Surgical pleth index: prediction of postoperative pain and influence of arousal

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Abstract

Background: There are conflicting reports concerning the outcome after anaesthesia guided by the surgical pleth index (SPI; GE Healthcare, Helsinki, Finland). One potential explanation may be the lack of evidence for the selection of SPI cut-off values. The aim of this trial was to investigate the correlation between SPI, arousal, and postoperative pain and to define a cut-off value for SPI to predict moderate-to-severe pain.

Methods: After obtaining ethical approval and written informed consent, 70 patients undergoing non-emergency surgery were enrolled. Data relating to SPI, heart rate, mean arterial pressure, and state entropy were recorded every 10 s for the last 10 min of surgery (state entropy <60 at all times). Subsequently, recordings continued during the phase of arousal. After recovery room admission, pain scores (numerical rating scale 0–10) were obtained every 3 min for 15 min.

Results: Data from 65 patients were analysed. Receiver-operating characteristic curve analysis revealed an optimal intraoperative cut-off SPI value of 30 to discriminate between numerical rating scale scores 0–3 and 4–10. For this value, the negative and positive predictive values to discriminate between numerical rating scale scores 0–3 and 4–10 were 50 and 89.7%, respectively. The SPI was significantly affected by arousal, and SPI scores obtained during this phase were not predictive of postoperative pain.

Conclusions: Surgical pleth index values are predictive of postoperative pain only if obtained before patient arousal. In contrast to previous studies, a relatively low SPI, >30, appears to predict pain with a high positive predictive value and may therefore be suggested for future studies of SPI-guided anaesthesia.

Clinical trial registration: Australian New Zealand Clinical Trials Registry: ACTRN12615000804583.

Key words: anaesthesia; monitoring intraoperative; nociception; postoperative pain; pulse wave analysis

The surgical pleth index (SPI; GE Healthcare, Helsinki, Finland) is a normalized score, which is based on the photoplethysmographic analysis of the pulse wave and the heart beat interval.1 Although a gold standard for the assessment of nociception is naturally difficult to assess, intraoperative SPI scores have been reported to reflect different surgical and non-surgical stimuli and different levels of autonomous nervous system activation with some accuracy.2–4

More recently, several studies have investigated the postoperative outcome after SPI-guided anaesthesia.5–8 However, although some authors reported benefits such as a faster recovery, others found the rate of postoperative agitation and pain scores to be higher after SPI guidance.5

Problematically, SPI cut-off values used to guide anaesthesia practice in previous studies appear to have been based on very little evidence. Hence, it was the aim of this trial to investigate the

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Editor’s key points

- Interpreting intraoperative photoplethysmography to predict postoperative analgesia requirements would have clinical utility.
- Surgical pleth index was studied around the time of awakening from general anaesthesia.
- Surgical pleth index was affected by arousal at the end of general anaesthesia.
- Surgical pleth index values before this may have some predictive value for postoperative analgesia requirements.

correlation between SPI and acute postoperative pain and to ascertain the value of SPI for the prediction of moderate-to-severe pain in the recovery room. We also assessed the effect of arousal on the SPI score per se and on its accuracy for the prediction of acute postoperative pain.

Methods

The trial was approved by the institutional review board (Ethics Committee of the South Metropolitan Health Service, protocol 15/23 from July 4 2015) and registered with the Australian and New Zealand Clinical Trials Registry (ACTRN12615000804583). After obtaining written informed consent, 70 patients undergoing non-emergency surgery at either of two hospitals (Armadale Health Service or the Royal Perth Hospital) were enrolled in this prospective observational trial.

Patients aged 18–95 yr undergoing planned sevoflurane- and fentanyl-based general anaesthesia with either an endotracheal tube or a laryngeal mask airway (LMA) were included. Exclusion criteria included the incapacity to consent, age <18 yr, severe percutaneous or a laryngeal mask airway (LMA) were included. Exclusion criteria included the incapacity to consent, age <18 yr, severe peripheral or cardiac neuropathy, significant arrhythmia (i.e. atrial fibrillation or atrioventricular block more than first degree), pacemaker, treatment (infusion or bolus) with vasoactive medication during the data acquisition interval, and any intraoperative treatment with ketamine, β-receptor blockers, clonidine, β-receptor agonists, or any other drug suspected to interact with the sympathovagal balance. Patients were also excluded if they were having neuraxial anaesthesia and or required surgery with a tourniquet (unless already deflated at the start of the intraoperative data acquisition interval; see below), because the tourniquet-related pain would potentially have influenced the recorded SPI values significantly. Data acquisition was also not performed during phases of patients being either in the steep (>10°) Trendelenburg or anti-Trendelenburg position.

The study commenced after induction of anaesthesia (midazolam, propofol, and fentanyl) and at least 15 min before the anticipated end of surgery. In addition to standard anaesthesia monitoring (S5 monitor; GE Healthcare, Helsinki, Finland), SPI and state entropy (SE) were assessed. Anaesthesia was maintained with sevoflurane and fentanyl, and SE was kept between 40 and 60 during the entire procedure. Ten minutes before the end of surgery (at skin closure), SPI, SE, and heart rate were recorded (S5 collect software; GE Healthcare) every 10 s, and the mean arterial pressure was monitored in 3 min intervals. The SE was permitted to increase to >60 only after skin closure, and recordings of all values continued during the phase of arousal. After tracheal extubation or LMA removal, all patients were admitted to the recovery room. Once able to communicate, the patients were asked to quantify their level of pain on a 0- to 10-point numerical rating scale (NRS) every 3 min for 15 min. Pain treatment was guided by our standard recovery room protocol [fentanyl 20 µg each time pain NRS >3 to a maximum of 100 µg (requiring anaesthetist review)] and not at all influenced by the study. The maximal pain score from the five scores assessed during the observation interval was used for further analysis.

Statistics

The initial sample size calculation of n=60 patients was based on a minimal detectable correlation between SPI and postoperative pain of r=0.35 (assumed to be the smallest r with clinical relevance) with an α error of 5% (based on a two-tailed test) and a power of 80%. We aimed to include 70 patients to allow for an approximate 10–15% loss of patients because of technical difficulties, protocol violations, or patient withdrawal.

All data were tested for normal distribution using the Kolmogorov-Smirnov test. Categorical data were compared using the χ² or Fisher’s exact test, as appropriate. Continuous data were compared using analysis of variance. The ‘best-fit’ cut-off values for SPI, heart rate, and mean arterial pressure to predict moderate-to-severe pain in the recovery room were calculated via receiver-operating characteristics (ROC). Receiver-operating characteristics compute the sensitivity and specificity for multiple hypothetical cut-off values of a parameter (i.e. SPI). The ‘best-fit’ cut-off for each parameter was defined as the value with the highest combined sensitivity and specificity. Data are provided as the mean (SD) and 95% confidence intervals, as appropriate.

Results

Data from 65 patients (46 female and 19 male; 43 (15) yr) were analysed. Five patients were excluded because of a protocol violation or technical problems.

Forty-five patients were tracheally intubated and 20 received an LMA. The operations were performed by general (48), plastic (5), orthopaedic (2), and other (10) surgical specialties.

After tracheal extubation or LMA removal, the first NRS was assessed after an average of 6.9 (4.0) min. During the 15 min observation time, five pain ratings were obtained from each patient. The highest pain scores from each patient were rated as no pain (NRS 0; n=8), mild (NRS 1–2; n=3), moderate (NRS 4–5; n=16), or severe pain (NRS 6–10; n=27) [NRS 6, n=8; NRS 7, n=7; NRS 8, n=9; and NRS 10, n=3].

Intraoperative SPI scores were significantly higher for patients with postoperative moderate-to-severe pain (NRS 4–10) vs no or mild pain (NRS 0–3) [mean (sd); 95% CI]: 33.2 [(12.5); 29.4–37.1] vs 25.5 [(10.8); 20.6–30.4]; P=0.019. However, no significant correlation was found between SPI and the postoperative pain scores per se (NRS 0–10).

The ROC curves were investigated for the intraoperative (in last 10 min of surgery) mean values of SPI, heart rate, and mean arterial pressure to distinguish between NRS 0–3 and 4–10. The only significant tie between one of these parameters and postoperative pain states was found for SPI (area under the curve 0.711; P=0.006; Fig. 1).

From the SPI ROC, an ‘ideal’ (highest sensitivity and specificity) cut-off value of 30 was defined post hoc to distinguish between the above states of pain. Although the negative predictive value of SPI 30 was low (50%), the positive predictive value (PPV) was very high (89.7%). Figure 2 shows the distribution of pain levels in relation to the mean value for SPI.

To investigate the relationship between arousal and SPI, 1754 SE-SPI data pairs from 65 patients during the phase of arousal (from SE >60 until awakening) were analysed. The SPI increased
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Fig 1 Receiver operating characteristics for surgical pleth index (SPI), heart rate (HR), and mean arterial pressure (MAP) to distinguish between patient-rated acute postoperative pain on a numerical rating scale (0–10) of 0–3 vs 4–10.

Fig 2 Scatterplot of the mean surgical pleth index (SPI) within the last 10 min of surgery and the highest pain score within 15 min from admission to the recovery room, grouped as no pain (numeral rating scale (NRS) 0), mild (NRS 1–3), moderate (NRS 4–5), and severe pain (NRS 6–10). The dotted line shows the calculated cut-off for SPI (30) to predict moderate-to-severe postoperative pain with the highest sensitivity and specificity.

significantly with the increase of awareness (SE), with a correlation coefficient of $r=0.36$, $P=0.01$.

The mean SPI values during this phase were not useful to predict or distinguish different states of postoperative pain (ROC analysis, area under the curve for SPI=0.62; not significant).

Discussion

In our study, we found that SPI values obtained during the last 10 min of surgery were able to distinguish or predict between pain NRS 0–3 and 4–10 in the first 15 min after admission to the recovery room. In this context, ROC analysis revealed a cut-off of SPI 30 as the ‘best fit’. An SPI of 30 had a low ability (negative predictive value) to exclude postoperative pain (would have resulted in 50% of our patients to be undertreated), but a very high PPV of 89.7% (only 10.3% would have been overtreated, i.e. opioid administered in the absence of at least moderate pain). Given that during the last minutes of surgery an opioid overtreatment is highly undesirable (prolonged recovery and in-theatre stay), the high PPV found by us may be considered advantageous (low risk of overtreatment). In the context of SPI-guided pre-emptive analgesia during the end of surgery, the results of our study suggest a relatively low SPI of 30, above which opioid administration might have been beneficial to prevent moderate-to-severe postoperative pain. This level of SPI is significantly lower than the one used in previous investigations, where usually an SPI of <50 was used as a target value. When using a target value of SPI 50, Park and colleagues’ found higher pain scores and higher rates of agitation in the SPI-guided anaesthesia group of children. They concluded that SPI may not be valid in children. Based on our results, it is conceivable that in their study too high a target value for SPI was used. A lower SPI target (i.e. 30 as defined by us) might have significantly improved the results in the SPI-guided anaesthesia group. Calculated from our data, the negative predictive value and PPV of an SPI target of 50 were only 67.8 and 66.7%, respectively. In fact, reviewing the SPI-related literature to date we were unable to identify any evidence for the use of 50 (or higher) as a suitable SPI target.

The target value of 30 identified post hoc by us in the present investigation might, of course, be valid only in the conditions of sevoflurane-based anaesthesia. The ‘ideal’ SPI target might be even lower in patients anaesthetized with isoflurane, because isoflurane anaesthesia has resulted in lower intraoperative SPI values overall. Under the assumption of a blunted sympathetic response during total i.v. (TIVA) vs volatile-based anaesthesia, specific SPI cut-offs may also need to be calculated for total i.v. anaesthesia.

The high association found between SPI and postoperative pain in the present study is in contrast to a previous investigation by us identifying no or little relationship between SPI and postoperative pain in awake patients. The latter is also underlined by a study by Thee and colleagues, who reported only a moderate correlation between SPI and acute pain in 100 awake subjects. As arousal per se is a potent sympathetic stimulus, and furthermore, as acute postoperative pain may not correlate well with the level of sympathetic activation, it is of no surprise that SPI does not accurately reflect states of pain when measured in awake subjects. The present study confirms a positive correlation between SE and SPI during the phase of arousal, and no pain-predictive value of SPI obtained during this time.

The high PPV described for SPI 30 in our study has to be seen within the context of the limitations of our protocol. We deliberately excluded patients with medications or conditions likely to affect SPI. We also avoided patients in a steep Trendelenburg or anti-Trendelenburg position because this has been found to alter SPI. The SPI values obtained in everyday clinical practice may therefore be different. However, the limitation of SPI recordings to the last 10 min of surgery may make the cut-off suggested by us a bit more useful. During this time, patient position is most often neutral, vasoactive medication may be less likely, and because of the more unspecific phase of the operation (i.e. skin closure), the type of surgery may be less relevant. The cut-off of SPI 30 proposed by us is also calculated post hoc and has neither been prospectively tested nor used in an SPI-guided anaesthesia study.
We conclude that an SPI of 30 may be a useful predictor of moderate-to-severe postoperative pain when obtained during the last minutes of surgery in anaesthetized patients. The SPI increases significantly with arousal, and SPI monitored during this phase appears not to be useful for the prediction of pain.

Authors’ contributions
All authors contributed significantly to both the study and the manuscript.
Study design: T.L., J.H.
Data collection: J.B., J.H.
Data analysis: T.L., J.B.
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References

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