Review Article

DOI: 10.7860/JCDR/2026/79653.23412

Anaesthesia Section

Advancements in Perioperative Pain Management: The Role of Perfusion Index as a Continuous Non Invasive Measure

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ABSTRACT

Pain management in the perioperative setting is crucial for patient comfort and optimising surgical outcomes. Poorly managed pain will trigger deleterious physiological effects, such as tachycardia, hypertension, and elevation of stress hormones, which can hinder recovery and potentially lead to chronic pain syndromes. Classic methods of evaluating pain, such as observations of Heart Rate (HR), Blood Pressure (BP), and pain scores using a subjective rating system, are unreliable because they depend on factors related to non painful stimuli. The Perfusion Index (PI) is a novel tool proposed to continuously and non invasively evaluate peripheral flow and sympathetic activation in response to painful stimuli. This review consolidates current evidence on PI as a dynamic, objective indicator of nociception in real-time clinical settings. It highlights its potential to bridge the gap between physiological monitoring and subjective pain assessment. This review examines the physiological basis of PI and its role in assessing pain and analgesia. Immediate feedback on peripheral perfusion offered by PI can assist anaesthesiologists in modifying their analgesic interventions, enhancing pain control, and reducing opioid consumption. Incorporation of PI into practice may lead to advances in individualised pain management strategies, particularly for high-risk patients.

Keywords: Anaesthesia, Analgesia, Haemodynamics, Monitoring, Sympathetic nervous system

INTRODUCTION

Perioperative pain management is essential not only for ensuring patient comfort but also for optimising surgical outcomes. Uncontrolled pain during surgery may produce uncomfortable physiological reactions like tachycardia and hypertension, heightened metabolic needs, and elevated levels of stress hormones like cortisol and catecholamines [1]. This stress response may compromise organ function, delay recovery, and increase the risk of chronic pain [2].

Intraoperative pain had previously been estimated based on parameters like HR, Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP), and Mean Arterial Pressure (MAP), among others. These are useful but non specific since they may be affected by factors unrelated to nociception, like depth of anaesthesia, fluid shifts, and pharmacological reactions [3]. Clinical evidence that could suggest pain, such as movement or lacrimation, is usually suppressed under general anaesthesia, mainly when using neuromuscular blocking drugs. The fallacies of the traditional approaches emphasise the need for a more precise, objective, and non invasive measure for evaluating analgesia under surgical conditions [4]. Under these circumstances, the PI, a pulse oximetry-derived parameter, emerges. The PI is representative of the proportion of pulsatile to non pulsatile peripheral blood flow and represents an indirect estimate of peripheral perfusion [5].

The Autonomic Nervous System (ANS) regulates peripheral perfusion and dynamically reacts to any nociceptive stimulus. In pain or lack of adequate analgesia, sympathetic activation causes peripheral vasoconstriction, decreasing peripheral blood flow and PI [6]. Once proper analgesia is achieved and the nociceptive input is reduced, peripheral perfusion improves, and stabilisation or a rise in PI occurs. Various clinical conditions have been utilised to test the application of the PI as an index of nociception and adequacy of analgesia [7]. In neonatal care, where conventional pain assessment methods are useless, encouraging results have been seen by using PI for pain detection and the direction of analgesic therapy [8-10]. For regional anaesthesia, PI has been used to demonstrate successful nerve blocks by detecting alterations in peripheral perfusion. Studies have also revealed that PI can be employed to predict hypotension from spinal anaesthesia, signifying that it is sensitive to alterations in autonomic and haemodynamic functions [8,9].

Pain is a complex phenomenon influenced by physiological, psychological, and environmental determinants, and its appraisal remains one of the most significant challenges in medical practice [11]. Incorporating PI into anaesthetic monitoring can shift the focus from adopting a “one-size-fits-all” strategy for analgesia to dynamically tailored approaches based on real-time patient needs. It would be beneficial in patients with a higher risk, such as the elderly, patients with cardiovascular co-morbidities, or patients with long and complex operations [12].

This review aimed to explore the potential of PI as a continuous, non invasive, and objective tool for assessing nociception and guiding analgesic management in the perioperative setting. It discusses the physiological underpinnings of PI and its responsiveness to pain-related autonomic changes. By evaluating current evidence, this review highlights the limitations of traditional pain assessment methods and explore PI as a promising adjunct for personalised and real-time pain management strategies in modern anaesthetic practice.

Perfusion Index (PI)

The PI is a highly non invasive dynamic measure that gives time-constant, real-time feedback on peripheral perfusion. PI is based on pulse oximetry, which has become the standard tool for monitoring patients’ oxygen saturation (SpO_2). In addition to SpO_2, modern pulse oximeters can measure PI, which reflects the ratio of pulsatile blood flow (arterial) to non pulsatile blood flow (venous and capillary) within the microvascular circulation [13]. This is achieved by plethysmography, which detects changes in blood volume during each heartbeat or pulsatile component through sensors

attached to the pulse oximeter. These oscillations are associated with mechanical variations in the blood flow due to cardiac cycle changes [14].

PI is usually measured as a numeric value. High values point towards normal peripheral perfusion, while low values signify reduced flow or vasoconstriction. In most clinical environments, a PI value of more than 1.0 is assumed to reflect a healthy, well-perfused peripheral state, and values < 0.5 often suggest decreased peripheral circulation due to vasoconstriction, hypovolemia, or shock [15]. Physiological factors such as blood pressure, volume, and vascular tone affect the pulsatile to non pulsatile blood flow ratio. PI is highly sensitive to the variation in blood flow resulting from sympathetic nervous system stimulation, which is a direct correlation between pain and the body's reaction to stress [13,16]. The physiological basis for measuring PI is related to blood circulation within the vascular system. Circulation, or blood flow, can be described as arterial and non arterial circulation. Arterial blood flow is pulsatile from the heart to the tissues, whereas non arterial blood flow includes venous and capillary blood. Each heartbeat causes arterial expansion and contraction, generating pulsatile flow detected through oscillations tied to the cardiac cycle [5,17].

The key benefit of PI is its capability to mirror peripheral perfusion changes in real-time using a non invasive method. This is essential mainly in surgeries where constant assessment of haemodynamics is unavoidable. The body's stress response activates the sympathetic nervous system whenever pain occurs, releasing catecholamines such as adrenaline and noradrenaline. These hormones lead to vasoconstriction of the peripheral vessels, resulting in decreased blood flow to the extremities and decreased PI. This decrease in PI can be used as an index of pain or distress during surgical procedures and to assess analgesia's effectiveness during surgery [18].

Acute pain experienced during surgery is a potent stimulus for sympathetic activation. The body is alert in response to pain, often termed the fight-or-flight response. One of the first effects of this response is the constriction of the peripheral blood vessels. Activation of the sympathetic nervous system results in the release of noradrenaline, which acts on alpha-adrenergic receptors in the smooth muscle of the blood vessels to cause constriction. This vasoconstriction reduces blood flow to peripheral tissues, reflected by decreased PI. PI can be used as a surrogate for sympathetic nervous system activity; thus, it can be a valuable tool in measuring the pain level and analgesia provided [18,19].

PI offers a continuous, non invasive way to monitor these physiological changes. Traditional methods for monitoring pain, such as measuring HR and blood pressure and using subjective pain scales, are often influenced by various factors unrelated to pain. For instance, tachycardia can be due to anxiety, hypovolemia, or even the depth of anaesthesia rather than pain itself. Blood pressure can fluctuate due to several factors, such as fluid shifts or the effects of anaesthetic agents. PI is a direct measure of peripheral blood flow and, therefore, a measure of sympathetic nervous system activity, which is likely more precise for assessing real-time pain during surgery [20].

The sensitivity of PI to changes in peripheral perfusion makes it useful for assessing pain and evaluating the adequacy of analgesic interventions. PI fall may be more significant if the analgesia given to the patient is inadequate. If the analgesic intervention is effective, PI may be maintained or even increased because the sympathetic nervous system is less activated. This continuous monitoring of PI allows the anaesthesia team to make more timely and precise adjustments to pain management, ensuring that the patient remains comfortable and that analgesic interventions are adequately effective throughout the surgical procedure [18,21].

The Role of Perfusion Index (PI) in Pain Monitoring

It is based on the physiological background that pain, especially acute postsurgical pain, releases sympathetic impulses that can be quantitatively appreciated through alterations of peripheral blood flow [22]. Pain is most commonly appraised by subjective measures, primarily patient-reported pain scores, such as the Visual Analog Scale (VAS) or Numerical Rating Scale (NRS), and objective measures, such as HR, blood pressure, respiratory rate, and other distress markers. Such methods are easily influenced by factors other than pain, including the depth of anaesthesia, fluid status, or the patient's general physiological condition [23].

One of the strengths of PI is that it can be measured continuously during the procedure. Traditional methods, such as HR and blood pressure, need regular monitoring, and even subjective pain scales depend on the patient's communication, which is challenging in sedated or intubated patients [24]. PI can be monitored continuously through pulse oximetry, already in place for routine SpO2 monitoring during surgery. Continuous PI feed during the surgery will provide instantaneous patient feedback on how the patient perceives painful stimuli, giving clinicians an earlier response in pain detection and modification of analgesia [25].

The continuous nature of PI measurement gives a more accurate and timely picture of how the patient is coping with the surgical pain. For example, a sudden fall in PI could indicate severe discomfort on the patient's part, and the anaesthesia team can then take action with further analgesics, including local anaesthetics, opioids, or other pain relief measures. Conversely, a stable or rising PI may reflect that analgesia is sufficient or that the sympathetic pain response is small. Such ongoing feedback from the PI can inform intraoperative decision-making for analgesia and ensure that patients are provided with appropriate pain relief during the procedure [22].

An essential aspect of PI in pain monitoring is its ability to complement standard haemodynamic monitoring. Although PI can give meaningful information regarding the patient's response to pain, it is best utilised when it is used with other standard monitoring parameters, including blood pressure, HR, and SpO_2. For instance, a simultaneous increase in HR and blood pressure, alongside a decrease in PI, may confirm that the patient is experiencing pain, allowing for a more accurate assessment of the need for additional analgesia [26].

PI has been advocated as a better marker of analgesic adequacy than traditional measures, especially when the patient's physiological responses are altered by anaesthesia. For instance, volatile agents and opioids can influence HR and blood pressure, thus possibly reducing their utility as markers in the assessment of pain when anaesthetics are applied. PI is more directly related to sympathetic nervous system responses towards pain; it is less influenced by the application of these anaesthetic agents, thus making it potentially a more stable, sensitive marker of pain intensity and effectiveness of analgesics [7,22]. [Table/Fig-1] summarises key clinical studies that investigated the role of the PI in pain assessment and analgesic effectiveness in various surgical settings [21,27-30].

Comparison of Perfusion Index (PI) and Traditional Pain Assessment Techniques

Traditional pain assessment during surgery is based on subjective and objective measures. Subjective techniques like the VAS or NRS require patients to report pain intensity. Such scales may not be used in the intraoperative scenario, especially if the patients are under general anaesthesia or incapacitated to communicate, being either sedated or under mechanical ventilation. Thus, as a substitute for subjective scales, objective measures of HR, SBP, DBP, and MAP are widely used as surrogate indicators for pain intensity. These haemodynamic parameters are thought to reflect the body's sympathetic response to pain, given that pain often activates the sympathetic nervous system, which can lead to increases in HR and BP. Although these traditional measures are widely used, they are severely limited in their ability to accurately

Study	Objective	Key findings	Clinical implications
Duran H et al., 2025 [27], Observational study, Turkey	To investigate the relative changes in PI following postoperative analgesia in 100 patients undergoing open abdominal surgery and evaluate its ability to predict analgesic requirements.	The relative change in PI showed a strong association with postoperative pain intensity. PI had a higher ability to predict the need for analgesia in patients with high postoperative VAS scores, particularly in those with hypertension.	PI can be a non invasive and objective method to predict postoperative pain and analgesic requirements. Monitoring PI may enhance individualised pain management, especially in hypertensive patients undergoing abdominal surgery.
Chu CL et al., 2018 [21], Observational study, Taiwan	To evaluate whether PI is a feasible indicator for objectively assessing pain relief and a potential criterion for discharge from the Post-Anaesthesia Care Unit (PACU) in 103 female patients undergoing gynaecological or general surgery.	PI increased significantly after administration of intravenous morphine, while VAS scores decreased. The mean percentage change in ΔPI at discharge was 66.2%, and a change greater than 12% from baseline could serve as an additional discharge criterion.	PI increases after analgesia and may serve as a supplemental, objective measure for assessing pain relief and readiness for PACU discharge, especially when patients cannot express pain verbally.
Yun HJ et al., 2023 [28], Observational study, Korea	To investigate the prognostic ability of PI for a successful adductor canal nerve block (ACB) in 39 patients and to determine the optimal PI cut-off value for predicting a successful block.	The change in PI (dPI) showed significant differences between groups at all measured time intervals. dPI at 5 and 20 minutes demonstrated good prognostic accuracy for successful ACB.	dPI is a reliable and objective predictor of successful ACB. Monitoring early changes in PI after block placement may help clinicians confirm block success without relying solely on sensory testing.
Ramegowda DS et al., 2025 [29], Observational study, India	To correlate PI with VAS for assessing postoperative pain objectively in 72 patients aged 18-50 years undergoing laparoscopic cholecystectomy.	PI values increased significantly after rescue analgesia. PI showed a significant negative correlation with haemodynamic parameters except Systolic Blood Pressure (SBP).	PI can be used as an objective tool for postoperative pain assessment and to guide analgesic administration decisions, reducing reliance on subjective pain scales like VAS.
Kumar S et al., 2019 [30], Observational study, India	To evaluate the correlation between VAS as a subjective indicator and PI as an objective indicator of postoperative pain in 50 adult patients of American Society of Anaesthesiologists (ASA) I status undergoing laparoscopic surgery.	PI was significantly higher after analgesia. This increase corresponded with a significant decrease in haemodynamic parameters and VAS, suggesting PI rises with pain relief. The correlation between PI and VAS was not statistically significant due to patient variability.	PI can supplement subjective pain scales like VAS for postoperative pain assessment, providing an additional objective parameter for monitoring analgesic effectiveness in the PACU.

[Table/Fig-1]: Studies evaluating PI as an objective indicator for postoperative pain assessment [21,27-30].

assess pain, especially in a surgical procedure's complex and controlled environment [20,23].

One of the significant disadvantages of the use of HR and BP is that they tend to be quickly affected by other factors that are not related to pain. An increased HR may not necessarily imply pain but rather could result from over-sedation, anxiety, or even a response to anaesthetic drugs. An additional variation will involve SBP and DBP, whereby different variables such as the effect on anaesthesia depth, fluid supplementation, or general physiological state by surgical intervention can cause movement or elevation of blood pressure outside pain. Blood pressure and HR require monitoring at intervals. They should be assessed for the changes occurring within a patient, which might lead to a delay in determining any significant change in pain levels. Such a delay may result in improper or inappropriate dosing of analgesics. PI can give a more immediate and objective indication of physiological responses in the patient related to pain [31]. PI is less prone to interference from factors unrelated to pain. While HR and BP can be influenced by anaesthesia depth, volume status, or other physiological variables, PI is primarily affected by the physiological changes associated with pain [31,32]. This makes PI a more reliable measure of pain intensity and analgesic adequacy, especially in cases where changes in HR and BP might not directly correlate with the pain level. For example, in patients on opioids or sedative agents, alterations in HR and BP can be attributed to the drugs rather than the pain. PI provides a more sensitive and stable measure of the sympathetic response to pain and, thus, is highly valued in surgical environments where fine-tuned pain control is required. Although PI is a potential new tool in pain monitoring, it must not be considered a substitute for standard pain measurement techniques but an addition to them [20,26].

Study	Objective	Key findings	Clinical implications
Bihani P et al., (2024) [23], Observational study, Jodhpur, India.	To assess the role of PI in postoperative pain measurement in 140 patients after upper limb surgeries under supraclavicular brachial plexus block.	Moderate negative correlation between PI and VAS; PI decreased as pain increased. A PI cut-off showed 100% specificity and 76.3% sensitivity for predicting the need for rescue analgesia.	PI can be used as an objective tool to guide postoperative pain management, complementing subjective VAS scores.
Gülen M et al. (2022) [33], Observational study, Turkey.	To evaluate PI in 144 patients as an objective pain indicator and its predictive value for rescue analgesia in renal colic patients in the Emergency Department (ED).	Significant changes in PI and VAS pre- and postanalgesia. ΔPI was a reliable predictor of additional analgesic need.	PI is a valuable objective marker for acute pain assessment in emergency settings, aiding rapid analgesic decision-making.
Sadek SAM et al., (2024) [34], Observational study, Egypt.	To assess baseline PI as a predictor of postspinal hypotension in lower abdominopelvic surgeries.	Patients with higher baseline PI were more likely to develop hypotension postspinal anaesthesia.	Baseline PI may be integrated into preoperative evaluations to identify and manage hypotension risk during spinal anaesthesia.
Mohamed SR et al., (2023) [35], Observational study, Egypt.	To investigate PI as a predictor of early hypotension in 30 elderly patients undergoing general anaesthesia.	PI ≤1.3 effectively predicted early hypotension with high sensitivity and specificity. Less effective for late hypotension.	PI can be used as a non invasive, preinduction marker to improve intraoperative monitoring and reduce hypotension risks in the elderly.

[Table/Fig-2]: Studies on pain assessment and PI [23,33-35].

Studies on PI and Pain Assessment

The list of studies on PI and pain assessment is depicted in [Table/Fig-2] [23,33-35].

Although PI appears to be a continuous and non invasive parameter for perioperative pain control, various limitations should be addressed. One such limitation is the absence of clinical standardisation of PI measurement. Different hospitals and clinics can utilise multiple devices or methods for measuring PI, which may lead to variability in results. Without a standardised protocol, it becomes difficult to compare results across sites, thereby reducing the reliability and generalisability of PI as a single, widely applicable tool. More research is required to create a single, unified methodology for PI measurement to enhance consistency and accuracy [26].

A further limitation is the lack of large-scale Randomised Controlled Trials (RCTs). Most existing research is observational or small-scale, making it challenging to draw absolute conclusions regarding the effectiveness of PI in pain management. Although encouraging correlations between pain intensity and PI have been reported, large-scale RCTs with a representative patient population are needed to confirm these findings and establish PI as a dependable instrument in clinical settings. Interfering factors affecting PI measurements also pose challenges. Factors such as patient

movement, temperature variation, peripheral vasoconstriction, and co-morbidities like diabetes complicate PI readings, making it challenging to use as a standardised pain assessment tool. Subsequent studies should consider controlling for these factors and ensuring that PI readings correlate with pain severity, rather than other physiological alterations [5].

Future directions for PI in pain management include developing standardised protocols for measurement and interpretation across healthcare settings, conducting large-scale, multicenre RCT to establish PI's predictive accuracy and impact on patient outcomes, and advancing technology to provide more precise PI measurements. By addressing these challenges, PI could become a valuable tool in personalised perioperative pain management, particularly for high-risk patients where optimal pain control is crucial [22,33].

CONCLUSION(S)

The PI represents a novel and promising tool for enhancing perioperative pain management. Its ability to assess analgesic adequacy dynamically allows for more precise adjustments in pain management, reducing the risk of under- or over-treatment and improving patient outcomes. As a non invasive, real-time indicator of sympathetic activity, PI may improve intraoperative pain assessment, especially in high-risk patients. Although further research is needed to validate its widespread use, PI holds significant potential for advancing pain management in the perioperative setting.

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PLAGIARISM CHECKING METHODS: [Jain H et al.]
- Plagiarism X-checker: Jun 12, 2025
- Manual Googling: Nov 19, 2025
- iThenticate Software: Nov 22, 2025 (1%)

ETYMOLOGY: Author Origin

EMENDATIONS: 6

AUTHOR DECLARATION:
- Financial or Other Competing Interests: None
- Was informed consent obtained from the subjects involved in the study? NA
- For any images presented appropriate consent has been obtained from the subjects. NA

Date of Submission: **Jun 03, 2025**
Date of Peer Review: **Sep 23, 2025**
Date of Acceptance: **Nov 25, 2025**
Date of Publishing: **May 01, 2026**