British Journal of Anaesthesia **97** (**2**): 187–91 (2006)
doi:10.1093/bja/ael119 Advance Access publication May 23, 2006

BJA

Skin conductance monitoring compared with bispectral index® monitoring to assess emergence from general anaesthesia using sevoflurane and remifentanil

T. Ledowski[1] *, M. J. Paech[2], H. Storm[3], R. Jones[1] and S. A. Schug[2]

[1]Department of Anaesthesia and Pain Medicine, Royal Perth Hospital, Perth, Australia. [2]School of Medicine and Pharmacology, The University of Western Australia, Perth, Australia. [3]The Skills Training Centre, University of Oslo, Norway

**Corresponding author: Department of Anaesthesia and Pain Medicine, Royal Perth Hospital, Wellington Street Campus, Perth WA 6000, Australia. E-mail: thomas.ledowski@health.wa.gov.au*

Background. Changes in skin conductance have previously been reported to correlate well with plasma levels of stress hormones and awakening stimuli. In this study, monitoring of skin conductance during emergence from general anaesthesia was compared with the monitoring of bispectral index (BIS).

Methods. Twenty-five patients undergoing minor elective surgery were investigated. The number of fluctuations in mean skin conductance (NFSC), BIS and haemodynamic parameters were recorded simultaneously. The performance of the monitoring devices to predict and distinguish between the clinical states 'steady-state anaesthesia', 'first reaction' and 'extubation' were compared using the method of prediction probability (P_K) calculation.

Results. Both monitors showed similar performance in distinguishing between 'steady-state anaesthesia' *vs* 'first reaction' (P_K NFSC 0.89; BIS® 0.94) and 'steady-state anaesthesia' *vs* 'extubation' (P_K NFSC 0.96; BIS® 0.96). The response times of the monitors, to indicate the likelihood of 'first reaction', were not significantly different.

Conclusions. NFSC, as a parameter of skin conductance, performed similarly to BIS in patients waking after a general anaesthetic.

Br J Anaesth 2006; **97**: 187–91

Keywords: anaesthesia, emergence from; measurement techniques, skin conductance; monitoring, bispectral index

Accepted for publication: April 15, 2006

The correlation of neurophysiological arousal, increased sympathetic tone and changes in electrogalvanic properties of the skin have been described by Wallin.[1] An increased activity in subcortical (e.g. brain-stem reticular substance, hypothalamus, amygdala and sympathetic pre-ganglions) and cortical (e.g. prefrontal cortex, orbitofrontal cortex) regions of the brain[2 3] finally lead to an increased firing rate of sympathetic, post-ganglionic cholinergic neurons. The resulting increase of sweat gland filling can be measured in terms of skin conduction (SC).[4]

The correlation of SC with perioperative stress has been described more recently by Storm and colleagues.[5] The same authors demonstrated changes in the mean SC, and in the number of fluctuations within the mean SC per second (NFSC), in patients experiencing either noxious stimuli or during arousal.[6]

The sensitivity and specificity of NFSC regarding the detection of noxious stimuli has been reported to reach 86% when compared with clinical parameters,[6] but there are no reports about the performance of NFSC monitoring as a tool to indicate arousal after anaesthesia.

As it has been shown that arousal after an anaesthetic correlates with an increase of sympathetic tone measured by heart rate variability (HRV) and stress hormone plasma levels,[7] we hypothesized that NFSC may be able to detect arousal after general anaesthesia.

The aim of this study was to determine the performance of NFSC during emergence from general anaesthesia and to

compare it with the monitoring of the bispectral index (BIS) as a means of detecting arousal.

Methods

After approval by the ethics committee of Royal Perth Hospital, 25 patients undergoing minor elective surgery (minor orthopaedic procedures such as stabilization of single, peripheral fractures, and minor general surgery such as appendectomy, laparoscopic cholecystectomy or hernia repair) gave consent to participate in the trial.

None of the participants received premedication on the day of surgery. The BIS and SC monitors were connected when the patient was positioned on the operating table in a supine position.

BIS monitoring was performed using the BIS® XP A 2000™ monitor (Aspect Medical Systems, Newton, MA, USA) with BIS QUATTRO™ single use electrodes (Aspect Medical Systems, Newton, MA, USA) and a smoothing rate of 15 s. A BIS® value greater than 60 was considered an indicator of light anaesthesia.

The SC monitoring was achieved using the MEDSTORM AS 2005 monitor (Medstorm Innovations, Oslo, Norway) with three single use Ag/AgCl paediatric ECG electrodes (NEOTRODE®, ConMed Corp., Utica, NY, USA) attached to the palmar surface of the hand. The exosomatic electrodermal activity was measured in terms of conductance, which was preferred to resistance because of the parallel nature of the electric polarization and conductance in the skin.[2] The equipment used an alternating current of 88 Hz, which was high enough to reduce the requirements for low electrode polarizability, but low enough to ensure minimal influence from layers of the skin other than the stratum corneum. An applied voltage of 50 mV (highest density 2.5 μA) and a 3-electrode system (measuring, counter and reference electrodes) were used for unipolar measurement with a constant voltage applied to the stratum corneum beneath the measuring electrode. The method has been described as not being disturbed by light movements or changes of the room temperature.[8] The monitor was connected to a laptop computer via a standard serial port connection to see and process the obtained data using a software program developed by Asbjoern Fremming and Hanne Storm and modified for the purpose of the study by Asbjoern Fremming and Thomas Ledowski. The mean SC was given in microsiemens (μS) with a refreshing rate of 1 s. The software was able to define valleys and troughs to determine the amplitude of fluctuations within the mean SC and from this count NFSC. To reduce the electronic noise the minimum amplitude was set at 0.02 μS. According to the study by Storm and coworkers,[6] an increase in the mean SC of >0.1 μS from baseline and/or a NFSC of >0.1 s^{-1} in a period of 15 s might be counted as a significant change and indicates an increase in the sympathetic outflow/arousal. Based on our pilot study (T.L., unpublished observations, data on file) to look for SC changes during awakening, we opted to use only a change of the NFSC of >0.1 s^{-1} in a period of 15 s for the purpose of this trial, as our experience suggested the changes in the derivate of the mean SC were not sufficiently sensitive to indicate arousal.

Anaesthesia was induced with propofol 2 mg kg^{-1} and remifentanil 0.5 μg kg^{-1} min^{-1}. Muscle relaxation was achieved with rocuronium 0.6 mg kg^{-1} and, after full recovery, no reversal agents where given at the end of surgery. After placement of the airway device, either a tracheal tube or a laryngeal mask, anaesthesia was maintained using sevoflurane and remifentanil, as clinically appropriate. Ten minutes before the anticipated end of surgery, the remifentanil infusion was stopped and fentanyl was given in a dose considered appropriate for postoperative analgesia (dose range 0–150 μg). Sevoflurane was ceased at the end of surgery. At the time of stopping the remifentanil infusion, a stopwatch was started and blood pressure, heart rate, BIS, NFSC and a clinical score of depth of sedation, the observer alertness assessment scale (OAA/S) were recorded every 2 min and at defined time points ('first clinical reaction', 'extubation'). The times from cessation of remifentanil and sevoflurane to the first BIS value >60 and NFSC >0.1 s^{-1}, and from a BIS >60 and NFSC >0.1 s^{-1} to the time of first clinical reaction (defined as any reaction of the patient that would clinically indicate a light anaesthesia, like coughing, movement or eye opening) and extubation were recorded. The patients were extubated as soon as they were considered clinically suitable and showed a minimum OAA/S of 3 points.

Statistical analysis

The accuracy to distinguish between the anaesthetic states of 'steady state' *vs* 'first clinical reaction' and 'steady state' *vs* 'extubation' were analysed with the prediction probability (P_K). This method has originally been described by Smith and colleagues[9] and recently published to compare the performance of BIS® and NARCOTREND® monitoring by Schmidt and colleagues.[10] For the calculation of the P_K values a custom spreadsheet macro (P_KMACRO) as described by Smith and colleagues[9] was used. A second spreadsheet (P_KDMACRO) was used to compute the *t*-value for a comparison between P_K values of the different monitors.

The standard error of the estimate was computed by the jackknife method. A P_K value of 1 means a 100% correct prediction of a certain clinical state by a specific monitor, whereas a value of 0.5 represents only a 50:50 chance.

Correlation of NFSC and BIS were estimated using the Spearman rank correlation coefficient (ρ). The probability for first reaction (OAA/S>0) compared with steady-state anaesthesia was calculated for certain values of BIS and NFSC.

Results

The data of 25 patients [5 female, 20 male; mean age (range): 35 (18–65) yr; mean weight (SD): 85 (17) kg;