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Estimation of Perfusion Index as an Objective Tool for Assessment of Analgesia During Laparoscopic Surgeries Under General Anesthesia: A Prospective Observational Study.

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Abstract

Background:

Painful surgical stimuli during general anesthesia trigger sympathetic responses that alter heart rate (HR), mean arterial pressure (MAP), and peripheral perfusion. The Perfusion Index (PI), derived from pulse oximetry, may serve as an objective indicator of nociception and analgesic adequacy during surgery.

Aim:

To evaluate the utility of PI as an objective tool for monitoring intraoperative analgesia during laparoscopic surgeries under general anesthesia.

Methods:

This prospective observational study included 40 ASA Physical Status I patients aged 20–50 years undergoing elective laparoscopic surgery under general anesthesia at a tertiary care teaching hospital. PI, Pleth Variability Index (PVi), HR, and MAP were recorded at predefined intraoperative time points, including laparoscopic port insertion. An additional fentanyl bolus (0.5 µg/kg) was administered after the first port insertion. Data were analyzed using paired t-tests and Pearson correlation analysis.

Results:

The mean age of participants was 42.5 ± 8.4 years, with females accounting for 60% of the study population. Mean PI increased significantly from 4.74 ± 1.67 at baseline to 13.61 ± 3.17 following fentanyl administration ($p < 0.001$). Concurrently, HR and MAP decreased significantly. PI demonstrated an inverse correlation with HR and MAP, indicating reduced sympathetic activity and improved analgesic adequacy.

Conclusion:

PI is a reliable, objective, and non-invasive indicator of intraoperative analgesic adequacy during laparoscopic surgery under general anesthesia.

Recommendation: Routine use of PI monitoring alongside conventional hemodynamic parameters may improve analgesic titration during surgery. Larger multicenter studies are recommended to establish standardized PI thresholds for clinical use.

Keywords: *Perfusion Index; General Anesthesia; Laparoscopic Surgery; Heart Rate; Mean Arterial Pressure; Analgesic Monitoring.*
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Introduction

Inadequate management of perioperative pain can cause negative physiological reactions in the respiratory, cardiovascular, gastrointestinal, endocrine, and neurological systems. It can also lead to persistent pain syndromes and delayed recovery. The significance of early and efficient analgesic methods is highlighted by the fact that the severity of initial postoperative pain is also a major predictor of chronic postsurgical pain. Multimodal analgesia has emerged as a key strategy to maximize perioperative pain management. In order to generate synergistic analgesic benefits while reducing opioid intake and associated side effects, it combines pharmacological drugs with various modes of action, such as acetaminophen, NSAIDs, opioids, and local or regional anesthetics.(1).

Analgesia under general anesthesia is still primarily assessed indirectly despite these developments. Heart rate (HR) and blood pressure (BP) are examples of conventional indicators that lack specificity for nociceptive detection because they are affected by a number of confounding factors, such as anesthetic depth, autonomic tone, and hemodynamic alterations. Nociceptive balance during anesthesia has been measured using methods such as the Analgesia ANI (Nociception Index), surgical pleth index, pupillometry, and skin conductance (2). Among these, the Perfusion Index (PI) is a non-invasive measure derived from the photoplethysmographic (PPG) waveform of a pulse oximeter that has been identified as having potential as a dynamic indicator of sympathetic activity and peripheral perfusion. The PI, the ratio of pulsatile (AC) to non-pulsatile (DC) blood flow, gives a numeric real-time measurement of microcirculatory perfusion. The present work aimed to assess the variations of the perfusion index in response to painful stimuli under general anesthesia in order to explore its potential as an objective and reliable indicator for intraoperative analgesia monitoring (3).

Materials and Methods

Study Design and Setting

This was a **hospital-based prospective observational cross-sectional study** conducted in the Department of Anesthesiology and Critical Care, Government Medical College Srinagar, Jammu and Kashmir, India, a tertiary care teaching hospital providing advanced surgical and critical care services. The study was carried out over a period of one year from **1 January 2024 to 31 December 2024**.

Eligibility Criteria

Inclusion Criteria

- Patients of either sex aged 20–50 years.
- American Society of Anesthesiologists (ASA) Physical Status I.
- Patients scheduled for elective laparoscopic surgery under general anesthesia.
- Patients who provided written informed consent for participation.

Exclusion Criteria

- History of neurological or psychiatric disorders.
- Chronic pain conditions or regular opioid use.
- Peripheral vascular disease.
- Hypertension.
- Diabetes mellitus.
- Ischemic heart disease.
- Autonomic dysfunction.
- Use of vasoactive medications affecting peripheral perfusion.
- Intraoperative complications requiring deviation from the standard anesthetic protocol.

Note: The criterion "refusal to participate" was removed because individuals who decline consent are not recruited and therefore cannot be considered excluded participants.

Study Variables

The **primary outcome** was the change in Perfusion Index (PI) in response to painful surgical stimuli and fentanyl administration.

The **secondary outcomes** included:

- Changes in Heart Rate (HR),
- Mean Arterial Pressure (MAP),
- Pleth Variability Index (PVi),
- Correlation of PI with HR and MAP during various intraoperative stages.

Bias and Measures to Minimize Bias

Potential sources of bias included:

- **Selection bias**, as only ASA Physical Status I patients from a single tertiary care center were included, potentially limiting the generalizability of findings.

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- **Measurement bias**, resulting from possible variability in pulse oximeter measurements and operator-dependent data recording.
- **Confounding bias**, due to factors such as ambient temperature, peripheral vascular tone, anesthetic depth, and vasoactive drug use that may influence perfusion index values.

To minimize these biases, all patients underwent a standardized anesthetic protocol, measurements were obtained using the same monitoring equipment and sensor placement technique, ambient temperature was maintained within a constant range, and all observations were recorded by trained anesthesia personnel under uniform operating room conditions.

Ethical Considerations

The study was approved by the **Institutional Ethics Committee of Government Medical College Srinagar, Jammu and Kashmir, India,** prior to commencement of the study. Written informed consent was obtained from all participants after explaining the objectives, procedures, potential risks, and benefits of the study. The study was conducted in accordance with the ethical principles of the **Declaration of Helsinki**.

Results

A total of **52 patients** scheduled for elective laparoscopic surgery under general anesthesia were initially assessed for eligibility between **1 January 2024 and 31 December 2024**. Of these, **12 patients were excluded**, including **7 patients who did not meet the eligibility criteria** and **5 patients who declined to provide informed consent for participation**. The remaining **40 eligible patients** were enrolled in the study and underwent standardized intraoperative monitoring and data collection. All enrolled participants completed the study protocol and were included in the final analysis.

The demographic distribution of the patients showed that most individuals were above 40 years of age, accounting for 72.5% of the study population, while 27.5% were below 40 years. The mean age was 42.5 ± 8.4 years. Among the 40 participants, 24 were females (60%), and 16 were males (40%), indicating a female predominance. The mean body weight was 61.4 ± 6.3 kg, and the mean height was 165.2 ± 7.1 cm [Table 1].

Table 1: Demographic Characteristics of the Study Population

Parameter	Category	Frequency (n)	Percentage (%)	Mean ± SD
Age (years)	<40	11	27.5	42.5 ± 8.4
	>40	29	72.5	--
Sex	Male	16	40	--
	Female	24	60	--
Weight (kg)	--	--	--	61.4 ± 6.3
Height (cm)				165.2 ± 7.1
ASA Class	I	40	100	--

Perfusion index values increased significantly after induction and port insertion, reflecting hemodynamic responses to painful stimuli. PI increased from 4.74 ± 1.67 at induction to 13.61 ± 3.17 at P3. The PVi values decreased progressively from 43.51 ± 15.51 at baseline to 13.60 ± 5.94 at 30 minutes, indicating improved perfusion stability after fentanyl administration [Table 2].

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Table 2: Perfusion Index (PI) and Pleth Variability Index (PVi) During Different Intraoperative Stages

Time Interval	PI (Mean ± SD)	PVi (Mean ± SD)
Pre-induction	4.74 ± 1.67	43.51 ± 15.51
Induction	6.85 ± 2.44	30.37 ± 19.00
After Intubation	6.20 ± 2.46	29.70 ± 14.93
Pneumoperitoneum (P0)	11.85 ± 4.01	24.10 ± 16.52
Port 1 (P1)	12.24 ± 3.57	23.38 ± 14.87
Port 2 (P2)	13.03 ± 3.55	16.24 ± 8.26
Port 3 (P3)	13.61 ± 3.17	19.13 ± 15.26
10 min	15.35 ± 3.12	13.07 ± 6.53
30 min	13.43 ± 2.60	13.60 ± 5.94

Heart rate was highest at the time of first port insertion (97.25 ± 10.31 bpm) and decreased after fentanyl administration, reaching 96.05 ± 11.14 bpm at the time of third port insertion. The trend showed a gradual stabilization in heart rate over time, suggesting the analgesic and hemodynamic stabilizing effects of fentanyl [Table 3].

Table 3: Changes in Heart Rate During Intraoperative Period

Time Interval	Heart Rate (bpm) Mean ± SD
Pre-induction	91.02 ± 10.21
Induction	90.57 ± 9.68
Before Intubation	87.17 ± 10.18
After Intubation	84.17 ± 10.68
P0	92.35 ± 9.38
P1	97.25 ± 10.31
P2	96.92 ± 11.53
P3	96.05 ± 11.14
15 min	90.37 ± 6.73
30 min	93.60 ± 6.22

After administration of fentanyl, there was a consistent rise in PI and a decline in PVi and HR, confirming the inverse relationship between sympathetic activity and PI. The difference in PI from port 1 to port 3 was statistically significant ($p < 0.001$), while HR showed a steady decline over the same period [Table 4].

Table 4: Comparison of Perfusion Index, Pleth Variability Index, and Heart Rate

Time Interval	PI (Mean ± SD)	PVi (Mean ± SD)	HR (Mean ± SD)
5 min	15.96 ± 3.23	13.87 ± 5.74	90.52 ± 7.06
7 min	15.54 ± 2.33	12.35 ± 6.19	90.67 ± 6.18
10 min	15.35 ± 3.12	13.07 ± 6.53	90.15 ± 5.80
15 min	15.12 ± 2.86	14.21 ± 7.84	90.37 ± 6.73
20 min	14.75 ± 2.35	18.67 ± 12.35	92.27 ± 7.15
30 min	13.43 ± 2.60	13.60 ± 5.94	93.60 ± 6.22

The systolic blood pressure (SBP) remained relatively stable, ranging from 115.15 ± 11.89 mmHg at P1 to 116.82 ± 13.40 mmHg at P3. Diastolic blood pressure (DBP) showed a slight but statistically significant reduction after fentanyl administration, decreasing from 66.92 ± 10.54 mmHg at P1 to 65.65 ± 7.52 mmHg at P2 [Table 5].

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Table 5: Systolic and Diastolic Blood Pressure Variations During Surgery

Time Interval	SBP (mmHg) Mean ± SD	DBP (mmHg) Mean ± SD
Pre-induction	131.97 ± 12.49	77.3 ± 7.93
After Intubation	109.32 ± 12.03	63.5 ± 11.02
P0	111.4 ± 17.41	62.92 ± 13.10
P1	115.15 ± 11.89	66.92 ± 10.54
P2	116.82 ± 13.40	65.65 ± 7.52
P3	119.02 ± 10.57	66.10 ± 10.27
15 min	124.17 ± 9.94	73.17 ± 8.88
30 min	127.35 ± 10.13	75.95 ± 8.49

It identified a substantial inverse connection between perfusion index and mean arterial pressure (MAP). As PI increased following fentanyl administration, MAP showed a corresponding decline, suggesting effective analgesia and reduced sympathetic tone. Mean MAP at P1 was 82.37 ± 7.53 mmHg, which decreased to 75.05 ± 7.04 mmHg at P2, followed by gradual normalization [Table 6].

Table 6: Correlation Between Perfusion Index and Mean Arterial Pressure

Time Interval	PI (Mean ± SD)	MAP (mmHg) Mean ± SD
P1	12.24 ± 3.57	82.37 ± 7.53
P2	13.03 ± 3.55	75.05 ± 7.04
P3	13.61 ± 3.17	82.17 ± 10.59
15 min	15.12 ± 2.86	85.57 ± 8.57
25 min	14.25 ± 2.75	87.35 ± 8.78
30 min	13.43 ± 2.60	88.00 ± 8.61

The study showed that the perfusion index is a sensitive metric of nociceptive response during general anesthesia. PI increased significantly after port installation and was inversely proportional to HR and mean arterial pressure. Fentanyl administration significantly stabilized hemodynamic responses, supporting its role in modulating sympathetic activity during surgical pain stimuli.

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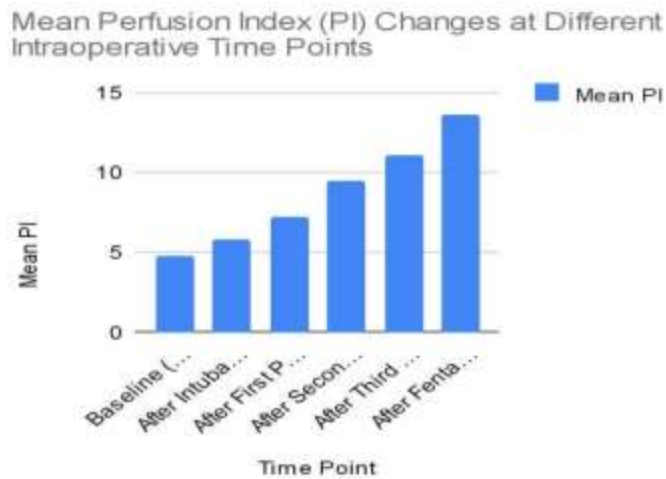
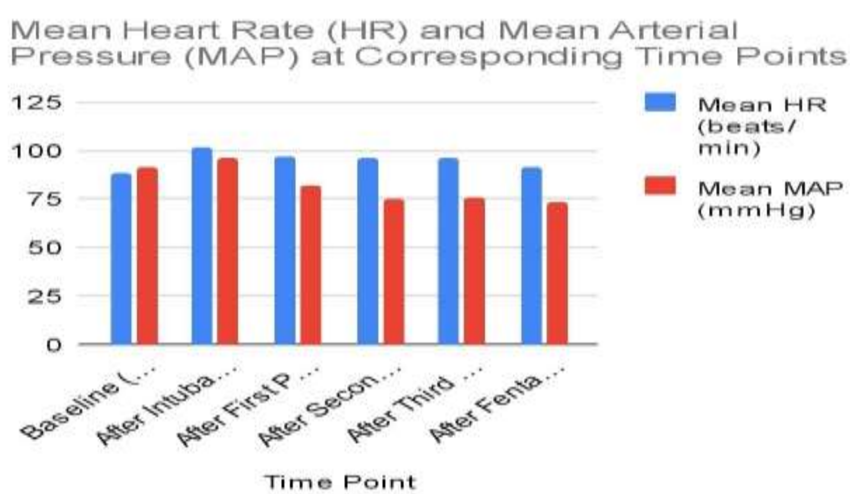


Bar graph 1: Mean Perfusion Index (PI) Changes at Different Intraoperative Time Points.



Bar graph 2: Mean Heart Rate (HR) and Mean Arterial Pressure (MAP) at Corresponding Time Points.

Discussion

The findings of this study are most applicable to ASA Physical Status I adults undergoing elective laparoscopic surgery under standardized general anesthesia. Although the results support the utility of PI monitoring in this population, caution should be exercised when extrapolating findings to elderly patients, pediatric populations, patients with significant comorbidities, or emergency surgical procedures. Multicenter studies involving diverse patient groups are required to improve external validity.

In this study of 40 patients undergoing laparoscopic surgery under general anesthesia, perfusion index (PI) was clearly shown to be sensitive to painful stimuli (laparoscopic port insertions) and fentanyl administration. Results indicate

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that, as expected, heart rate (HR) and mean arterial pressure (MAP) were different. The perfusion index (PI) increased significantly following port insertions and fentanyl administration. The idea that PI can serve as an impartial instrument for monitoring intraoperative analgesia is supported by these findings(4).

Following fentanyl, a decrease in sympathetic tone is correlated with an increase in the Perfusion Index (PI). Sympathetic reactions to painful stimuli, including port insertion, usually result in peripheral vasoconstriction and reduced perfusion. Vasodilation follows the administration of analgesics, which raises PI and lowers HR and MAP.(5). According to our findings, HR and MAP decreased while the Perfusion Index (PI) significantly increased from P1 to P3. Other research has noted the same tendency, such as Surekha et al. It was discovered that under comparable circumstances, the Perfusion Index (PI) rose following fentanyl and was associated with a drop in HR.(6).

The fact that changes in the Perfusion Index (PI) were more noticeable and constant than those in MAP or HR was another significant finding. After fentanyl was administered, HR gradually decreased, although MAP responded more subtly or slowly over a longer period of time. This implies that under some circumstances, PI may be able to identify minor changes in peripheral perfusion earlier or more accurately than conventional hemodynamic indices. According to some writers, blood pressure may not reflect nociceptive stimulation as quickly as PI and may be affected by a variety of parameters, including volume status, vascular tone, and anesthetic depth(7).

These results suggest that anesthesiologists may be able to more accurately titrate analgesia during laparoscopic procedures by using the Perfusion Index (PI). Perfusion index (PI) may be used as an additional monitor to identify insufficient analgesia, particularly when HR or MAP are steady despite discomfort (or are lowered by anesthetics). This should enhance patient comfort, lessen the intraoperative stress response, and possibly lessen postoperative problems brought on by uncontrolled nociception.(8).

There are a few restrictions to be aware of. First, even if the Perfusion Index (PI) showed a significant response, values may still be affected by confounders, including patient peripheral vascular tone, vasoconstrictive medications, or ambient temperature.(9). To lessen some of these confounders, the current study used warmed fluids, maintained thermoneutrality, etc. Second, the sample size (n=40) is modest; more extensive research would enhance the generalizability. Third, although both HR and MAP decreased following fentanyl, the amount of change in MAP was inconsistent or occasionally not statistically significant at specific time periods, which is consistent with results from related research. (10).

Conclusion

In conclusion, PI is a promising objective technique for evaluating analgesia under general anesthesia during laparoscopic surgery, as evidenced by the observed considerable rise in PI and its inverse connection with HR and MAP following painful stimuli and fentanyl administration. It could support more responsive analgesic control and enhance hemodynamic monitoring.

Generalizability

The findings of this study are primarily applicable to adult patients with **ASA Physical Status I** undergoing **elective laparoscopic surgeries under standardized general anesthesia** in tertiary care settings. The observed relationship between perfusion index and conventional hemodynamic parameters suggests that PI may be useful as an adjunct tool for monitoring intraoperative analgesia in similar patient populations. However, caution should be exercised when extrapolating these findings to pediatric patients, elderly individuals, patients with significant comorbidities, emergency surgeries, or procedures associated with different anesthetic techniques. Further multicenter studies involving diverse patient populations are required to improve the external validity and broader applicability of the findings.

Limitations

The study had several limitations. First, the sample size was relatively small (**n = 40**), which may limit the statistical power of the study. Second, this was a **single-center study**, potentially affecting the generalizability of the findings to other healthcare settings. Third, only **ASA Physical Status I patients** were included, limiting applicability to patients with comorbid conditions. Fourth, perfusion index measurements may be influenced by factors such as peripheral vascular tone, ambient temperature, vasoactive medications, and technical factors related to pulse oximetry despite attempts to standardize measurement conditions.

Recommendation

Routine incorporation of **Perfusion Index monitoring** alongside conventional hemodynamic parameters may

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improve real-time assessment of intraoperative analgesic adequacy and facilitate more precise analgesic titration during laparoscopic surgery. Future multicenter studies with larger sample sizes should evaluate PI-guided analgesic administration and establish clinically meaningful threshold values for routine clinical practice. Comparative studies with other nociception monitoring modalities, such as Analgesia Nociception Index (ANI), Surgical Pleth Index (SPI), and pupillometry, are also recommended.

Acknowledgment

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List of Abbreviations

Abbreviation	Full Form
PI	Perfusion Index
PVi	Pleth Variability Index
HR	Heart Rate
MAP	Mean Arterial Pressure
SBP	Systolic Blood Pressure
DBP	Diastolic Blood Pressure
ASA	American Society of Anesthesiologists
BP	Blood Pressure
PPG	Photoplethysmography
ANI	Analgesia Nociception Index
SPI	Surgical Pleth Index

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No funding was received for this study.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this study.

Author Contributions

Author	Contribution
Dr. Mubasher Ahmad Bhat	Conceptualization, study design, supervision, manuscript review, and editing
Dr. Nidhi Breya	Data collection, patient recruitment, statistical analysis, manuscript drafting
Dr. Rajjat Sharma	Literature review, data interpretation, manuscript preparation, and correspondence with the journal

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- **Data Collection:** Nidhi Breya
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Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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