suzuki and Ikeda[10] who showed that BIS was an accurate indicator of sedation but could not predict movement after skin incision during sevoflurane anaesthesia.

In a previous study, we reported that BIS was related closely to the target blood concentration of propofol.[17] In the present study, target blood concentrations achieved in both non-movers and movers were similar. BIS is related mainly to the hypnotic component of anaesthesia[9 10] and so may not be expected to differentiate movers from non-movers when hypnotic concentrations are similar. In contrast, our previous study showed that AEP index provided a clearer indication of the level of arousal of the patient compared with BIS, SEF or MF. AEP index was related less to the target blood concentration of propofol than BIS.

With regard to SEF and MF, the results of our study were consistent with those of a previous study,[10] in which neither SEF nor MF could distinguish movers from non-movers in response to skin incision during sevoflurane anaesthesia. The present study revealed that no surface EEG derivatives (BIS, SEF and MF) could successfully predict movement in response to insertion of the LMA.

In our study, the target blood concentration of propofol was increased progressively. Although target blood concentrations could be controlled by the Diprifusor TCI system, propofol concentrations in blood and at the effective site would not be in equilibrium at the time of insertion of the LMA. The non-steady-state propofol concentrations may explain the lack of differences between movers and non-movers in target blood propofol concentrations and in the amount of propofol infused. Therefore, we could not determine the median effective dose (ED_{50}) of propofol blood concentration for preventing movement in response to LMA insertion. We merely showed that the target blood propofol concentration at LMA insertion and amount of propofol infused until LMA insertion could not predict movement on LMA insertion under the conditions of this study.

Because our study was performed under clinical conditions, loss of eyelash reflex was necessary to confirm that the patient was unconscious at LMA insertion and sufficient relaxation of the jaw was also essential to attempt LMA insertion. There were no spontaneous patient movements at the time of insertion of the LMA. The level of anaesthesia required to achieve these two criteria made the variability of depth of anaesthesia small. This small variability could be a possible reason why BIS, 95% SEF and MF values were not different between movers and non-movers.

Variables such as heart rate, systolic arterial pressure, predicted propofol blood concentration and amount of infused propofol, did not predict movement in response to

insertion of the LMA. These variables may be related to the level of anaesthesia in each subject, but large variations between patients may conceal the differences between movers and non-movers. Despite the limitations described above, our study suggested that AEP has a greater ability to predict responses to noxious stimuli compared with surface EEG derivatives. This may be because the AEP reflects not only cortical but also subcortical brain activities.

In summary, AEP index discriminated between movers and non-movers in response to insertion of the LMA, but BIS, 95% SEF, MF, heart rate, systolic arterial pressure and predicted blood propofol concentration did not.

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