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RESEARCH REPORT

Using a pulse oximeter to determine clinical depth of anesthesia—investigation of the utility of the perfusion index

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What is already known

- The pulse plethysmograph contains information in addition to oximetric data that relates to vascular perfusion and tone. Manufacturer and clinician focus on the oximetric component has obscured the utility of perfusion-related pulse plethysmograph data, specifically that related to vascular tone. The perfusion index metric is related to clinical depth of anesthesia in adults.

What this article adds

- The perfusion index can track the clinical depth of anesthesia in children undergoing minor procedures.

Keywords
intraoperative monitoring; vasodilation; plethysmography; pulse oximeter; perfusion index; children

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Summary

Background: Peripheral vasodilation is a well-recognized side effect of general anesthesia, and induces changes in the amplitude of the pulse plethysmograph (PPG) waveform. This can be continuously quantitaed using the Perfusion Index (PI), a ratio of the pulsatile to nonpulsatile signal amplitude in the PPG waveform. We hypothesized that the perfusion index would rise with the induction of anesthesia in children, and fall with emergence, and performed a prospective, observational study to test this.

Aim: Our primary aim was to test whether the different clinical stages of anesthesia were associated with changes in the perfusion index, and the secondary aim was to test the correlation between the normalized perfusion index and the MAC value.

Methods: Twenty-one patients between the ages of 1 and 18 undergoing minor procedures with no anticipated painful stimuli were recruited. Patients with significant illnesses were excluded. Data collection commenced with a preinduction baseline, and data were collected continuously, with event marking, until completion of the anesthesia and removal of the pulse oximeter. Data collected included perfusion index, heart rate, and anesthetic gas concentration values. A normalized perfusion index was calculated by subtracting the initial baseline perfusion index value from all perfusion index values, allowing changes, from a standardized initial baseline value of zero, to be analyzed.

Results: During induction, the mean normalized perfusion index rose from 0.0 to 4.2, and then declined to 0.470 when the patients returned to consciousness. $P < 0.001$ using repeated measures ANOVA test. The normalized

perfusion index was correlated with MAC values ($r^2 = 0.33$, 95% CI 0.18–0.47, $P < 0.01$).
Conclusion: The perfusion index changed significantly during different stages of anesthesia. There is a significant correlation between the perfusion index, measured by pulse oximetry, and the MAC value, in pediatric patients undergoing minor procedures.

Introduction

Clinical monitoring of depth of anesthesia via physiological parameters such as heart rate, blood pressure, and respiratory rate depends on acute changes in sympathetic tone for detection of light planes of anesthesia. Most induction agents will cause a patient's sympathetic tone to decrease, leading to peripheral vasodilation. Conversely, painful surgical stimuli will increase sympathetic tone and cause vasoconstriction. The degree to which vasomotor tone changes is reliant on many factors, including drug type, dosage, route, as well as type and severity of surgical stimulus and pain. The patient's own comorbidities as well as natural physiological variance between patients also play a part.

Vasomotor tone can be partially quantified by the perfusion index (PI), a metric that is calculated from the pulse plethysmograph. The perfusion index is a ratio of the pulsatile to nonpulsatile signal obtained from the pulse plethysmograph (1), and is provided by several modern pulse oximetric systems. The plethysmograph waveform is a visual representation of the degree of pulsation of arterial vessels. Over seconds to minutes, the primary variable influencing the PI is the degree of arterial vasodilation present. In vasoconstriction, this change is minimal, but during vasodilation, it is larger. Therefore, the perfusion index will be lower during vasoconstriction, and higher during vasodilation (2).

Modern pulse oximeters focus primarily on the provision of accurate oximetric data across as wide a variety of perfusion states as possible. Initial graphic displays of the pulse plethysmograph (PPG) waveform did not autoscale (change the *y*-axis scaling automatically to provide a standard sized waveform), and thus clinicians could visually see reductions in PPG amplitude during clinical care. As the focus on oximetric data and waveform shape predominated, autoscaling was introduced, removing potentially valuable data from clinical interpretation (3). More recent systems have provided the PI as a separate numeric, initially as a signal quality metric, but one that contained information lost during the introduction of autoscaling (2).

Changes in the perfusion index during anesthesia have been previously described in adults (4,5) and in children (6), but no prospective studies in children undergoing anesthesia have been performed.

We hypothesized that the perfusion index would be correlated with the depth of anesthesia. Our primary aim was to test whether the different clinical stages of anesthesia were associated with changes in the perfusion index, and the secondary aim was to test the correlation between the normalized perfusion index and the MAC value.

Methods

A prospective study was conducted, recruiting children aged 1–18 years, ASA 1-2, undergoing minor procedures, with patient and/or parent consent. Recruitment occurred by convenience sampling based on eligibility and researcher availability. Those with significant illness and those undergoing major procedures were excluded from the study. Ethics approval was obtained from the Sydney Children's Hospital Network HREC.

Standard anesthesia monitoring was applied prior to the start of the anesthetic. The pulse oximeter was placed on a finger, kept on the same finger during the procedure, and care taken to minimize movement artifact. Anesthesia was conducted at the discretion of the treating anesthetist and no study-related alterations in clinical care occurred. No sedative premedication was used. Induction and maintenance of anesthesia was conducted using sevoflurane or propofol.

A laptop-based data capture system (ixTrend, iXellence, Germany) was used to record the time stamped perfusion index (PI), pulse oximetric oxygen saturation (SpO_2 Nellcor sensors, Philips boards), heart rate (HR), endtidal sevoflurane (ET Sevo), endtidal nitrous oxide (ET N_2O), and minimum alveolar concentration (MAC) provided by the Philips anesthesia monitor (MP 70, manufacture date 2007, Philips, North Ryde, Australia). The MAC value is

calculated by the Philips monitoring system using sevoflurane and nitrous oxide concentrations.

The following timestamps were used: baseline (initial data on pulse oximeter attachment), preinduction, airway manipulation (immediately prior to airway manipulation), start of procedure, end of procedure, cessation of anesthesia (last dose of all anesthetic agents), and emergence (when patients opened eyes, or responded to voice or touch). Two preanesthetic timestamps were recorded; baseline and preinduction. This is to show that the perfusion index is a stable metric that is largely only affected by anesthetic agents and sedation, and would not change markedly before the use of induction agents. These timestamps indicate the clinical stages of anesthesia.

All data processing, statistical analysis, and graphing were performed with Microsoft Excel (Redmond WA, USA). Perfusion Index data are presented as mean ± standard deviation. The PI is a relative metric with a variable preanesthetic baseline in each subject. Raw PI data were processed after acquisition by adjusting initial baseline values to zero for all patients, to allow consistent analysis of changes from baseline. A repeated measures ANOVA test was then applied to assess statistical significance, which was taken as $P < 0.05$.

Results

The patient's characteristics, including age, sex, baseline PI, ASA grade, anesthesia time, induction agents, and procedure are recorded in Table 1. All procedures were carried out as planned except for patient 13, where an eye examination proceeded unexpectedly to enucleation. No patients required any vasopressors, fluid boluses, or significant changes in planned anesthetic technique due to hemodynamic instability.

Figure 1 displays the raw perfusion index data of all 21 patients, with the raw PI of each patient plotted against the time stamps. As can be seen, each patient had a differing baseline perfusion index, which could be due to large number of reasons, from local probe positioning and body temperature, through to preoperative anxiety. A normalized perfusion index was thus calculated by subtracting the initial baseline perfusion index value from all perfusion index values, allowing changes, from a standardized initial baseline value of zero, to be analyzed. A repeated measures ANOVA test of normalized perfusion index over time showed significant variation ($P < 0.001$).

In Figure 2 we can see the relationships between normalized PI and MAC. The graph demonstrates the correlation between the two metrics ($r^2 = 0.33$, 95% CI

Table 1 Patient demographics and characteristics

Patient	Age	Sex	Baseline PI	ASA	Anaesthesia time (min)	Induction agent	Procedure
1	10	F	0.32	1	71	Sevoflurane	Calf biopsy
2	16	F	0.38	1	47	Sevoflurane	Sclerotherapy
3	5	M	2.6	2	33	Sevoflurane	Bone marrow biopsy
4	16	M	0.39	2	33	Sevoflurane	Bone marrow biopsy
5	17	M	0.42	2	37	Sevoflurane + propofol	Lumbar puncture
6	7	M	2.8	2	9	Sevoflurane + propofol	Lumbar puncture
7	13	M	0.67	2	14	Propofol	Lumbar puncture
8	5	M	3	1	52	Sevoflurane	Circumcision
9	9	M	0.6	1	41	Sevoflurane	Knee biopsy
10	5	M	0.34	2	30	Sevoflurane	Lumbar puncture
11	5	M	3.3	2	37	Sevoflurane + propofol	Bone marrow biopsy, lumbar puncture
12	9	F	1.4	1	119	Sevoflurane + propofol	Excision of canthus
13	11	M	0.75	1	151	Sevoflurane	Eye enucleation (planned examination only)
14	4	F	0.53	2	45	Isoflurane + propofol	Insertion of femoral vascath
15	12	F	0.31	1	27	Sevoflurane + propofol	Lip laceration repair
16	15	M	0.65	2	26	Sevoflurane	Finger biopsy
17	7	M	1.5	2	53	Sevoflurane + propofol	Line removal
18	3	F	1.2	2	23	Sevoflurane + propofol	Line removal
19	1	M	1.6	1	72	Sevoflurane + propofol	Excision biopsy
20	4	M	3.1	1	58	Sevoflurane	Circumcision
21	10	M	0.39	1	32	Sevoflurane + propofol	Excision of lesion

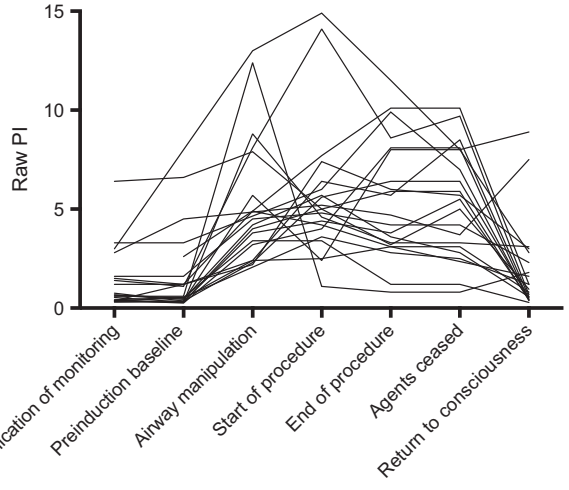

Figure 1 Raw perfusion index values in all patients, at each time point.

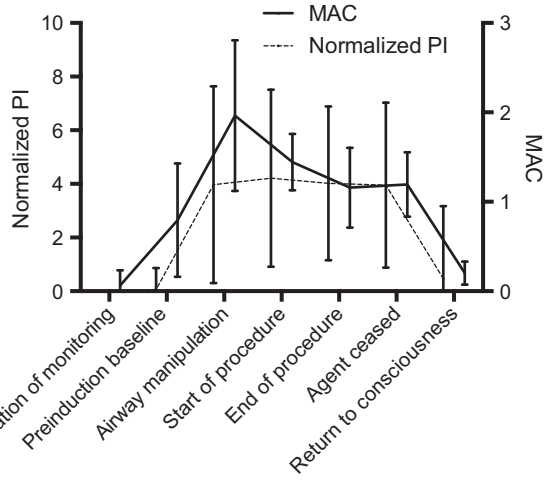

Figure 2 Change in mean normalized perfusion index values and mean MAC values over time (mean ± standard deviation).

0.18–0.47, $P < 0.01$) for the whole group across all time points. During the induction period, between 'preinduction baseline' and 'start of procedure', the correlation between normalized PI and MAC was $r^2 = 0.33$ (95% CI 0.11–0.57). During the emergence period, between 'agents ceased' and 'return to consciousness' the correlation between normalized PI and MAC was $r^2 = 0.54$ (95% CI 0.24–0.77).

Figure three demonstrates the changes in normalized PI against average heart rate during the procedures, at each time point.

Discussion

The results demonstrate that there is a statistically significant ($P < 0.001$) variation in the perfusion index over

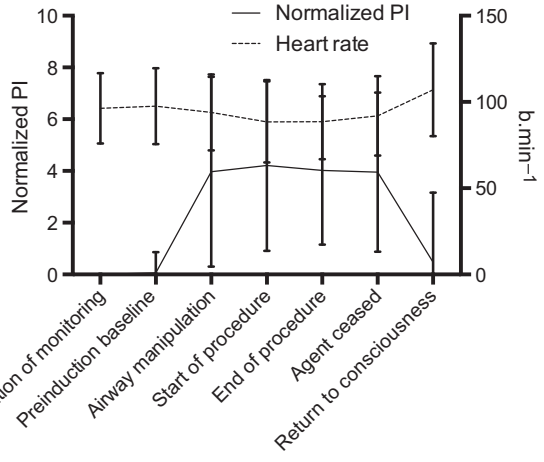

Figure 3 Change in normalized perfusion index values and heart rate over time (mean ± standard deviation).

time, on repeated measures ANOVA test. A strong correlation was found between the perfusion index and MAC ($r^2 = 0.33$, 95% CI 0.18–0.47). The perfusion index increased significantly as the anesthetic was administered, and returned to baseline after the anesthetic was ceased.

After calculating normalized PI and adjusting the baseline to 0 at application of monitoring, it can be seen that there is a slight negative dip to below 0 in mean normalized PI for the 21 patients to the preinduction baseline timestamp. This does not reflect an actual negative PI value, but rather displays the realistic trend in the average normalized PI of the 21 patients. This can be clinically explained by a number of factors. Although no drugs were administered between these two timestamps (other than perhaps oxygen), the time between the two timestamps did vary for each patient. Therefore, anxiety, fear, and stress levels (vasoconstrictors) may have increased as the time for induction and surgery neared, leading to a dip in the patients' PI.

Two recent studies have reported comparable results. Enekvist and Johansson (5) investigated the relationship between perfusion index and time till eye opening (return of consciousness) in adults. They found that the perfusion index had lowered from end of surgery, to eye opening, indicating a return to a presurgery baseline. Kowalczyk *et al* (4) found a significant correlation between the perfusion index and endtidal desflurane concentrations, similar to the results from our study. These results support the hypothesis that the perfusion index correlates with the depth of anesthesia. This is due to the perfusion index's ability to measure the distension of the peripheral vasculature. As depth of anesthesia increases, sympathetic tone decreases, leading to peripheral vasodilation. Conversely, painful stimuli can lead to

an increase in sympathetic tone, and therefore peripheral vasoconstriction. This is reflected in a drop in the perfusion index (7). This phenomenon was noticed a few times during the study, primarily during airway manipulation (a strong stimulus). Ezri *et al.* observed similar results in 1998 during routine D&C procedures in women, where dilation of the cervix resulted in a drop in perfusion index. They also noticed in some women that the perfusion index dropped near to preanesthetic levels, which was associated with symptoms of light anesthesia (movement, tachycardia, and hypertension) (8). Korhonen and Yli-Hankala's findings also support the relationship between nociception and perfusion index. They compared the nociceptive-antinociceptive (NAN) balance, and its effect on the perfusion index (9). The NAN balance is largely affected by analgesia, and less so by the hypnotic effects of induction and maintenance agents. Therefore, the type and amount of analgesia used, and the type of surgery and its perceived level of nociception would all have an effect on the perfusion index. This could have possibly confounded the results.

The type of induction agent used was left to the treating anesthetist. Because of this, both propofol and sevoflurane were used either individually or together for induction. Although this may be seen as lacking standardization, it actually helps to strengthen the significance of the results, proving that the findings reflect the GABA-ergic effects of anesthesia, rather than agent specific effects.

Our study included several limitations. 21 patients were studied, and they were all under the age of 18. Also, the patients suffered from a wide range of conditions, and were undergoing different types of surgery. Despite this, only elective patients undergoing relatively minor procedures (including CT scans, lumbar punctures, and bone marrow aspirations) were selected. Although every effort was made to exclude patients with significant comorbidities, it is hard to account for the natural variance in physiology between each individual. None of the patients was of ASA (American Society of Anesthesiologists) status 3–5, in which significantly altered sympathetic tone and reduced cardiovascular reserve may alter the changes in perfusion index seen in the ASA 1–2 patients in this study. Coregistering BIS values along with recording the PI would have been beneficial for comparison. However, BIS monitoring was not routinely used and recorded, due to the range of ages in the study population. Many of the younger awake children would not have tolerated the discomfort associated with sensor attachment. However, this is an integral part of future follow-up studies in older populations. Lastly, the MAC values measured do not include the hypnotic component of the propofol doses used during induction for 11 of the cases. This means that the initial MAC values for those patients are an underestimate of the actual anesthetic drug concentration present in the patient.

The results support the existing literature, and are the first to look at changes in the pediatric surgical population. They demonstrate the potential for the use of perfusion index in clinical practice, as an additional metric to aid in the assessment of anesthetic depth. As Ezri's teams noticed, early drops in perfusion index can be used to forecast an inadequate level of anesthesia or analgesia. Additional drugs can then be administered to avoid symptoms such as patient movement.

The use of the perfusion index as an added monitoring tool during anesthesia provides the anesthetist with a number of benefits. It is a useful tool to forewarn the clinician of possible light planes of anesthesia, allowing for agent dose adjustment. It is a preexisting technology that is already widely available and used in most urban, regional, and rural centers, in both developed and developing countries, is noninvasive, continuous, and inexpensive.

In conclusion, our results showed that there is a clear correlation between the perfusion index and onset and offset of anesthesia in children. The perfusion index increased with the administration of anesthesia, and decreased after the cessation of anesthesia

Ethics

The study was approved by the Human Research Ethics Committee of the Sydney Children's Hospital Network (LNR/13/SCHN/262)

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Conflict of interest

No authors have any conflicts of interest or disclosures with regard to this study.

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