Skin Conductance Fluctuations Correlate Poorly with Postoperative Self-report Pain Measures in School-aged Children


ABSTRACT

Background: The number of fluctuations of skin conductance per second (NFSC) has been shown to correlate with induced pain and self-report pain scales. This study aimed to evaluate the validity and feasibility of NFSC as an objective measurement of nociception intensity in school-aged children after surgery.

Methods: After approval by the research ethics board and obtaining consent, 100 subjects participated in this prospective observational study. Preoperatively, NFSC was measured for 60 s at rest and during response to a self-report pain scale (numeric rating scale [NRS], Faces Pain Scale-Revised) and anxiety scoring (NRS). Postoperative measurements were repeated every 10 min for 30 min or until NRS pain score was ≤ 4 for two consecutive scores. Spearman rank correlation coefficients were calculated to investigate the relationship between NFSC and NRS pain, Faces Pain Scale-Revised, and NRS anxiety. The clinical utility of using NFSC in determining NRS pain threshold was investigated using receiver operator characteristics analysis. For clinical relevance, a cutoff NFSC was chosen that optimizes both specificity and sensitivity. Although selecting a low cutoff value increases the sensitivity of the NFSC in diagnosing pain, it does so at the expense of specificity.

Results: Data from 90 subjects (64.4% male) aged 7–17 yr (median age 13 yr) were analyzed (217 postoperative datasets). NFSC correlated weakly with NRS pain scores (P = 0.21; P < 0.002). NFSC did not correlate with NRS anxiety scores (P = 0.15, P < 0.03). NRS pain scores correlated strongly with Faces Pain Scale-Revised (P = 0.89, P < 0.0001) and weakly with NRS anxiety scores (P = 0.34, P < 0.0001). A threshold of 0.23 NFSC predicted severe pain (NRS ≥ 7) with 56.3% sensitivity (95% CI = 37.7–73.6%) and 78.4% specificity (95% CI = 71.7–84.1%). The area under receiver operator characteristic curve for NFSC was 69.1%.

Conclusions: NFSC measurement is feasible in a perioperative setting but was not specific for postoperative pain intensity and was unable to identify analgesia requirements when compared with self-report measures.

What We Already Know about This Topic

❖ The number of fluctuations of skin conductance (NFSC) correlates with pain self-report in children in some settings, but its utility in school-age children after surgery is unclear

What This Article Tells Us That Is New

❖ In 90 children, aged 7–17 yr, undergoing surgery, application of the NFSC in the acute postoperative period was feasible but was not specific to postoperative pain intensity

The difficulties of using self-report measures of pain in verbal children can be significant, because the measures must be age and developmentally appropriate, validated, and sensitive to a child’s conceptual and language skills.1–3 The abil-

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ity to objectively measure nociceptive intensity with an algometric device would be an important advance.

An innovative proprietary skin conductance monitor, the Med-Storm monitor (Med-Storm Innovation AS, Oslo, Norway), has been used to obtain skin conductance data sets in a variety of clinical settings (see figure, Supplemental Digital Content 1, which shows the palmar Med-Storm electrode placement, http://links.lww.com/ALN/A591). This method and the computer analysis used to generate the number of fluctuations of skin conductance per second (NFSC) have previously been described in detail (see figure, Supplemental Digital Content 2, which shows an example of the Med-Storm recording trace, http://links.lww.com/ALN/A592). The device has been used clinically to measure pain in neonates, infants, and children in critical care settings.5–9

NFCS may be a promising method of determining postoperative nociceptive intensity.10,11 NFSC correlated well with self-report postoperative pain measures (0–10 numerical rating scale [NRS]) and was more useful than increases in heart rate or blood pressure in adults. In this study of 25 subjects and 110 data sets, a post hoc NFCS rate of 0.1 predicted an NRS greater than 3 with a sensitivity of 89% and specificity of 74%, and it was responsive to algicinal intervention.10

The purpose of this study was to evaluate the utility and accuracy of this device for the objective measurement of postoperative pain intensity in school-aged children when compared with self-report pain scales and anxiety scales. In addition, the determination of an optimum sampling window was studied.

Materials and Methods

Study Design and Patients

This was a prospective observational study in a tertiary care pediatric hospital and was approved by the Children’s and Women’s Hospital and University of British Columbia’s Research Review Committee and Research Ethics Board (Vancouver, British Columbia, Canada).

After obtaining consent from the parents and assent from the subjects, we enrolled 100 healthy children aged between 7 and 17 yr. Subjects were considered eligible if they were American Society of Anesthesiologists physical status I or II and if they could understand and perform self-report assessment of pain and anxiety as determined by preoperative assessment.

Before each operation, the Med-Storm Stress Detector was used to measure baseline NFSC for 60 s before administration of the pain and anxiety scales while the subject was resting quietly. NFSC was then measured for an additional 60 s during pain and anxiety scoring. Palmar skin temperature was measured using a temperature probe. State anxiety was measured using an NRS with a technique previously validated in children.12 A script was followed to ensure consistency of the pain and anxiety intensity tools. Two self-report pain scales, the NRS, and the Faces Pain Scale - Revised (FPS-R) were used to determine an optimum sampling window was studied.

Preoperatively, the administration of analgesic medications was according to current institutional practice. The number and type of analgesic interventions were recorded. Anxiety was measured using the NRS once the patient was awake.

Vital signs were measured on arrival in the postanesthesia care unit (PACU) and then at 10-min intervals until the subject’s pain score was less than or equal to 4. The PACU nurse evaluated the recovery using the standard PACU five-category arousal score.

The NRS and FPS-R pain scales were used to measure pain intensity on the subject’s arrival in the recovery room and then every 10 min thereafter until two consecutive pain scores were less than or equal to 4 to a maximum of 20 min. The scales were presented in a consistent order of NRS anxiety, FPS-R, and NRS pain. Analgesia was administered if NRS was more than 4, or at the attending nurse’s discretion. NFSC was measured continuously for 60 s, marking 15-s and 30-s intervals with the Med-Storm Stress Detector during each pain and anxiety scoring. Palmar skin temperature was measured. A single researcher (E.C.) collected all data and administered the pain and anxiety scales.

When self-report measures were not possible because of lack of subject cooperation or understanding of the scales postoperatively, data were collected but excluded from comparative analysis.

Statistical Analysis

The power analysis was based on a PACU audit of 171 consecutive patients in 2007.16 This audit described a pain prevalence of more than 4 in 17% of the population. A sample size of 100 subjects was estimated to provide a power of 80% to detect any correlation greater than 0.30.

Agreement among 15-, 30-, and 60-s sampling intervals was assessed by plotting of the mean difference between two sampling intervals against their mean as described by Bland and Altman.17 Spearman rank correlation coefficients were calculated to investigate the relationship between NFSC and NRS pain, FPS-R, and NRS anxiety (all postoperative samples were included). The clinical utility of using NFSC in determining NRS pain threshold was investigated using receiver operator characteristic (ROC) analysis. Optimized threshold values were calculated based on equal sample allocation ratio. Statistical calculations were performed using the computerized statistical program StatsDirect (StatsDirect Ltd., Cheshire, United Kingdom).
Results

Subject Characteristics

One hundred subjects scheduled for day surgery were recruited. Ten subjects were excluded from the analysis. Five received anticholinergic medication, three (aged 7, 11, and 13 yr) were unable to cooperate with pain and anxiety scoring postoperatively, and two were excluded because of Med-Storm software errors. The remaining 90 subjects had a median age of 13 yr (range 7–17). There were 58 (64.4%) boys and 32 (35.6%) girls. The procedures included 28 orthopedic, 19 urology, 12 otolaryngology, 7 plastic, 11 general, and 13 other surgeries. The mean duration of anesthesia was 71.6 min (SD = 86.9). Data from all 90 subjects (217 postoperative data sets) were included for analysis. Alternate analysis including only one dataset per subject yielded similar results.

The postoperative palmar skin temperatures were variable (range, 29–33°C) but did not preclude monitoring. Postoperative parental presence was variable based on the sedation score of the child such that most initial scores were done without parental presence and subsequent scores in the presence of the caregiver.

Distribution of Pain Intensity and Reliability of Pain Scoring

The initial postoperative pain scores (NRS) of the 90 subjects were 24 (27%) none, 36 (40%) mild (less than 4), 19 (21%) moderate (greater than or equal to 4 to less than 7), and 11 (12%) severe (greater than or equal to 7) pain. On the basis of the initial postoperative anxiety scores, 36 had none, 27 had mild (less than 4), 21 had moderate (greater than or equal to 4 to less than 7), and 6 had severe anxiety (greater than or equal to 7). Pain and anxiety scores and NFSC paired sets were obtained 217 times postoperatively. The overall pain intensity (NRS) scores were none in 49 (23%), mild in 89 (41%), moderate in 47 (21.5%), and severe in 32 (14.5%) patients. There was a strong correlation between the FPS-R and the NRS for postoperative pain intensity ($P = 0.89, P < 0.0001$).

Sampling Interval Analysis

The upper and lower limits of agreement between 60- and 30-s sampling intervals were $0.075$ and $0.080$ NFSC, respectively (fig. 1). When repeated to compare 60- and 15-s sampling intervals, the limits of agreement were found to be $0.16$ and $0.20$ NFSC, respectively (fig. 2). On the basis of the sampling interval analysis presented above, a 60-s sampling period was used to generate the values for NFSC.

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correlate with postoperative NRS anxiety scores ($P = 0.15$, $P < 0.03$). The values of NFSC were not different when pain was categorized as none, mild (less than 4), moderate (greater than or equal to 4 to less than 7), or severe (greater than or equal to 7; fig. 4).

**Responsiveness of NFSC to Intravenous Analgesia**

Intravenous analgesic rescue was given to 23 subjects. Nineteen of these subjects with NRS greater than 4 and four with FPS-R or NRS less than or equal to 4 received intravenous analgesia as a result of nursing decision. A
reduction in NFSC was shown in the 23 subjects who
received intravenous analgesia (see figure, Supplemen-
tal Digital Content 3, which shows the ROC for moderate
pain [NRS greater than or equal to 4] receiving intra-
The pretreatment NFSC was 0.22 (0.23; median [inter-
quartile range]) compared with the posttreatment NFSC
at 10 min of 0.15 (0.19) and the lowest posttreatment
NFSC of 0.08 (0.19).

ROC Analyses
An ideal diagnostic test would be both 100% specific and
100% sensitive for the desired outcome. Cutoff points can be
lowered to increase the sensitivity of the test at the expense of
specificity. There is limited utility in a test that is highly
sensitive but nonspecific. For clinical relevance, we have
chosen to report a cutoff value that optimizes both sensitivity
and specificity. This corresponds to the point closest to the
upper-left corner of the ROC plot. The area under the curve
(AUC) of a ROC curve also provides insight into the perfor-
mance of a test. An AUC of 1.0 is both 100% specific and
100% sensitive. An AUC of 0.5 is statistically equivalent to a
coin toss. An AUC of 0.75 is generally accepted as a clinically
relevant test.

The NFSC cutoff point of 0.2 (based on equal weighting
of sensitivity and specificity) was able to predict subjects with
moderate pain (NFSC greater than or equal to 4) with 51.9%
sensitivity (95% CI = 40.4–63.3%) and 71.0% specificity
(95% CI = 62.7–78.4%). The AUC of ROC curve for
NFSC was 62.3%. This is shown compared with AUC for
heart rate, resting rate, and systolic blood pressure (fig. 5).

The cutoff point of 0.23 NFSC was able to predict sub-
jects with severe pain (NFSC greater than or equal to 7) with
56.3% sensitivity (95% CI = 37.7–73.6%), and 78.4%
specificity (95% CI = 71.7–84.1%). The AUC of ROC
curve for NFSC was 69.1%. This is shown compared with
AUC for heart rate, resting rate, and systolic blood pressure
(fig. 6).

Discussion
The use of the Med-Storm Stress Detector is feasible in
both the preoperative and postoperative assessment of
cognitively normal school-aged children. Successful appli-
cation, functioning, retention of electrode placement, and
the use of Med-Storm Stress Detector software for 60-s
sampling intervals were possible in a PACU environment
in 98% of subjects. The self-report pain intensity scales
had a poor correlation with mean NFSC. In severe pain
(NRS greater than or equal to 7), there was a low sensitiv-
ity but high specificity.
Feasibility

The Med-Storm Stress Detector was sensitive to any type of electrode movement. An increase in NFSC secondary to movement added artifacts that pose a challenge similar to collecting electrophysiologic data such as electrocardiogram and electroencephalographic data. Increased movement is not specific to pain intensity, and many patients with severe pain have diminished spontaneous movement. In addition, anxious or sensory neurologically impaired subjects may also move excessively.

Sampling Interval Analysis and Cutoff Threshold

The ideal duration of the NFSC sampling window has not been previously specified. Previous investigators have evaluated intervals from 5 to 60 s. A window that is too long (more than 60 s) may decrease the clinical utility by increasing the time required to record a measurement. A short (5–7.5 s) interval may miss important fluctuations and increase the risk of contamination by noise, especially if the NFSC is lower. The ideal sampling window should be significantly greater than the time between fluctuations. On the basis of these results, an NFSC sampling window of 60 s was selected. The sampling interval is then larger than the lowest frequency of interest. A sampling window greater than 60 s may improve the results but may be technically more difficult to achieve.

The diagnostic performance is affected by the threshold chosen for classifying subjects with significant pain. A threshold (0.20) that would produce the optimum tradeoff between sensitivity and specificity was identified. Selecting a low-threshold value may result in potentially random fluctuations being interpreted as being clinically important. Although this increases the sensitivity of the NFSC in diagnosing pain, it does so at the expense of specificity. Clinically, this could result in the over-diagnosis of pain, inappropriate analgesic administration, and increased risk of adverse medication effects.

Pain Intensity Measurement

This study has shown that surrogate indicators of pain such as heart rate and blood pressure that are used in composite observation pain scales were neither specific nor sensitive for mild to moderate pain in the PACU setting. Neither NFSC nor traditional physiologic parameters such as heart rate or respiratory rate were sensitive or specific indicators of moderate pain. In severe pain, heart rate was even less predictive than that of moderate pain compared with the NFSC.

Our subjects were selected on the basis of obtaining reliable pediatric subjective pain intensity scores to use as a comparison with the NFSC. The most robust and currently standard metric in this group is a self-report score. The

![Fig. 6. Receiver operator characteristic (ROC) analysis for severe pain (numeric rating scale [NRS] greater than or equal to 7) comparing median number of fluctuations of skin conductance (NFSC), mean NFSC, heart rate (HR), systolic blood pressure (SBP), and respiratory rate (RR). AUC = area under the curve.](http://anesthesiology.pubs.asahq.org/pdfaccess.ashx?url=/data/journals/jasa/931096/)
reliability of the scores was demonstrated by the concordance between the two pain scoring systems (FPS-R and NRS) used and the ability of our subjects to separate anxiety intensity from pain intensity. The study group is not representative of a population that will derive the most benefit from an objective pain intensity measurement device, such as younger children and those with sensory neurologic impairments who are unable to cooperate with self-report scales.

Few subjects (12%) experienced severe pain (greater than or equal to 7), as expected in a tertiary care PACU setting. It would be unethical to alter the study design to generate a higher number of subjects experiencing severe pain.

**Predictive Potential**

The optimum NFSC threshold for moderate pain, balancing sensitivity and specificity, as determined by ROC analysis, was higher in children than that reported in adults (0.2 vs. 0.1). Previous studies on adults have suggested that a post hoc threshold value for NFSC of 0.1 at a sampling interval of 15 s was able to discriminate pain scores more than 3. Statistical analysis revealed this cutoff to have a sensitivity of 89% and a specificity of 74%. A second study tested this cutoff value in a larger sample of 75 adults. The threshold value was determined to distinguish between patients reporting pain ratings of less than or equal to 3 and those of greater than or equal to 4 (a level indicating the need for further analgesia) with 88.5% sensitivity and 67.7% specificity. These previous studies were performed in adults, and the pain categories were lower. A study published after the completion of this study showed that in children aged 8–16 yr, an NFSC cutoff of 0.13 predicted the prevalence of moderate to severe pain with 85.2% specificity and 67.1% sensitivity. Hullet et al. chose a lower endpoint that optimized the sensitivity of their measure; however, the AUC of ROC curve remains similar (although not reported). The authors suggested that the poor positive-predictive value of using NFSC as a measurement could be due to the nonspecific nature of the sympathetic skin response. They suggested that NFSC could be influenced by factors other than pain.

**Generalized Arousal Response**

The variability in postoperative NFSC could potentially be explained by a generalized arousal response. An increase in NFSC was elicited when the subject responded to baseline pain and anxiety scoring (see figure, Supplemental Digital Content 4, which shows a box-and-whiskers plot of median NFSC preoperatively before and during preoperative testing, http://links.lww.com/ALN/A594). The magnitude of this effect has been found to vary depending on the type of interaction between the subject and investigator. A similar effect has been described in infants undergoing nonpainful tactile versus painful (heelprick) stimulation. We minimized the variability in interaction with subjects by ensuring a constant investigator for all data collection. Other variables, such as the presence of the same nurse during the recovery period, continuous parental presence, and the use of a discontinuous category arousal level score, were not standardized in this investigation.

**Conclusions**

Further work is needed to more fully determine the clinical applicability of the Med-Storm device in the PACU, in other settings such as during surgery, and in more complicated populations such as cognitively impaired children.

The results of this prospective observational study show that although the measurement of NFSC using the Med-Storm Stress Detector is both feasible and practical, the device did not reliably indicate increases in pain intensity in school-aged children postoperatively. The physiological response elicited by a verbal response to a pain scale was not distinguishable from that produced by postoperative pain.

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Mariani’s Coca Plant

In 1863 a Corsican native named Angelo Mariani (1838–1914) became one of France’s most famous and wealthy chemists by concocting a “coca wine” that would be marketed worldwide as “Vin Mariani.” Hailed as a panacea by thousands of leading physicians, this cocaine-and-Bordeaux tonic was even publicly endorsed from London by Queen Victoria and from Rome by at least two Popes. One of Mariani’s many coca-inspired illustrations is this example (above, courtesy of the Wood Library-Museum), his Reproduction of a Coca Plant Presented by Mr. Mariani to the Paris Botanical Gardens. His Vin Mariani would inspire the development of America’s leading cocaine tonic, Coca Cola. (Copyright © the American Society of Anesthesiologists, Inc. This image appears in color in the Anesthesiology Reflections online collection available at www.anesthesiology.org.)

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