Anaesthesia, 2007, **62**, pages 989–993 doi:10.1111/j.1365-2044.2007.05191.x

The assessment of postoperative pain by monitoring skin conductance: results of a prospective study*

T. Ledowski,[1,2] J. Bromilow,[3] J. Wu,[3] M. J. Paech,[4] H. Storm[5] and S. A. Schug[4]

1 Specialist Anaesthetist and 3 Registrar Anaesthetist, Department of Anaesthesia and Pain Medicine, Royal Perth Hospital, Perth WA, Australia
2 Lecturer, Department of Anaesthesia and Intensive Care Medicine, University Hospital Schleswig-Holstein, Campus Kiel, Kiel, Germany
4 Professor, Pharmacology and Anaesthesiology Unit, School of Medicine and Pharmacology, The University of Western Australia, Perth, Australia
5 Associate Professor, Skills Training Centre, Rikshospitalet, University Hospital, University of Oslo, Norway

Summary

The number of fluctuations of skin conductance per second correlates with postoperative pain. The aim of this prospective study was to test the cut-off value for the number of fluctuations of skin conductance per second obtained from a previous study. Seventy-five patients were asked to quantify their level of pain on a numeric rating scale (0–10) in the recovery room. The number of fluctuations of skin conductance per second was recorded simultaneously. The number of fluctuations of skin conductance per second was different between patients with no (0.07), mild (0.16), moderate (0.28) and severe pain (0.33); $p < 0.001$. The tested cut-off value for the number of fluctuations of skin conductance per second (0.1) distinguished a numeric rating scale ≤ 3 from > 3 with 88.5% sensitivity and 67.7% specificity. The number of fluctuations of skin conductance per second may be a useful means of assessing postoperative pain.

Correspondence to: T. Ledowski
E-mail: Thomas.ledowski@health.wa.gov.au
**Presented in part at the 65th Annual Scientific Meeting of the Australian Society of Anaesthetists, Coolum, Australia, October 2006, and the German Meeting of Anaesthesiologists, Hamburg, Germany, May 2007.*
Accepted: 29 May 2007

Postoperative complications may be prevented by a suitable choice of analgesic technique [1]. Moreover, adequate pain control is a prerequisite for the use of rehabilitation programmes to accelerate recovery from surgery [1], and existing data indicate that effective pain relief may lead to an improved overall postoperative outcome [2].

Accurate assessment of postoperative pain is a key factor for successful pain management. Though various scoring systems are available for this purpose, they rely almost entirely on the co-operation of the patient. Hence these systems are bound to fail in unconscious, confused or otherwise uncooperative subjects. A more objective, subject-independent parameter for the assessment of pain is therefore highly desirable. As pain greatly modifies the surgical stress response [3], monitoring of parameters of postoperative stress, such as sympathetic tone, could be a helpful tool for assessment of analgesia. Increased sympathetic tone leads to a higher rate of firing in sympathetic, postganglionic cholinergic neurones [4, 5]. The resulting change of sweat gland filling can be measured in terms of skin conductance. The number of fluctuations within the mean skin conductance per second has been reported to correlate well with intra-operative noxious stimuli, with a sensitivity and specificity of 86% for their detection [6].

In a pilot study [7] we confirmed correlation between the number of fluctuations of skin conductance per second and postoperative pain in the recovery room rated on a numeric rating scale (0–10). As the number of fluctuations of skin conductance per second was highly

variable between subjects, a cut-off value of 0.1 was calculated post hoc as achieving the highest sensitivity (89%) and specificity (74%) for distinguishing between patients with no or mild, or moderate and severe pain. The aim of this double-blinded trial was to test this cut-off value prospectively in a larger sample of patients.

Methods

After approval by the Research Ethics Committee and written informed consent from participants, 75 patients scheduled for minor elective general, plastic or orthopaedic surgery were included. Exclusion criteria included age < 18 or > 85 years, autonomic neuropathy, presence of a pacemaker, medication with anticholinergic drugs, use of ketamine, clonidine or a continuous infusion of vasoactive drugs, purely regional anaesthesia, and postoperative analgesia using a continuous infusion of opioid. The attending anaesthetists provided an anaesthetic technique of their choosing, with no restrictions based on the study protocol (except the use of drugs specified under the exclusion criteria). All patients were kept normothermic.

After arrival in the recovery room, and once able to communicate, patients were asked by a recovery nurse blinded to the skin conductance monitor to rate their pain on a 0–10 numeric rating scale, with 0 representing 'no pain' and 10 'the worst possible pain'. Among patients reporting a rating scale ≤ 3, this rating was repeated after 10 min. For patients with a score > 3, a bolus of 30 μg fentanyl was administered intravenously. This procedure was repeated every 3 min until a score ≤ 3 was achieved. At each pain assessment, the number of fluctuations of skin conductance per second was recorded by a second observer, as described in previous publications [4–7]. In brief, a MEDSTORM AS 2005 monitor (Medstorm Innovations, Oslo, Norway) was attached to the palmar surface of the hand using three single-use Ag/AgCl paediatric ECG electrodes (NEOTRODE®, ConMed Corp., Utica, NY, USA). The equipment used an alternating current of 88 Hz and an applied voltage of 50 mV (highest density 2.5 μA). The monitor was connected to a laptop computer via a standard serial port connection to display and process the obtained data using software developed (HS) and modified for the purpose of the study (TL) by the authors. The mean skin conductance was given in microsiemens (μS) with a refreshing rate of 15 and a sampling rate of 5 s. The software was able to define peaks and troughs within the mean skin conductance to determine the amplitude of fluctuations. Any fluctuation of amplitude > 0.02 μS was automatically counted. The number of these fluctuations within a second determined the number of fluctuations of skin conductance per second.

Systolic blood pressure and heart rate were also recorded at the same time as conductance. Data points were excluded from analysis if, at the time of skin conductance measurement, patients complained of nausea or were actively vomiting, or were shivering. Postoperative nausea and vomiting was treated with ondansetron and metoclopramide.

Patients were discharged from the recovery room after two consecutive pain scores ≤ 3, provided they also met standard discharge criteria.

Given that statistically significant data had been obtained in the pilot study [7], a total of 100 skin conductance readings might have been sufficient to evaluate the derived cut-off values prospectively. However, because our aim was to test the cut-off value in a larger population, we opted to obtain at least 150 readings per group for patients with either no or mild pain, or moderate or severe pain. We thus included three times the number of patients as in the pilot trial ($n = 25$). All data were tested for normal distribution using the Kolmogorov-Smirnov Test. Spearman's correlation coefficient (ρ) was used to describe correlation between the number of fluctuations of skin conductance per second and pain scores (NB: the calculation of ρ does not account for the variation in the number of assessments per patients and can therefore only be seen as a basic description of the obtained data). Pain scores were categorised into none (score of 0), mild (score 1–3), moderate (4–5) and severe (> 5). The accuracy of using 0.1 fluctuations in skin conductance per second as a cut-off for distinguishing between patients with no or mild (numeric rating scale ≤ 3) or moderate or severe pain (numeric rating scale > 3), was assessed by prediction probability (Pk). This method was originally described by Smith et al. [8], who also provided the custom-made EXCEL spreadsheet macro (PkMACRO). A Pk 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 of correct prediction. As well as the correlation co-efficient, Pk values are not adjusted for variance in the number of assessment per patient. A receiver operating characteristic curve was drawn to compare the area under the curve of the number of fluctuations of skin conductance per second, systolic blood pressure and heart rate to predict a numeric rating scale > 3. Mean values and standard error for skin conductance parameters at different states of pain were calculated by the use of a linear regression analysis (PROC mixed in SAS) adjusting for multiple measurements per patient.

Results

In all, 322 measurements from 73 patients (30 female, 43 male; age range 19–81 years) were included in the

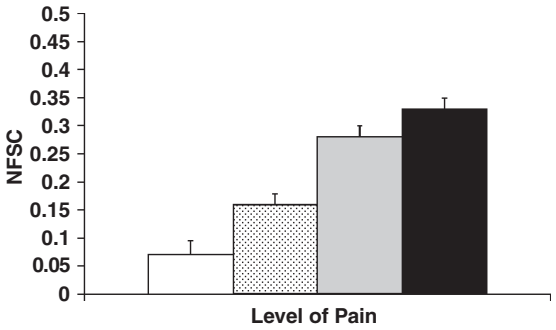

Figure 1 Mean (SE) fluctuations of skin conductance per second (NFSC) for different levels of pain as assessed by numeric rating scale and categorised: none (score 0; □) mild (score 1–3; ▨), moderate (score 4–5; ▩) and severe (score 6–10; ■). $p < 0.001$ for the difference between the groups.

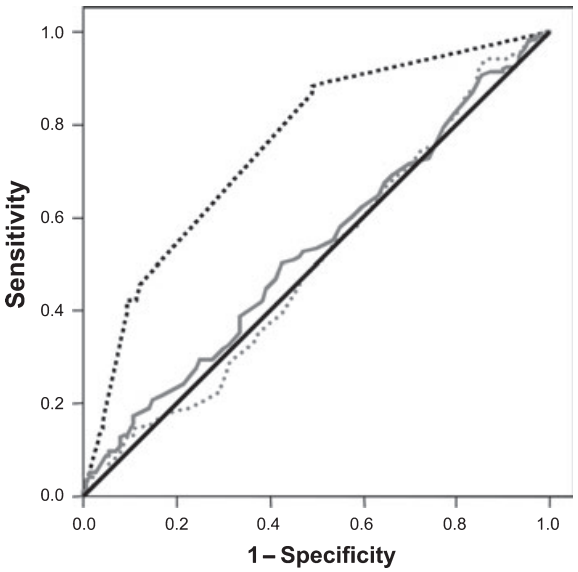

Figure 2 Receiver operating characteristic curves for the prediction of pain score > 3 by the number of fluctuations of skin conductance per second (– – –), systolic blood pressure (———), and heart rate (– – –). The bold black line shows the line of no prediction; black dotted = skin conductance; solid grey = blood pressure; grey dotted = heart rate.

calculation. Data from two patients had to be excluded because they had received intra-operative anticholinergic drugs. There were 42 orthopaedic, 16 plastic and 15 general surgical cases, with a mean (SD) duration of surgery of 87 (49) min. Patients were able to communicate effectively on average 12 (8.5) min after arrival in the recovery room. On arrival, patients were normothermic (body temperature 36.3 (0.56) °C) and no correlation was seen between body temperature and the number of fluctuations of skin conductance per second or the numeric rating scale scores. For each patient, a variable number of assessment points was obtained (median (IQR [range]) 2 (2–6 [1–16]) with a total of 53 assessments in patients with no pain, 97 in those with mild pain, 90 in those with moderate pain and 82 in those with severe pain.

The number of fluctuations of skin conductance per second correlated significantly with pain scores ($\rho = 0.477$; $p < 0.01$), whereas systolic blood pressure and heart rate did not show a correlation with the reported level of pain. When the pain scores were categorised as none, mild, moderate or severe, the corresponding values for the number of fluctuations of skin conductance per second were significantly different (Fig. 1).

The number of fluctuations of skin conductance per second was significantly lower after administration of a fentanyl bolus than before (0.2 (0.2–0.4 [0–0.8]) vs 0.2 (0.13–0.4 [0–0.8]), respectively; $p < 0.013$). Systolic blood pressure and heart rate did not change significantly after administration of fentanyl. The number of fluctuations of skin conductance per second followed the time course of pain scores for admission vs on discharge in 59 patients (81%), but did not reflect it in 14 patients (19%).

Prospectively tested, the number of fluctuations of skin conductance per second cut-off value of 0.1 (as obtained from the pilot study [7]) gave a 88.5% sensitivity and a 67.7% specificity for differentiating between patients with no or mild pain, and those with moderate or severe pain. Receiver operating characteristic curve analysis revealed a greater area under the curve for the number of fluctuations of skin conductance per second (75.5%) compared to systolic blood pressure (53.2%) and heart rate (50.5%; Fig. 2). The prediction probability calculation resulted in a Pk (SE) of 0.775 (0.025) for the cut-off of 0.1 as a means of distinguishing the investigated clinical states (pain scores ≤ 3 or > 3). If the tested cut-off value had been used to decide whether or not to treat pain, patients with pain scores > 3 (mean (SD) 5.5 (1.4)) would not have been treated on 20 of 96 occasions (21%). Patients with pain scores < 3 (mean (SD) 2.0 (1.2)) would have received a non-indicated bolus of fentanyl on 73 of 226 occasions (31%).

Discussion

Treatment of pain may reduce morbidity and mortality because pain is a major contributor to the postoperative stress response [9, 10]. The assessment of acute pain is an essential component of postoperative care [11] and leads to improved pain control [12]. However, assessment of pain is complicated by it being not only a sensory, but also

an emotional experience, and by definition pain is always subjective [13]. Therefore, evaluation of pain intensity has to rely on patients' self-assessment and a variety of scoring systems are available to permit such self-assessment of pain intensity [14–16]. However, these scoring systems have significant limitations in patients with speaking, hearing and language difficulties and cognitive impairment, and cannot assess pain intensity in small children, unconscious or delirious patients. In particular in these settings, a monitor that measures the stress caused by pain as a surrogate for pain intensity could be helpful to improve the management of postoperative pain.

In this study we demonstrated a correlation between sympathetic activity measured as the number of fluctuations of skin conductance per second and subjective pain intensity using a numeric rating scale among postoperative patients in the recovery room. Using a predetermined cut-off value for the number of fluctuations of skin conductance per second, the parameter provided high sensitivity in identifying patients with an immediate need for analgesia (on the basis of a numeric rating scale pain score >3). The high sensitivity of the number of fluctuations of skin conductance per second in detecting pain has previously been reported for intra- (86%) and postoperative (89%) painful stimuli [6, 7]. Though retrospectively supported by our results, these calculations were made posthoc and on a very limited number of subjects. Our study is thus the first to report prospective data regarding the use of cut-off values of the number of fluctuations of skin conductance per second to assess pain.

It is important to note that the number of fluctuations of skin conductance per second is more useful for peri-operative assessment of stress and pain than the mean value of skin conductance because the latter is highly variable and influenced by the type and placement of electrodes used. Mean skin conductance does therefore not allow a meaningful interindividual comparison [7, 17]. Our current data, as well as the data from the pilot study [7], suggest that even when using the number of fluctuations of skin conductance per second as a parameter of skin conductance, the absolute values may be too variable to allow a detailed differentiation of pain (e.g. into categories such as no, mild, moderate or severe pain). Therefore, the identification of appropriate cut-off values, as tested in this trial, appears more promising. Nevertheless, using parameters of skin conductance for the monitoring of postoperative pain may have limitations. Drugs, such as anticholinergic drugs or α_2-agonists, which have effects on the autonomic nervous system, potentially affect skin conductance measurement. As an example, it has been suggested that propofol infusion during a total intravenous anaesthetic may result in impaired monitoring of skin conductance [18]. Most recent pilot data, however, suggest that the influence of anticholinergic drugs, at least, on skin conductance readings may be not significant, with no differences in the skin conductance response to noxious stimuli found between intra-operative patients with and without atropine medication (Roeggen II, Storm H, Raeder J. Will detection of sympathetic activation with sweating and altered skin conductance from noxious stimulation be attenuated by atropine? A pilot study of the Pain-detector device. Abstract. International Society for Anaesthetic Pharmacology, Chicago, USA; 2006: Poster 31).

Not only pharmacological, but also physiological effects have to be considered here. Although pain, being an emotional experience, results in stress and thereby an increase in sympathetic tone, other emotional states such as anxiety or confusion may also alter sympathetic tone, and are likely also to affect skin conductance [7]. As such stressors might not always require analgesics as a treatment, they may confound the use of skin conductance readings as a measure of the need for analgesia. Despite these considerations, in this study, as well as in the published pilot data [7], the cut-off values for the number of fluctuations of skin conductance per second distinguished between patients with no/mild or moderate/severe pain with high sensitivity.

Acknowledgements

This study was funded by the research fund of the Department of Anaesthesia and Pain Medicine, Royal Perth Hospital, Perth, Australia. We would like to thank Mr Richard Parsons PhD, biostatistician, Perth, Australia, for his help with the statistical analysis of the data.

HS is co-owner of MedStorm Innovations, the company that invented the prototype device used in this study for monitoring of skin conductance. The company may in the future produce commercial devices to measure skin conductance. Neither HS nor any other member of MedStorm had any access to raw data obtained in this investigation or was involved in statistical analysis and writing of the submitted paper. SAS, MJP and TL may theoretically benefit from a contract of co-operation between MedStorm and the University of Western Australia (UWA), the latter receiving payments in exchange for advice regarding the construction of a final commercial version of a skin conductance monitor. Any such payments are not bound to any specific research, nor are they subject to any specific publication or non-publication of data. MedStorm has no right of veto regarding any publications and will not have permission to view, analyse or modify raw data or results of related trials.

References

1 Bonnet F, Marret E. Influence of anaesthetic and analgesic techniques on outcome after surgery. *British Journal of Anaesthesia* 2005; **95**: 52–8.

2 Rosenberg J, Kehlet H. Does effective postoperative pain management influence surgical morbidity? *European Surgical Research* 1999; **31**: 133–7.

3 Kehlet H, Dahl JB. Postoperative pain. *World Journal of Surgery* 1993; **17**: 215–9.

4 Wallin BG. Sympathetic nerve activity underlying electrodermal and cardiovascular reactions in man. *Psychophysiology* 1981; **18**: 470–6.

5 Storm H. Skin conductance and the stress response from heel stick in preterm infants. *Archives of Disease in Childhood* 2000; **83**: 143–7.

6 Storm H, Shafiei M, Myre K, Raeder J. Palmar skin conductance compared to a developed stress score and to noxious and awakening stimuli on patients in anaesthesia. *Acta Anaesthesiologica Scandinavica* 2005; **49**: 798–803.

7 Ledowski T, Bromilow J, Paech MJ, Storm H, Hacking R, Schug SA. Monitoring of skin conductance to assess postoperative pain intensity. *British Journal of Anaesthesia* 2006; **97**: 862–5.

8 Smith WD, Dutton RC, Smith NT. Measuring the performance of anaesthetic depth indicators. *Anesthesiology* 1996; **84**: 38–51.

9 Kehlet H. Surgical stress: the role of pain and analgesia. *British Journal of Anaesthesia* 1989; **63**: 189–95.

10 Vaurio LE, Sands LP, Wang Y, Mullen EA, Leung JM. Postoperative delirium: the importance of pain and pain management. *Anesthesia and Analgesia* 2006; **102**: 1267–73.

11 Lynch M. Pain: the fifth vital sign. Comprehensive assessment leads to proper treatment. *Advance for Nurse Practitioners* 2001; **9**: 28–36.

12 Gould TH, Crosby DL, Harmer M, et al. Policy for controlling pain after surgery: effect of sequential changes in management. *British Medical Journal* 1992; **305**: 1187–93.

13 Merskey H, Bogduk N. *Classification of Chronic Pain*, 2nd edn. Seattle: IASP Press, 1994.

14 Bosenberg A, Thomas J, Lopez T, Kokinsky E, Larsson LE. Validation of a six graded faces scale for evaluation of postoperative pain in children. *Paediatric Anaesthesia* 2003; **13**: 708–13.

15 Rodriguez CS, McMillan S, Yarandi H. Pain measurement in older adults with head and neck cancer and communication impairments. *Cancer Nursing* 2004; **27**: 425–33.

16 Guignard B. Monitoring analgesia. *Best Practice and Research, Clinical Anaesthesiology* 2006; **20**: 161–80.

17 Harrison D, Boyce S, Loughnan P, Dargaville P, Storm H, Johnston L. Skin conductance as a measure of pain and stress in hospitalized infants. *Early Human Development* 2006; **82**: 603–8.

18 Ledowski T, Paech MJ, Bromilow J, Hacking R, Storm H. Skin conductance monitoring compared with Bispectral Index® monitoring to assess emergence from total intravenous anaesthesia using propofol and remifentanil. *British Journal of Anaesthesia* 2006; **97**: 817–21.