Research Square

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Association Between Intraoperative Low Perfusion Index Under General Anesthesia and Postoperative Complications

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Abstract

Purpose

The perfusion index (PI), derived from photoplethysmography, is a noninvasive indicator of peripheral perfusion and may be useful for detecting intraoperative circulatory impairment. This study investigated whether the minimum intraoperative PI (PI min) is associated with postoperative complications.

Methods

Among 1,948 patients who underwent surgery under general anesthesia at our institution between July and September 2024, 186 patients with an intraoperative radial arterial catheter were included. PI was automatically recorded at 3-s intervals using a NIHON KOHDEN monitor. PI min was defined as the lowest PI value between the start and end of surgery. Postoperative complications were assessed using the Clavien–Dindo classification, and grade ≥ II was defined as complications. We also performed multivariable logistic regression analysis adjusted for surgical category (cardiac vs non-cardiac surgery), age, and body mass index (BMI), and evaluated the correlation between PI min and the time-weighted mean PI (TWM-PI).

Results

Lower PI min was significantly associated with postoperative complications (Clavien–Dindo grade ≥ II) and remained significantly associated after minimal adjustment for surgical category, age, and BMI. PI min showed a significant positive correlation with TWM-PI (Spearman's $\rho = 0.5228$, $p < 0.0001$).

Conclusion

Minimum intraoperative PI may serve as a simple intraoperative marker associated with postoperative complications, although further validation is required.

Introduction

Pulse oximetry monitoring of peripheral oxygen saturation (SpO_2) is essential during general anesthesia and in intensive care. While SpO_2 has an established normal range and is widely interpreted in routine practice, the clinical significance of the perfusion index (PI), which can be measured simultaneously during pulse oximetry monitoring, remains incompletely understood. PI is derived from the photoplethysmography (PPG) signal—an optical signal obtained through the skin that contains both pulsatile (arterial) and nonpulsatile components—and represents the ratio of the pulsatile component to the nonpulsatile (baseline) component [1]. Depending on the device and manufacturer, similar concepts are referred to as the peripheral perfusion index (PPI) or the pulse-amplitude index (PAI); in the present study, these are collectively referred to as PI.

Because PI can be obtained continuously and in real time, it has attracted interest as a surrogate marker of peripheral perfusion and hemodynamics during anesthesia and critical care. Sun et al. suggested that PI may reflect peripheral microcirculation relatively independently of macrocirculatory variables and highlighted its potential role in shock resuscitation, fluid management, and hemodynamic assessment [2]. Elshal et al. reviewed evidence that PI reflects cardiac output and autonomic balance and may be applied to grading circulatory failure severity, guiding fluid therapy, and even assessing analgesia [3]. Højlund et al. reported that changes in PI after induction of general anesthesia were significantly associated with changes in blood pressure and cardiac output, supporting the use of PPI as a tool for real-time assessment of circulatory fluctuations [4]. PI also responds rapidly to noxious stimulation; during periods of strong stimuli such as tracheal intubation, recovery from neuromuscular blockade, and extubation, PI decreases by more than 10% and shows a negative correlation with conventional hemodynamic indices (heart rate, systolic/diastolic blood pressure, and mean arterial pressure) [5].

Several studies have further suggested associations between intraoperative PI-related measures and postoperative outcomes. Lower intraoperative PI averaged over 15-min intervals has been reported to be associated with postoperative complications [6]. Krone et al. reported that, among patients undergoing major non-cardiac surgery who required continuous vasopressor infusion, the intraoperative area under a PI threshold and the cumulative time below a PI threshold were significantly associated with postoperative acute kidney injury (AKI) [7]. Lau et al. reported that surgical patients with low intraoperative PPI (< 1.5) in combination with anemia (Hb < 9.7 g/dL) had a significantly higher risk of postoperative complications and 90-day mortality than those with PPI within the normal range (PPI ≥ 1.5) [8]. In addition, fluid management guided by the pleth variability index (PVI)—a PPG-derived parameter reflecting respiratory variation and used to assess fluid responsiveness—has been reported to reduce postoperative serum lactate and creatinine levels compared with conventional approaches [9].

Despite the growing body of evidence, analytical approaches and PI-derived endpoints vary widely across studies, and clinically applicable standards have not been established. Prior work has shown that time-based metrics, such as the time-weighted mean PI, can be associated with postoperative complications; however, such metrics generally cannot be finalized until a defined observation period has elapsed (e.g., at the end of surgery), which limits their utility for timely intraoperative interpretation. Therefore, we focused on a simpler and more readily interpretable “one-point” metric: the minimum intraoperative PI (PI min), representing how low PI decreases in an individual patient during general anesthesia. The primary objective of this study was to examine whether PI min is associated with postoperative complications and whether this association persists after minimal adjustment for selected confounders. As a secondary objective, we evaluated the correlation between PI min and a representative time-based PI metric (time-weighted mean PI). By focusing on the minimum value rather than temporal fluctuations, this study may contribute to establishing a simpler and more broadly applicable perioperative monitoring marker.

Methods

Study design and patients

This retrospective observational study included 186 patients selected from 1,948 consecutive surgical cases performed under general anesthesia at our institution between July 16 and September 30, 2024. Eligible patients were those who underwent intraoperative invasive arterial blood pressure monitoring via a radial arterial catheter.

Data source and PI measurements

Intraoperative perfusion index (PI) data were retrospectively extracted from the anesthesia information management system, Prime Gaia (NIHON KOHDEN, Japan), which automatically records PI at 3-s intervals. PI was measured using a disposable pulse oximeter probe (NIHON KOHDEN) placed on the index or middle finger of the upper extremity. According to the manufacturer, the lower measurement limit of PI is 0.02. Although the manufacturer refers to this parameter as the pulse-amplitude index, it is equivalent to the perfusion index; therefore, we use the term PI throughout this manuscript.

Because PI may not reliably reflect peripheral perfusion during cardiopulmonary bypass, all PI values recorded during bypass (from initiation to termination) were excluded, and only values recorded outside this period were analyzed.

Definitions of PI-derived variables

Minimum PI (PI min) was defined as the lowest PI value observed between the start and end of surgery.

To assess whether PI min represented a transient artifact, we calculated the longest continuous duration during which PI remained within a tolerance band around PI min. The tolerance band was defined as: PI min ± max(0.05, 0.15 × PI min). We identified all contiguous time segments meeting this criterion and defined the maximum length of these segments as the longest continuous duration near PI min (seconds). This band uses the larger of an absolute margin (± 0.05) or a relative margin (± 15%) to avoid an unrealistically narrow tolerance when PI values are very low.

The time-weighted mean PI (TWM-PI) was defined as the time-weighted average of PI from the start to the end of surgery and was calculated as: TWM-PI = $\sum PI_i \Delta t_i / \sum \Delta t_i$. Because PI was sampled at a constant interval (3 s), TWM-PI is equivalent to the arithmetic mean of PI over the analyzed period.

Postoperative complications

Postoperative complications were retrospectively extracted from inpatient medical records and graded using the Clavien–Dindo classification. Grade I denotes any deviation from the normal postoperative course not requiring pharmacological treatment or surgical, endoscopic, or radiological interventions. Grade II requires pharmacological treatment (including blood transfusion and total parenteral nutrition).

Grade III requires surgical, endoscopic, or radiological intervention (IIIa, without general anesthesia; IIIb, under general anesthesia). Grade IV denotes life-threatening complications requiring ICU management (IVa, single-organ dysfunction; IVb, multi-organ dysfunction), and Grade V denotes death [10]. In the present study, Clavien–Dindo grade ≥ II was defined as the presence of postoperative complications. Because the number of cases with grade ≥ III was small and could lead to unstable statistical estimates, grade ≥ II was used for the primary analysis.

Statistical analysis

Because PI min and TWM-PI were not normally distributed, comparisons between patients with and without postoperative complications were performed using the Mann–Whitney U test. The association between PI min and TWM-PI was evaluated using Spearman's rank correlation coefficient. Receiver operating characteristic (ROC) analyses were performed to assess the ability of PI min and TWM-PI to discriminate patients with postoperative complications, and the area under the curve (AUC) and optimal cutoff values were obtained.

In addition, multivariable logistic regression analysis was performed to assess whether the association between PI min and postoperative complications persisted after adjustment for selected confounders. Postoperative complications defined as Clavien–Dindo grade ≥ II were used as the dependent variable. PI min was entered as the main explanatory variable, and surgical category (cardiac vs non-cardiac surgery), age, and body mass index (BMI) were included as covariates. Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated. A two-sided p value < 0.05 was considered statistically significant. Because this study was exploratory, no adjustment for multiple comparisons was performed.

Results

A total of 186 patients who underwent surgery under general anesthesia were included in the analysis. By surgical specialty, cardiac surgery accounted for the largest proportion of cases (32.3%), followed by gastrointestinal surgery (22.6%) and thoracic surgery (16.7%). The mean PI min was 0.25 ± 0.23, and the mean time-weighted mean PI (TWM-PI) was 2.76 ± 1.80. The longest continuous duration near PI min was 50.4 ± 185.9 s. The distribution of postoperative complications according to the Clavien–Dindo classification was grade 0–I in 170 patients, grade II in 11 patients, and grade ≥ III in 5 patients; thus, 16 patients had complications defined as Clavien–Dindo grade ≥ II. Patient characteristics are summarized in Table 1.

Table 1
Patient characteristics and perioperative variables (n = 186).

Age (years)	**n = 186**
	61.1 ± 21.2
Sex (male)	103 (55.4%)
Height (cm)	158.8 ± 19.6
Weight (kg)	56.6 ± 15.8
BMI	21.8 ± 4.1
Cardiac surgery	60 (32.3%)
Gastrointestinal surgery	42 (22.6%)
Thoracic surgery	31 (16.7%)
Urological surgery	19 (10.2%)
Obstetric and gynecologic surgery	10 (5.4%)
Neurosurgery	7 (4.6%)
Otorhinolaryngologic surgery	6 (3.8%)
Pediatric surgery	5 (2.7%)
Orthopedic surgery	5 (2.7%)
Emergency Medicine surgery	1 (0.5%)
Duration of surgery (min)	295.7 ± 181.9
Fluid volume (mL)	2514.8 ± 1542.6
Blood transfusion volume (mL)	878.2 ± 2504.5
Urine output (mL)	707.8 ± 905.0
Blood loss (mL)	775.0 ± 2290.1
PI min	0.25 ± 0.23
TWM-PI	2.76 ± 1.80
ICU admission	104 (55.9%)
ICU length of stay (day)	7.1 ± 11.0

Notes: Data are presented as mean ± SD or n (%), as appropriate. Surgical specialties and perioperative variables are summarized, including intraoperative PI metrics (PI min and time-weighted mean PI). Postoperative outcomes include ICU admission/length of stay, hospital length of stay, and complications graded by the Clavien–Dindo classification.

Age (years)	**n = 186**
	61.1 ± 21.2
Hospital length of stay (day)	20.0 ± 15.8
Clavien–Dindo classification	
No complications or grade I	170 (91.4%)
grade ≥ II	16 (8.6%)
grade ≥ III	5 (2.7%)
Notes: Data are presented as mean ± SD or n (%), as appropriate. Surgical specialties and perioperative variables are summarized, including intraoperative PI metrics (PI min and time-weighted mean PI). Postoperative outcomes include ICU admission/length of stay, hospital length of stay, and complications graded by the Clavien–Dindo classification.	

Patients with postoperative complications (Clavien–Dindo grade ≥ II) had significantly lower PI min than those without complications ($p = 0.0005$). Similarly, TWM-PI was significantly lower in patients with complications than in those without complications ($p = 0.0014$).

In multivariable logistic regression analysis adjusted for surgical category (cardiac vs non-cardiac surgery), age, and BMI, lower PI min remained significantly associated with postoperative complications, whereas surgical category, age, and BMI were not significant in the model (Table 2). However, the overall model fit was modest, and the results should be interpreted as exploratory given the limited number of outcome events.

Table 2
Multivariable logistic regression analysis for postoperative complications.

Variable	Odds ratio	95% CI	p value
PI min (per 0.1-unit increase)	0.61	0.38–0.96	0.032
Non-cardiac surgery (vs cardiac surgery)	1.18	0.66–2.09	0.582
Age (per 1-year increase)	1.00	0.97–1.02	0.843
BMI (per 1-kg/m² increase)	0.97	0.85–1.11	0.669

Notes: Postoperative complications were defined as Clavien–Dindo grade ≥ II. The model included PI min as the main explanatory variable and surgical category (cardiac vs non-cardiac surgery), age, and body mass index (BMI) as covariates. For interpretability, the odds ratio for PI min is presented per 0.1-unit increase.

PI min was positively correlated with TWM-PI (Spearman's ρ = 0.5228, p < 0.0001; 95% confidence interval, 0.44–0.64). The smoothing curve overlaid on the scatter plot (locally weighted regression) indicated an overall increasing trend in TWM-PI with increasing PI min (Fig. 1).

Receiver operating characteristic (ROC) analyses were performed to evaluate PI min and TWM-PI for discriminating postoperative complications (Clavien–Dindo grade ≥ II) (Fig. 2). PI min yielded an AUC of 0.68, with an optimal cutoff value of < 0.10 (Fig. 2a). TWM-PI yielded an AUC of 0.64, with an optimal cutoff value of < 1.88 (Fig. 2b).

Discussion

The primary outcome of this study was the association between the minimum intraoperative perfusion index (PI min) and postoperative complications defined as Clavien–Dindo grade ≥ II. We found that PI min was significantly lower in patients who developed postoperative complications, and this association remained significant after minimal adjustment for surgical category (cardiac vs non-cardiac surgery), age, and BMI. In addition, the time-weighted mean PI (TWM-PI), calculated as a metric that may reflect the temporal exposure to reduced peripheral perfusion, was also significantly lower in the complication group. Collectively, these findings suggest that impaired peripheral perfusion during general anesthesia may be associated with an increased risk of postoperative complications. However, discrimination performance in ROC analyses was modest (AUC 0.68 for PI min and 0.64 for TWM-PI), and the adjusted analysis should be interpreted as exploratory. Therefore, rather than positioning PI as a stand-alone test to predict complications with high accuracy, it is more appropriate to view PI as a practical intraoperative

marker that can visualize peripheral hypoperfusion and prompt additional hemodynamic assessment and clinical vigilance.

Accumulating evidence indicates that intraoperative PI is more informative when evaluated as a time-dependent exposure rather than as a single time-point value. Agerskov et al. showed that, in patients undergoing high-risk acute surgery, not only low mean intraoperative PPI but also the cumulative time spent below predefined PPI thresholds was associated with severe postoperative outcomes defined as Clavien–Dindo grade ≥ III or death [6]. Krone et al. reported that, among patients undergoing major non-cardiac surgery who required continuous vasopressor infusion, both cumulative time and area below a PI threshold were associated with postoperative acute kidney injury, and that a time-weighted average PI was associated with postoperative acute kidney injury and 30-day mortality [7]. Similarly, Kang et al. demonstrated in a retrospective study that spending more than 10% of surgical time with PPI < 0.5 was independently associated with an increased risk of postoperative acute kidney injury, supporting the importance of the duration of low PPI exposure [11]. Together, these studies support the concept that quantifying the time course of peripheral hypoperfusion may be useful for understanding postoperative outcomes.

Despite their theoretical appeal, time-based indices (e.g., TWM-PI, cumulative time below a threshold, and area under a threshold) have a practical limitation when used for intraoperative decision-making: the final value generally cannot be determined until the observation window closes (e.g., at the end of surgery). Thus, even when clinicians monitor PI in real time, it is difficult to know during surgery what the eventual TWM-PI or cumulative exposure will be until the procedure is completed. In this context, a readily interpretable “one-point” metric that can be recognized immediately during surgery—such as PI min—offers clear practical advantages. The key value of the present study is that it addressed this real-world constraint by focusing on PI min as a simple intraoperative marker and demonstrating its association with postoperative complications.

Low PI values have been linked to perioperative circulatory instability and severity across multiple clinical settings. Bassant et al. reported that a pre-induction PI ≤ 3.03 was associated with a significantly higher risk of post-induction hypotension [12]. Another study suggested that hypertensive patients with low pre-induction auricular PI may be more prone to hypotension after anesthesia-induced vasodilation, because they cannot adequately compensate for the reduction in vascular tone [13]. PI has also been highlighted as a predictor of hypotension after spinal anesthesia [14], further supporting the concept that low PI may reflect vulnerability to perioperative circulatory derangements. In infectious and septic contexts, PI has been discussed as an indirect marker of peripheral circulatory failure [15]. Moreover, Xinge Shi et al. reported that, among postoperative ICU patients, PPI may detect tissue hypoperfusion earlier than lactate [16]. In light of these observations, our primary finding—an association of PI min and TWM-PI with postoperative complications—appears consistent with the broader literature suggesting that PI can reflect peripheral perfusion and microcirculatory impairment.

The secondary outcome of this study was the correlation between PI min and TWM-PI. While TWM-PI may reflect the overall time-weighted exposure to reduced PI, PI min represents a single nadir value and may capture a different dimension of hypoperfusion. The moderate positive correlation observed between PI min and TWM-PI ($\rho = 0.5228$, $p < 0.0001$) suggests that PI min shares, to some extent, concordant information with the overall intraoperative PI level (i.e., average exposure), supporting the possibility that PI min could serve as a simple surrogate or complementary marker for time-dependent indices in pragmatic risk assessment. At the same time, the correlation was far from perfect, implying that some patients experience a brief, sharp drop in PI (low PI min) without sustained low exposure (higher TWM-PI), or conversely have prolonged moderate hypoperfusion without an extreme nadir. These findings raise the possibility that PI min (depth) and TWM-PI (duration-weighted exposure) may provide partially distinct clinical information. Future research should examine, by outcome type, whether the depth of PI reduction or the duration of low PI exposure is more strongly associated with specific postoperative complications.

To explore whether PI min could be driven primarily by transient artifacts, we calculated the longest continuous duration near PI min, which averaged 50.4 s. Although variability was substantial, this finding provides some reassurance that PI min was not explained solely by momentary noise or isolated artifacts in many cases.

In this cohort under relatively standardized physiological conditions of general anesthesia, the optimal cutoffs derived from ROC analyses were < 0.10 for PI min and < 1.88 for TWM-PI. PI is known to be influenced by the measurement site (e.g., finger vs ear), device type, sympathetic tone, patient positioning, and vasoactive drug administration (e.g., phenylephrine), and therefore establishing a universal “normal range” is challenging. Accordingly, the external validity of these cutoffs requires confirmation; nevertheless, our results suggest that extremely low PI values during general anesthesia may be linked to an increased risk of postoperative complications and may provide a clinically interpretable threshold for intraoperative attention.

This study has several limitations. First, its retrospective, single-center design may limit generalizability. Second, the study population was restricted to patients who had a radial arterial catheter, which may have introduced selection bias toward higher-risk or more invasive procedures. Third, although we performed a minimally adjusted multivariable logistic regression analysis including surgical category, age, and BMI, the number of complication events was limited and the overall model performance was modest. Therefore, the adjusted analysis should be interpreted as exploratory. In addition, residual confounding by other perioperative factors, such as surgical invasiveness, operative duration, blood loss/transfusion, vasoactive drug use, and ICU-related care, cannot be excluded. Future studies with larger event numbers and external validation are warranted to evaluate whether PI-derived indices provide independent prognostic information beyond established perioperative risk factors.

Conclusion

In this study, the minimum intraoperative perfusion index (PI min) was significantly associated with postoperative complications, and this association remained significant after minimal adjustment for surgical category, age, and BMI. PI min also showed a moderate positive correlation with the time-weighted mean PI (TWM-PI), suggesting that it shares concordant information with time-dependent PI metrics to some extent. Because PI min is a simple “one-point” measure that can be recognized intraoperatively as the single lowest observed value, it may serve as a practical marker associated with postoperative complications. However, its discriminative performance was modest, and the adjusted analysis should be interpreted as exploratory. Further external validation is required to clarify the clinical utility and applicability of PI min.

Statements and Declarations

This study was conducted in strict accordance with the principles of the Declaration of Helsinki (World Medical Association, 1964) and its subsequent revisions, which set internationally accepted ethical standards for research involving human subjects.

Author contributions

A.No. and T.Yu. designed the study, analyzed the data, and drafted the manuscript. Y.Ma., S.Ya., A.I. and T.Yo. supervised the study and provided intellectual input. All authors discussed the results and critically reviewed the manuscript.

Ethics approval

This retrospective study was approved by the Institutional Review Board of Osaka University Hospital (approval No. 24358), December 10, 2024. The need for written informed consent was waived, and an opt-out procedure was used.

Funding details

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Consent to participate

This study employed an opt-out method in accordance with the ethical guidelines. Written informed consent was not obtained from any participant. Instead, comprehensive information about the study's purpose, procedures, risks, and handling of personal information was made available to potential participants through posters displayed in areas frequented by the target population, and pamphlets placed or distributed at relevant locations.

Data availability

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

Conflict of Interest Statement

The authors report no conflict of interest.

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Figures

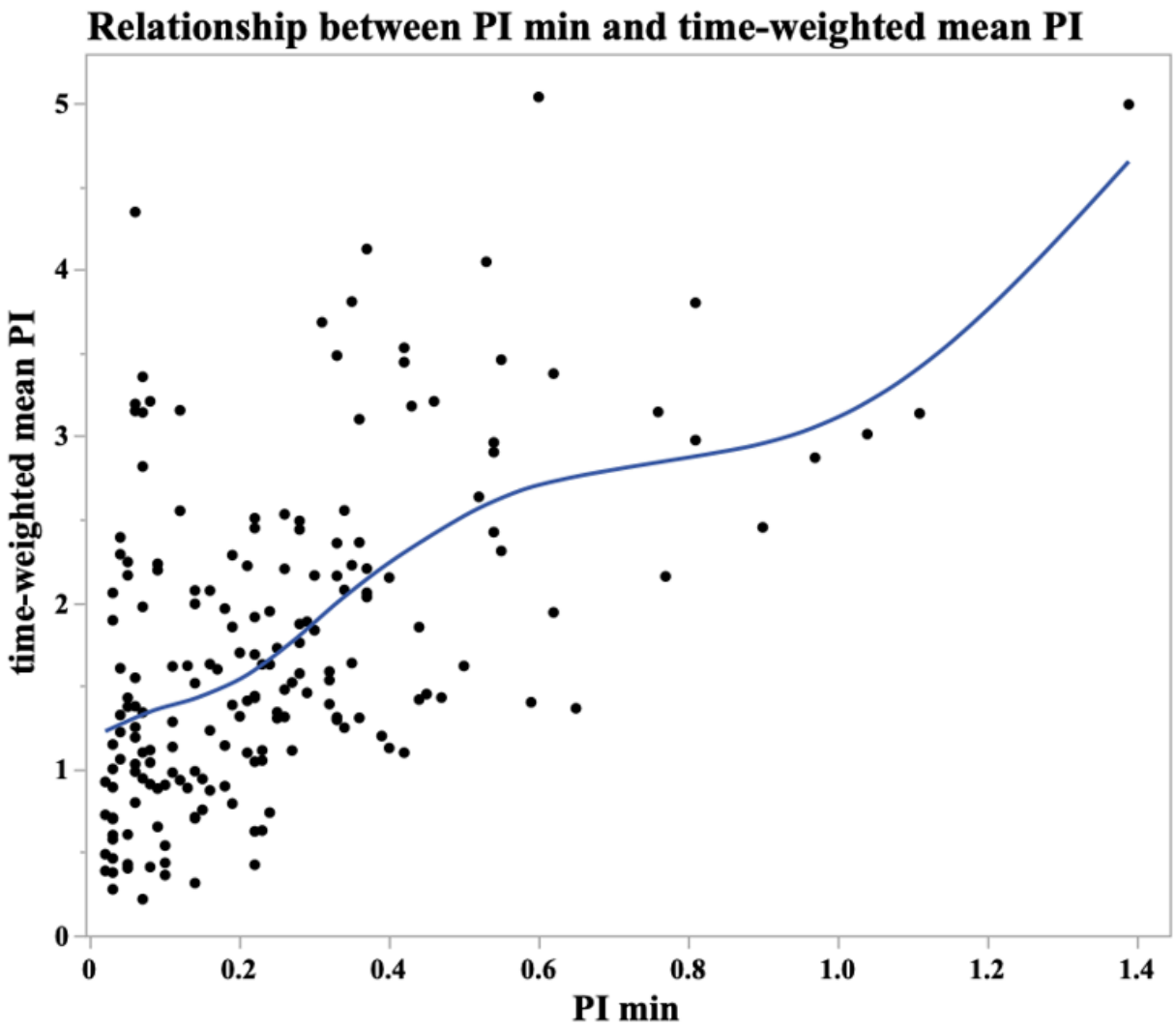


Figure 1

Relationship between minimum intraoperative perfusion index (PI min) and time-weighted mean perfusion index (TWM-PI).

Scatter plot showing the association between PI min (x-axis) and TWM-PI (y-axis) across individual patients (each dot represents one case). The overlaid smooth curve represents a nonparametric fitted trend (smoothing curve) to aid visual interpretation of the overall relationship. PI min and TWM-PI demonstrated a significant positive correlation (Spearman's $\rho = 0.5228$, $p < 0.0001$; 95% CI, 0.44–0.64).

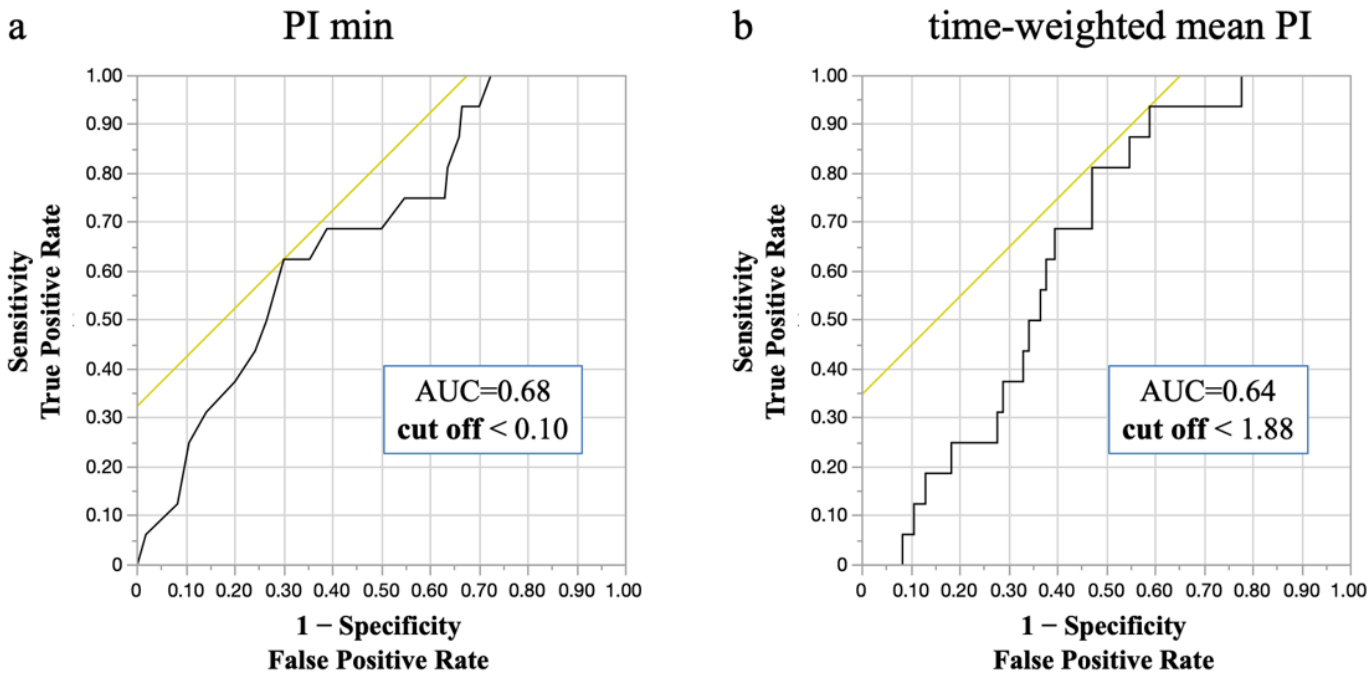


Figure 2

Receiver operating characteristic (ROC) curves for predicting postoperative complications using intraoperative PI metrics.

ROC analysis was performed with postoperative complications defined as Clavien–Dindo grade ≥II. (a) ROC curve for PI min (AUC = 0.68), with the optimal cutoff indicated in the panel (PI min < 0.10). (b) ROC curve for TWM-PI (AUC = 0.64), with the optimal cutoff indicated in the panel (TWM-PI < 1.88). The diagonal reference line indicates no-discrimination performance (AUC = 0.5). Lower PI values correspond to higher complication risk, and the curves illustrate the sensitivity–specificity trade-off across thresholds.