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Review Article

Novel Perioperative Utilities of the Newer Co-Oximetery Parameters: A Practical Review

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Abstract

The radical-7 signal extraction technology (SET) Masimo pulse co-oximeter has raised the technology bar with non invasive and continuous measurement of haemoglobin, carboxy haemoglobin and methemoglobin and newer parameters like perfusion index, pleth variability index and acoustic respiratory index. These can be measured intraoperatively and in the critical care setup. We reviewed the current literature for the clinical utility of these parameters and to what extent this technology has translated into improved patient care.

Keywords: *Co oximeter; Perfusion index; Pleth variability index; Anaesthesia*

Introduction

Measure through motion and low perfusion technology, Masimo signal extraction technology (SET) utilizing a Radical-7™ finger pulse oximetry device (Masimo Corp., Irvine, CA, USA)(Figure-1) has revolutionized pulse oximetery [1-4]. Non invasive and continuous measurement of perfusion index (PI) helps assess peripheral blood flow. Non invasive, point of care haemoglobin (SpHb) aids in early recognition of intraoperative blood loss and helps avoid unnecessary blood transfusions with their attendant complications [5]. Pleth Variability Index (PVI), a measure of dynamic changes in PI during a complete respiratory cycle, aids in assessing fluid responsiveness and serves as a guide to intravascular fluid management [6-15]. Efficacy of PVI is proven to be comparable to other invasive hemodynamic monitors like central venous pressure CVP [16], stroke volume variation [17,18] (SVV), pulse pressure variation (PPV)[19] and esophageal Doppler [20] used for goal directed fluid therapy [21]. Acoustic respiratory rate helps the clinician assess breathing and avoid respiratory distress.

A thorough MEDLINE search was done for this review article with the key words: perfusion index; pleth variability index; acoustic respiratory rate; masimo SET radical-7 and spHb. All the relevant articles found in Google, Pubmed, ePUB and EBESCO were fully reviewed.

Perfusion Index

PI is a numerical value that indicates the strength of infrared rays (940 nm) returning from a specific monitored site (hand, finger, toe) and is an indirect and non invasive measure of peripheral perfusion. PI is calculated by means of pulse oximetry by expressing the pulsatile signal (during arterial inflow) as a percentage of the non pulsatile signal and ranges from 0.02% (very feeble pulse) to 20% (very strong pulse strength) [1,2]. A co oximeter sensor should ideally be placed at the site which gives the highest PI number. Changes in sympathetic nervous system tone (as after sympathectomy /subarachnoid block/epidural block) by affecting the smooth muscle tone

influence the blood vessel calibre and hence regional perfusion. Masimo SET is affected by the amount of blood at the site being monitored and not the oxygen saturation of this blood as it is the ratio of pulsatile (arterial) to non pulsatile (venous, capillary, tissue) component of blood. In low peripheral perfusion states (cold extremities, arterial spasm, shock, high dose noradrenalin infusion, patient attached to heart lung machine) where an ordinary pulse oximeter fails to pick up any signals, the co oximeter not only picks up the signals but also quantifies the amount of perfusion via the PI. While local vasoconstriction and vasodilatation affect it, PI is independent of parameters like heart rate variability, SaO2, oxygen consumption, or temperature. Trending and alarms facility for PI changes available in Masimo SET devices may reveal subtle changes in perfusion that may otherwise be overlooked in static displays [1-4].

Clinical Indications

Various novel clinical situations (excluding the extensively studied use of PVI for goal directed fluid therapy) where the role of the humble pulse oximeter can interestingly be extended are discussed below:

1. A prerequisite for radial artery cannulation to obtain invasive blood pressure and for periodic arterial blood gas sampling is the Allen's test. PI gives a fair indication of the collateral ulnar blood supply in the hand after manual radial artery occlusion. Almetwalli RR demonstrated PI as an objective alternative to the Allen Test using Doppler ultrasonography as a reference test [22]. PI diagnosed abnormal collateral hand circulation with high sensitivity (100%), specificity (98.8%) and positive predictive value (75.5%).
2. PI may be utilized to provide an idea of perfusion in the salvaged limb after limb salvage surgery for long bone osteosarcomas and other malignancies. Perfusion in reimplanted body parts such as fingers or hands may also be provided by pulse co oximetery.
3. PI may give a fair indication of perfusion in flaps utilized for reconstructive surgery. Pectoralis muscle myocutaneous flap, nasolabial flap etc used for reconstruction after radical resection of carcinomas of the retro molar trigone, buccal mucosa, tongue, maxilla and mandible, radial artery free flaps and anterolateral thigh free flaps often used to fill larger defects, fibular free flaps used to fashion resected mandibles and latissismus dorsi flap used for reconstruction after radical mastectomies all heavily depend upon adequate perfusion in the flap used for reconstructive surgery. A low flap-perfusion may herald the dreaded complication of flap necrosis.
4. PI for intraoperative identification of successful thoracic sympathectomy [23,24] was demonstrated by Klodell., et al. [25] Ginosar., *et al*. [26] evaluated 29 patients receiving 0.5% and 0.25% bupivacaine for lumbar epidural block and found that at 20 min, PI increased by 326%, MAP decreased by 10% and toe temperature increased by 3%, respectively. 15/29, 26/29 and 29/29 of the subjects met the PI sympathectomy criteria at of 100% increase at 5, 10 and 20 min, respectively, compared with 4/29, 6/29 and 18/29 for MAP and 3/29, 8/29 and 14/29 for toe temperature changes leading to the conclusion that PI is an early and sensitive indicator of epidural-induced sympathectomy onset compared to skin temperature or MAP.
5. The traditional method to evaluate adequacy of neuraxial blocks for surgery is based on loss of sensory response to stimuli, and entails patient cooperation. Testing for onset/failure of neuraxial block while the patient is under general anaesthesia has always proved to be a dilemma for the anaesthetist. PVI finds clinical application value in patients undergoing surgery under thoracic epidural block combined with general anesthesia as a noninvasive indicator to monitor volume change resulting from epidural block. Xu., *et al.* [27] observed the changes in stroke volume index (SVI), PVI, stroke volume variation (SVV), pulse pressure variation (PPV) and central venous pressure (CVP) in 26 patients undergoing elective upper abdominal operations, immediately before and 10 minutes after T8-9 thoracic epidural block given after inducing general anaesthesia. Patients with SVI change greater than 10% were placed in the response group to epidural block. They found that before epidural block, the PVI, SVV and PPV baseline values in patients of response group were significantly higher than those in patients of non-response group. PVI, SVV and PPV after epidural block were significantly higher than immediately before epidural block. They found a positive co relation between PVI (r= 0.7), SVV(r=0.71) and PPV(r=0.63) baseline values immediately before epidural block and ΔSVI. The optimal critical values for PVI, SVV and PPV to predict response to T8-9 interspace epidural block under general anesthesia were 16% (sensitivity 80%, specificity 92%), 13% (sensitivity 90%, specificity 62%) and 12% (sensitivity 90%, specificity 77%), respectively. Hence, in patients having a pre epidural- block PVI of 16% or more, at least a 10% change in stroke volume index is predicted after the regional block.

6. To evaluate the effect of caudal epidural block in paediatric patients PI is a promising non invasive tool. Whether PI may be applied to detect the onset of caudal block in pediatric patients under intravenous ketamine basal anaesthesia, was investigated by Xu., *et al*. [28] in 40 ASA I boys, aged 2-8 years, scheduled for elective circumcision surgery. The two groups (n=20) in this randomized controlled trial were: Group I: anesthetized by 2 mg•kg^{-1} ketamine intravenous injection (IV) followed by caudal block using 1 mL•kg^{-1} lidocaine (1%); Group II: anesthetized by 2 mg•kg^{-1} ketamine IV alone. PI on the toe in Group II decreased by 33 ± 12%, 71 ± 9% and 65 ± 8% at 1 min, 15 min, and 30 min after ketamine injection. Compared to the PI value before caudal lidocaine, PI in Group I increased by 363 ± 318% and 778 ± 578% at 5 min and 20 min after caudal block, while no significant changes in MAP and HR were found compared to the baseline before caudal block. Thus, they concluded that PI is an early, non invasive, objective, and more sensitive indicator of onset of caudal block under basal ketamine anaesthesia.
7. PI can also detect whether the epinephrine containing epidural test dose injection is intravascular or not as demonstrated by Mowafi., *et al*. [29] in their study on propofol-anesthetized adults.
8. Baseline PI can predict the incidence of spinal anaesthesia-induced hypotension during Caesarean delivery [30]. Hypotension during subarachnoid block for Caesarean delivery occurs firstly due to decreased vascular resistance resulting from sympathetic blockade and secondly due to decreased cardiac output resulting from blood pooling in the blocked regions (lower limbs and part of abdomen). Change in baseline peripheral vascular tone due to pregnancy may affect the degree of such hypotension and the PI has been used for assessing the changes in peripheral vascular tone in pregnant patients. As per Toyama et al, a cut-off PI value of 3.5 identifies parturients at risk for spinal anaesthesia-induced hypotension (sensitivity 81% and specificity 86%). The change of PI in parturients with baseline PI ≤ 3.5 was not significant during the observational period, while PI in parturients with baseline PI > 3.5 demonstrated marked decreases after spinal injection. Hence, a higher baseline PI was associated with profound hypotension.
9. PI may serve as a predictor for neonatal illness severity. De Felice., *et al*. [31] observed that a decreased preanaesthetic PI in patients posted for elective cesarean section is a maternal predictor of increased neonatal morbidity and is significantly associated with subclinical placental inflammatory disease. They analysed pulse oximetry-derived signals (perfusion index, pulse rate, and oximetry) SBP, DBP, differential blood pressure, maternal arterial and venous newborn cord blood gases and placental histology. Early respiratory complications (transient tachypnea of the newborn; respiratory distress syndrome) were observed in 13.6% of the newborns. A maternal PI ≤ 1.9 (lower quartile) during the preanesthesia phase was found to be an independent predictor of early adverse neonatal respiratory outcome (odds ratio 68.0) Low superior vena cava (SVC) flow is a risk factor for intraventricular hemorrhage (IVH) in the preterm infant. Takahashi., et al. [32] studied the accuracy of PI for detecting low SVC flow (cut-off value for the PI to detect low SVC flow was 0.44) in very low birth weight infants born before 32 weeks of gestation. PI is an accurate predictor of neonatal severity of illness [33].
10. PI and transcutaneous oxygen challenge test are predictive of mortality in the critical care setup, in septic patients after resuscitation [34].
11. Mizuno., *et al*. [35] observed in their study of 21 adult patients that general anaesthesia induction significantly increased PI from 2.1 ± 1.7 to 3.8 ± 2.3 and significantly decreased PVI from 22.9 ± 8.1 to 17.1 ± 7.2. They concluded that PI and PVI may be useful for monitoring changes in peripheral vasodilation and sympathetic tone during general anaesthesia [36]. Another study shows a significant correlation between the PI and the end-tidal desflurane concentration [37] ($r = 0.807$; $P = 0.001$) while no correlation was observed between propofol or remifentanil concentrations and PI. PI changes during emergence from anaesthesia can predict emergence in children as per Skowno., *et al*. [38].
12. PI is a promising non invasive tool for detection of stress response to supraglottic airway and endotracheal tube insertion during propofol, fentanyl and isoflurane anaesthesia as evaluated by Atef., *et al*. [39]. They also compared the reliability of PI with conventional hemodynamic criteria in sixty adult patients randomized to three groups- i-gel, LMA and ETT (n=20/group) Definition of stress response was an increase in heart rate(HR) ≥ 10bpm, increase in systolic/ diastolic blood pressures(SBP/DBP) to ≥ 15mmHg and decrease in PI ≤ 10% . They found that HR, SBP and DBP significantly increased in the LMA and ETT groups while PI decreased significantly by 40%(I-GEL)and 100%(LMA and ETT groups) after insertion of airway device. The sensivity was 92% for PI and 44.4% and 55.6% for SBP and DBP criteria respectively.

13. Temperature, intravascular fluid volume and end tidal volatile anaesthetic concentration result in degrees of vasodilatation and vasoconstriction which affect the PI. Painful stimulus in anaesthetized patients causes vasoconstriction resulting in a decrease in PI values. PI is an indicator of painful stimulus that is independent of anesthesia concentration and may find clinical utility in the assessment of pain in the anesthetized state. Hager., *et al*. [40] applied standard painful electrical stimulus (70Ma, 100 Hz tetanic current for 10 seconds on bilateral thigh) to volunteers under 1%,1.5%, 2% and 2.5% sevoflurane in random order. Both the heart rate and mean arterial pressure increased significantly as expected. The PI dipped from 11.07 ± 1.19 to 5.42 ± 2.39 which is statistically highly significant.
14. PI increases in the affected extremity of complex regional pain syndrome (CRPS) patients (even in the early stages), compared to other extremities, as per the results of a clinical trial by Tutoglu., et al. [41].
15. PI increases after successful interscalene nerve blockade and therefore may be used as an indicator for successful block placement in awake patients. This is applicable for brachial plexus block at the supraclavicular, infraclavicular and axillary levels too. The PVI values before and after a fluid challenge can be useful to detect changes in preload, and this can be performed in both blocked and unblocked arms. Excellent analgesia is obtained by interscalene blocks, but there are no objective criteria for early assessment of correct catheter placement. Sebastiani., *et al*. [42] used pulse oximetry technology to evaluate changes in PI and PVI in both blocked and unblocked arms in 30 orthopedic patients who received an interscalene catheter at least 25 min before induction of general anaesthesia. Data were evaluated at baseline, at zero, five, ten, and 15 min after injection of local anaesthetic and after induction of general anaesthesia; also prior to, immediately after and another five minutes after a 500 mL colloid fluid challenge. They found that in patients with successful blocks (n=25), the difference between the PI readings in the blocked and unblocked arms increased within five minutes of local anesthetic injection and progressively thereafter until 15 mins. Induction of general anaesthesia saw a rise in PI in the unblocked arm while PI remained unchanged in the blocked arm, thus reducing the bilateral difference in PI. A fluid challenge resulted in a bilateral decrease in PVI values.
16. Kus., *et al*. [43] investigated whether PI is a reliable and objective method for assessing the adequacy of infraclavicular block in patients scheduled for elective hand, wrist and forearm surgery and described the time course of PI changes once peripheral nerve block had been achieved. The pulse oximetry sensor was affixed to a finger ipsilateral to the side of the infraclavicular block for continuous measurement of PI. Baseline values of PI ranged from 0.6 to 4.7 % in 44 patients for whom infraclavicular block was effective and 1.8 to 2.4 % in 2 patients for whom infraclavicular block failed. Differences were not significant ($p = 0.60$). In the successful infraclavicular block group, PI rose continuously during the 30-min observation period. At 10 min, mean PI increased by 120 % from baseline. At 20 and 30 min, perfusion index increased by 133 % and 155 % from baseline. All changes from baseline were significant ($p < 0.01$). The biggest changes in PI occurred 30 min after local anaesthetic administration but significant changes in PI were detected as early as 10 min after injection. PI may provide a highly valuable tool to quickly evaluate the success of upper extremity blocks.
17. Non-invasive blood haemoglobin (SpHb), PI and PVI were monitored during brachial plexus block in twenty patients by Bergek., *et al*. [44] to study the effects of a sympathetic block on these measurements. Readings were taken up to 20 min after local anaesthetic injection and venous blood samples were drawn from the non-blocked arm at corresponding intervals of time. Latter 10 mins of the study saw median increase in SpHb by 8.6%, decrease in PVI by 54% and increase in PI by 188% in the blocked arm (statistically significant changes). In the non-blocked arm, the changes were not statistically significant. They concluded that regional nervous control of the arm strongly influences the plethysmographic measurements obtained by the Radical-7 co-oximeter.

Relation between PI and PVI

Respiratory variations in pulse oximetric plethysmographic waveform amplitudes are believed to predict fluid responsiveness. The non-invasive PVI is a variable based on the computation of changes in PI. Accuracy of the PVI in predicting fluid responsiveness depends on the PI as demonstrated by Broch., *et al*. [45] in their study of eighty one coronary artery surgery patients. The patients were monitored using Stroke volume index by transpulmonary thermodilution (SVI(TPTD)),PPV, stroke volume variation (SVV) and systemic vascular resistance index (SVRI) using the PiCCO monitor, PI and PVI using the non-invasive Masimo monitoring system and CVP. The

specific time points were: at baseline, after induction of anaesthesia and during passive leg raising (PLR). > 15% rise in SVI after PLR was seen in responders. The highest area under the curve (AUC) was found for PPV (AUC: 0.83) and SVV (AUC: 0.72), in contrast to PVI (AUC: 0.60, P=0.11; statistically insignificant) and CVP (AUC: 0.60). Analysing PVI only of patients with PI above 4% (n=45) achieved statistically significant results (AUC: 0.72, P=0.01). PVI was not able to predict fluid responsiveness with sufficient accuracy in patients with lower perfusion states suggesting a significant influence of PI on PVI.

Conclusion

PI is a valuable tool to verify Allens test, assess reconstructive flap perfusion and viability of limb after limb salvage surgery. PI is an early, non invasive and sensitive indicator of onset/failure of neuraxial block (including caudal epidural) in adult/paediatric patients under general anaesthesia. PI can also serve as an early indicator of onset of interscaline, supraclavicular, infraclavicular and axillary brachial plexus blocks. Maternal PI is a sensitive monitor of foetal well being and can also predict the amount of hypotension that occurs after subarachnoid block in parturients. PI serves to quantify the hemodynamic stress response associated with supraglottic airway device and endotracheal tube insertion. The accuracy of PVI in predicting fluid responsiveness improves with higher PI readings and PVI becomes an insensitive monitor at PI values below 4%. Future perspectives would entail PI and PVI guided fluid management in robotic surgery.

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