

Minimum intraoperative perfusion index is associated with end-of-surgery hyperlactatemia under general anesthesia

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Abstract

Background

The perfusion index (PI) is a continuously available pulse oximetry-derived marker of peripheral perfusion; however, its relationship with perioperative metabolic stress remains unclear. Although previous studies have examined intraoperative PI-related metrics and postoperative outcomes, whether the minimum intraoperative PI (PI min) is associated with end-of-surgery hyperlactatemia has not been well characterized. This study aimed to examine the association between PI min and end-of-surgery hyperlactatemia in patients undergoing surgery under general anesthesia.

Methods

This single-center retrospective observational study reviewed 1,948 consecutive patients who underwent surgery under general anesthesia and analyzed 186 patients with radial arterial catheterization and arterial blood gas analysis performed between the start of wound closure and operating room exit. PI min was defined as the lowest PI recorded during surgery, excluding cardiopulmonary bypass periods. The primary outcome was end-of-surgery hyperlactatemia, defined as lactate > 2.0 mmol/L.

Results

Hyperlactatemia occurred in 40 patients (21.5%). Lower PI min was associated with hyperlactatemia ($p = 0.019$), and this association remained significant after adjustment for age, sex, and surgical category (adjusted odds ratio per 0.1-unit increase, 0.73; 95% confidence interval, 0.57–0.95; $p = 0.017$). Receiver operating characteristic analysis showed modest discrimination (area under the curve, 0.657), with an optimal cutoff of PI min < 0.08. PI min was moderately correlated with the time-weighted mean PI.

Conclusions

Lower PI min was associated with end-of-surgery hyperlactatemia in patients undergoing general anesthesia with intraoperative arterial catheterization. To our knowledge, this study is among the first to specifically link the intraoperative PI nadir with end-of-surgery hyperlactatemia. PI min may serve as a simple intraoperative marker associated with metabolic evidence of hypoperfusion-related stress, although its discriminative performance was modest and prospective validation is required.

Background

Monitoring peripheral oxygen saturation (SpO₂) using pulse oximetry is essential during general anesthesia and intensive care. SpO₂ has an established normal range and is widely interpreted in routine

practice; however, the clinical significance of the perfusion index (PI), which can be measured simultaneously during pulse oximetry monitoring, remains unclear. PI is derived from the photoplethysmography 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 component (1). Depending on the device and manufacturer, similar concepts are referred to as the peripheral perfusion index (PPI) or the pulse-amplitude index; in this study, these are collectively referred to as PI.

PI can be obtained continuously and in real time; hence, it has attracted interest as a surrogate marker of peripheral perfusion and hemodynamic state 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 useful for grading circulatory failure severity, guiding fluid therapy, and assessing nociception or analgesia (3). Hojlund et al. reported that changes in PI following 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).

Notably, several studies have suggested associations between intraoperative PI-related measures and postoperative outcomes. Reportedly, lower intraoperative PI averaged over 15-min intervals is associated with postoperative morbidity and mortality (5). Krone et al. reported that, among patients undergoing major non-cardiac surgery who required continuous vasopressor infusion, intraoperative exposure to low PI was associated with postoperative acute kidney injury and other adverse outcomes (6). Lau et al. reported that patients undergoing surgery who have low intraoperative PPI and anemia had higher risks of postoperative complications and 90-day mortality (7). These studies suggest that intraoperative PI may provide clinically relevant information regarding impaired peripheral perfusion during surgery.

End-of-surgery hyperlactatemia is a clinically relevant marker of metabolic stress and may reflect tissue hypoperfusion, impaired oxygen delivery, catecholamine-related metabolic activation, or delayed lactate clearance. Blood lactate is widely used as a marker of global circulatory stress; however, it is obtained intermittently and may lag behind early changes in peripheral perfusion. In contrast, PI is continuously available from standard monitoring systems. Therefore, a readily interpretable intraoperative PI metric could serve as an early signal associated with subsequent end-of-surgery hyperlactatemia.

Analytical approaches for PI vary widely across studies. Time-based metrics, such as the time-weighted mean PI (TWM-PI), cumulative time below a threshold, or area under a threshold, may more comprehensively reflect exposure to low peripheral perfusion. However, these metrics generally cannot be finalized until the end of the observation period. In routine intraoperative practice, the minimum intraoperative PI (PI min) is simpler and can be recognized immediately when a low value occurs. Despite growing evidence linking intraoperative PI-related metrics with postoperative outcomes, the specific relationship between the intraoperative PI nadir and end-of-surgery hyperlactatemia has not

been well established. To our knowledge, no previous clinical study has specifically evaluated whether PI min is associated with end-of-surgery hyperlactatemia as the primary outcome in patients undergoing general anesthesia. Accordingly, we aimed to examine whether PI min is associated with end-of-surgery hyperlactatemia. As additional analyses, we evaluated exploratory associations between PI min and selected postoperative outcomes and examined the correlation between PI min and TWM-PI to determine whether the single nadir value was concordant with a time-based PI metric.

Methods

Study design and patients

This single-center retrospective observational study included 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 and had arterial blood gas analysis performed between the start of wound closure and operating room exit. At our institution, arterial blood gas analysis is routinely performed during this period in almost all patients with an intraoperative arterial catheter to facilitate postoperative handover and immediate postoperative management. Therefore, the study cohort was designed to evaluate hyperlactatemia among patients for whom end-of-surgery lactate values were routinely available as part of usual perioperative care.

Data source and PI measurements

Intraoperative 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 PI measurement limit is 0.02. The manufacturer refers to this parameter as the pulse-amplitude index, but it is equivalent to the perfusion index; therefore, the term PI is used throughout this manuscript.

PI may not reliably reflect peripheral perfusion during cardiopulmonary bypass; therefore, 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

PI min was defined as the lowest PI value recorded during surgery. As a complementary time-based metric, TWM-PI was defined as the time-weighted average of PI during the same analyzed period and was calculated as $\sum(PI_i \times \Delta t_i) / \sum \Delta t_i$. Because PI was sampled at a constant interval of 3 s, TWM-PI was

equivalent to the arithmetic mean of PI over the analyzed period after excluding cardiopulmonary bypass periods.

Outcomes

The primary outcome was end-of-surgery hyperlactatemia, defined as a blood lactate concentration > 2.0 mmol/L obtained from arterial blood gas analysis performed between the start of wound closure and operating room exit. Exploratory secondary outcomes included postoperative hypotension, postoperative renal dysfunction, SSI, PONV, BTP, and POD.

Postoperative hypotension was defined as any recorded systolic blood pressure < 90 mmHg from the end of surgery through postoperative day 3. Postoperative renal dysfunction was defined as an increase in serum creatinine of ≥ 0.3 mg/dL or ≥ 1.5 -fold from the preoperative value on postoperative day 1, in accordance with Kidney Disease: Improving Global Outcomes stage 1 criteria. SSI was defined as an event occurring within 30 days after surgery, meeting standard clinical criteria, including purulent drainage, pathogenic organisms isolated from a wound specimen, clinical signs of inflammation accompanied by wound opening or physician diagnosis, or a clinician's diagnosis of superficial incisional SSI. PONV was defined through postoperative day 3 as patient-reported nausea and/or vomiting for which an antiemetic was administered. BTP was defined through postoperative day 3 as the administration of as-needed analgesia for incisional pain; cases in which analgesics were clearly administered for non-incisional indications were excluded. POD was defined through postoperative day 3 as suspected delirium by screening with the Intensive Care Delirium Screening Checklist or the Confusion Assessment Method for the ICU, together with formal diagnosis and therapeutic intervention by the in-house Elder Care Team.

Statistical analysis

Continuous variables are presented as mean $\pm$ standard deviation or median [interquartile range], as appropriate, whereas categorical variables are presented as n (%). PI min was not normally distributed; therefore, between-group comparisons were performed using the two-sided Mann–Whitney U test. The association between PI min and end-of-surgery hyperlactatemia was evaluated using receiver operating characteristic (ROC) analysis, and the area under the curve and optimal cutoff value were obtained. Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated at the ROC-derived threshold.

A minimally adjusted logistic regression model was constructed for the primary outcome. End-of-surgery hyperlactatemia was used as the dependent variable, PI min as the main explanatory variable, and age, sex, and surgical category (non-cardiac surgery vs cardiac surgery) as prespecified covariates. The number of covariates was intentionally restricted to reduce the risk of overfitting. The OR for PI min is presented per 0.1-unit increase. Exploratory secondary outcomes were assessed using unadjusted comparisons only; multivariable adjustment and multiplicity correction were not performed for these secondary analyses. The association between PI min and TWM-PI was evaluated using Spearman's rank

correlation coefficient. A two-sided p-value < 0.05 was considered statistically significant. All analyses were performed using JMP Pro (SAS Institute Inc., Cary, NC, USA).

Results

This study included 186 patients who underwent surgery under general anesthesia. 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 and TWM-PI were 0.25 ± 0.23 and 2.76 ± 1.80 , respectively. End-of-surgery hyperlactatemia occurred in 40 patients (21.5%). Postoperative hypotension occurred in 53 patients (28.5%), postoperative renal dysfunction in 12 (6.5%), surgical site infection (SSI) in 18 (9.7%), postoperative nausea and vomiting (PONV) in 48 (25.8%), breakthrough pain (BTP) in 126 (67.7%), and postoperative delirium (POD) in 13 (7.0%). Patient characteristics and perioperative variables 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 (days)	7.1 ± 11.0
Hospital length of stay (days)	20.0 ± 15.8
Lactate > 2.0 mmol/L	40 (21.5%)

Age (years)	n = 186
	61.1 ± 21.2
Postoperative hypotension	53 (28.5%)
Postoperative renal dysfunction	12 (6.5%)
SSI	18 (9.7%)
PONV	48 (25.8%)
BTP	126 (67.7%)
POD	13 (7.0%)

Notes: Data are presented as mean ± SD or n (%), as appropriate. PI min, minimum intraoperative perfusion index; TWM-PI, time-weighted mean perfusion index; ICU, intensive care unit; SSI, surgical site infection; PONV, postoperative nausea and vomiting; BTP, breakthrough pain; POD, postoperative delirium.

Patients with end-of-surgery hyperlactatemia had significantly lower PI min than those without hyperlactatemia ($p = 0.019$; Fig. 1). In the minimally adjusted logistic regression model including age, sex, and surgical category, higher PI min was associated with lower odds of hyperlactatemia (adjusted odds ratio per 0.1-unit increase, 0.73; 95% confidence interval, 0.57–0.95; $p = 0.017$; Table 2). The overall model was statistically significant according to the likelihood ratio test (chi-square = 11.45, $df = 4$, $p = 0.0219$).

Table 2. Multivariable logistic regression analysis for end-of-surgery hyperlactatemia.

Variable	Adjusted OR	95% CI	p value
PI min, per 0.1-unit increase	0.73	0.57–0.95	0.017
Age, per 1-year increase	0.99	0.97–1.01	0.245
Female sex	0.96	0.45–2.03	0.845
Non-cardiac surgery vs cardiac surgery	0.81	0.38–1.75	0.284

Notes: Model likelihood ratio test: chi-square = 11.45, $df = 4$, $p = 0.0219$. Hyperlactatemia was defined as lactate levels >2.0 mmol/L measured between the start of wound closure and operating room exit. The model was adjusted for age, sex, and surgical category. OR, odds ratio; CI, confidence interval; PI min, minimum intraoperative perfusion index.

Receiver operating characteristic analysis showed modest discrimination of end-of-surgery hyperlactatemia by PI min (area under the curve = 0.657; Fig. 2). The optimal cutoff was PI min < 0.08. Patients with PI min < 0.08 had higher odds of hyperlactatemia than those with PI min ≥ 0.08 (odds ratio, 3.30; 95% confidence interval, 1.58–6.89; $p = 0.0017$; Table 3).

Table 3. ROC-derived cutoff of PI min for end-of-surgery hyperlactatemia.

Outcome	AUC	Cutoff	Comparison	Odds ratio	95% CI	p value
Lactate >2.0 mmol/L	0.657	<0.08	PI min <0.08 vs ≥0.08	3.30	1.58–6.89	0.0017

Notes: The cutoff was derived from ROC analysis. AUC, area under the curve; CI, confidence interval; PI min, minimum intraoperative perfusion index; ROC, receiver operating characteristic.

In exploratory secondary analyses, lower PI min was observed in patients with postoperative hypotension ($p = 0.032$), SSI ($p = 0.0002$), and POD ($p = 0.033$). PI min was not significantly associated with postoperative renal dysfunction, PONV, or BTP (Table 4). These analyses were exploratory and were not adjusted for multiplicity or potential confounders.

Table 4. Exploratory associations between PI min and secondary postoperative outcomes.

Secondary outcome	No. of events, n/N (%)	Direction of association	p value
Postoperative hypotension	53/186 (28.5)	Lower PI min in patients with postoperative hypotension	0.032
Surgical site infection	18/186 (9.7)	Lower PI min in patients with surgical site infection	0.0002
Postoperative delirium	13/186 (7.0)	Lower PI min in patients with postoperative delirium	0.033
Postoperative renal dysfunction	12/186 (6.5)	No significant association	0.65
PONV	48/186 (25.8)	No significant association	0.41
Breakthrough pain	126/186 (67.7)	No significant association	0.85

Notes: These analyses were exploratory and were not adjusted for multiplicity or potential confounders. PI min, minimum intraoperative perfusion index; PONV, postoperative nausea and vomiting.

PI min was positively correlated with TWM-PI (Spearman's $\rho = 0.52$, $p < 0.0001$; Fig. 3), suggesting that the intraoperative nadir reflects information concordant with the overall time-weighted PI level.

Discussion

In this single-center retrospective observational study of patients undergoing general anesthesia with intraoperative radial arterial catheterization and arterial blood gas analysis obtained between the start of wound closure and operating room exit, lower PI min was associated with end-of-surgery hyperlactatemia. This association remained significant after minimal adjustment for age, sex, and surgical category. The discriminative performance of PI min was modest; however, patients with PI min < 0.08 had higher odds of hyperlactatemia. Overall, these findings suggest that an extremely low intraoperative PI nadir may serve as a simple real-time signal associated with metabolic evidence of hypoperfusion or circulatory stress at the end of surgery.

The primary outcome of this study was end-of-surgery hyperlactatemia rather than a broad composite of postoperative complications. This choice was based on the pathophysiological link between peripheral hypoperfusion and lactate elevation. Blood lactate is widely used as a global marker of circulatory stress,

but it is measured intermittently and may be influenced by multiple factors, such as impaired oxygen delivery, catecholamine-related metabolic activation, and delayed clearance (8). In contrast, PI is continuously available from a standard pulse oximeter and may provide a real-time peripheral perfusion signal. Previous studies have suggested that peripheral perfusion indices may detect low-flow states earlier than lactate and that abnormal peripheral perfusion is associated with postoperative complications (9, 10). Our findings extend this concept by showing that lower intraoperative PI min was associated with lactate levels > 2.0 mmol/L measured between the start of wound closure and operating room exit.

Notably, several studies have evaluated intraoperative PI using time-dependent exposure metrics. Agerskov et al. reported that lower mean intraoperative PPI and greater cumulative time spent below predefined PPI thresholds were associated with major postoperative morbidity and mortality (5). Krone et al. reported that cumulative time and area below a PI threshold were associated with postoperative acute kidney injury in patients undergoing major non-cardiac surgery and receiving vasopressors (6). These time-based metrics are physiologically appealing because they incorporate the duration of low-perfusion exposure. However, they generally require post hoc calculation or completion of the observation window. In contrast, PI min is immediately identifiable during surgery and, therefore, may be more practical as a bedside warning signal. In the present study, PI min showed a moderate positive correlation with TWM-PI, suggesting that the nadir was not entirely discordant with the overall intraoperative PI profile. Concurrently, PI min and TWM-PI likely capture different dimensions of low peripheral perfusion: depth versus duration-weighted exposure.

The exploratory secondary analyses suggested that lower PI min was observed in patients with postoperative hypotension, SSI, and POD. The association with postoperative hypotension is consistent with previous studies suggesting that PI-derived parameters may be related to hypotension following the induction of general anesthesia (11, 12). These findings are biologically plausible, as impaired peripheral perfusion may reflect broader circulatory compromise. However, these outcomes are influenced by multiple patient-, surgical-, and management-related factors. In particular, SSI and POD have complex multifactorial etiologies, and the number of events in this cohort was limited. Therefore, these secondary findings should be interpreted strictly as hypothesis-generating and not as evidence that PI min independently predicts these complications.

This study's findings should not be interpreted as establishing a treatment target for PI. If clinicians observe an extremely low PI during surgery, the finding should instead prompt reassessment of signal quality, probe position, peripheral temperature, arterial pressure, cardiac output, bleeding, hemoglobin concentration, vasoactive drug use, and metabolic markers such as lactate. Whether interventions guided by PI can improve postoperative outcomes requires prospective investigation.

This study has several limitations. First, its retrospective, single-center design limits causal inference and generalizability. Second, although arterial blood gas analysis between the start of wound closure and operating room exit is routinely performed in almost all patients with an intraoperative arterial

catheter at our institution, the study population was restricted to patients requiring arterial catheterization, likely introducing selection bias toward higher-risk or more invasive surgical cases. Therefore, the findings should not be generalized to all patients undergoing general anesthesia. Future studies should evaluate PI-derived metrics in broader, less selected surgical cohorts, including patients without arterial catheterization. Third, PI min is a single nadir value and may be susceptible to transient artifacts, probe-related signal problems, peripheral compression, body position, temperature, and vasoactive drugs (13). The correlation between PI min and TWM-PI provides some reassurance that PI min was concordant with the overall intraoperative PI profile; however, it does not eliminate the possibility of measurement noise. Fourth, the threshold for hyperlactatemia (> 2.0 mmol/L) may not perfectly reflect tissue hypoperfusion in all perioperative contexts. Fifth, the minimally adjusted model included only a limited number of covariates, and residual confounding from surgical invasiveness, operative duration, blood loss, transfusion, vasoactive drug use, and intensive care unit (ICU)-related care cannot be excluded. Finally, the secondary outcome analyses were exploratory and were not adjusted for multiplicity or potential confounders.

Conclusions

In this single-center retrospective observational study, lower PI min was associated with end-of-surgery hyperlactatemia in patients undergoing general anesthesia with intraoperative arterial catheterization. To our knowledge, this is among the first studies to specifically identify an association between the intraoperative PI nadir and end-of-surgery hyperlactatemia. PI min was also moderately correlated with TWM-PI, suggesting partial concordance with a time-based PI metric. Because PI min is simple and can be recognized intraoperatively, it may serve as a practical marker associated with metabolic evidence of hypoperfusion-related stress. However, its discriminative performance was modest, and these findings require prospective validation in broader surgical populations.

Abbreviations

ABG
arterial blood gas
AUC
area under the curve
BMI
body mass index
BTP
breakthrough pain
CI
confidence interval
ICU
intensive care unit
OR

odds ratio
PI
perfusion index
PI min
minimum intraoperative perfusion index
POD
postoperative delirium
PONV
postoperative nausea and vomiting
PPI
peripheral perfusion index
ROC
receiver operating characteristic
SSI
surgical site infection
TWM-PI
time-weighted mean perfusion index.

Declarations

Ethics approval and consent to participate

This retrospective study was approved by the Institutional Review Board of Osaka University Hospital (approval No. 24358; December 10, 2024). The study was conducted in accordance with the principles of the Declaration of Helsinki and relevant institutional guidelines. The Institutional Review Board waived the requirement for written informed consent, and an opt-out procedure was used.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Authors' information

Not applicable.

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Author Contribution

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.

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Data Availability

The datasets generated and/or analyzed during the current study are not publicly available because they contain potentially identifiable clinical information but are available from the corresponding author on reasonable request and with permission from the Institutional Review Board of Osaka University Hospital.

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Figures

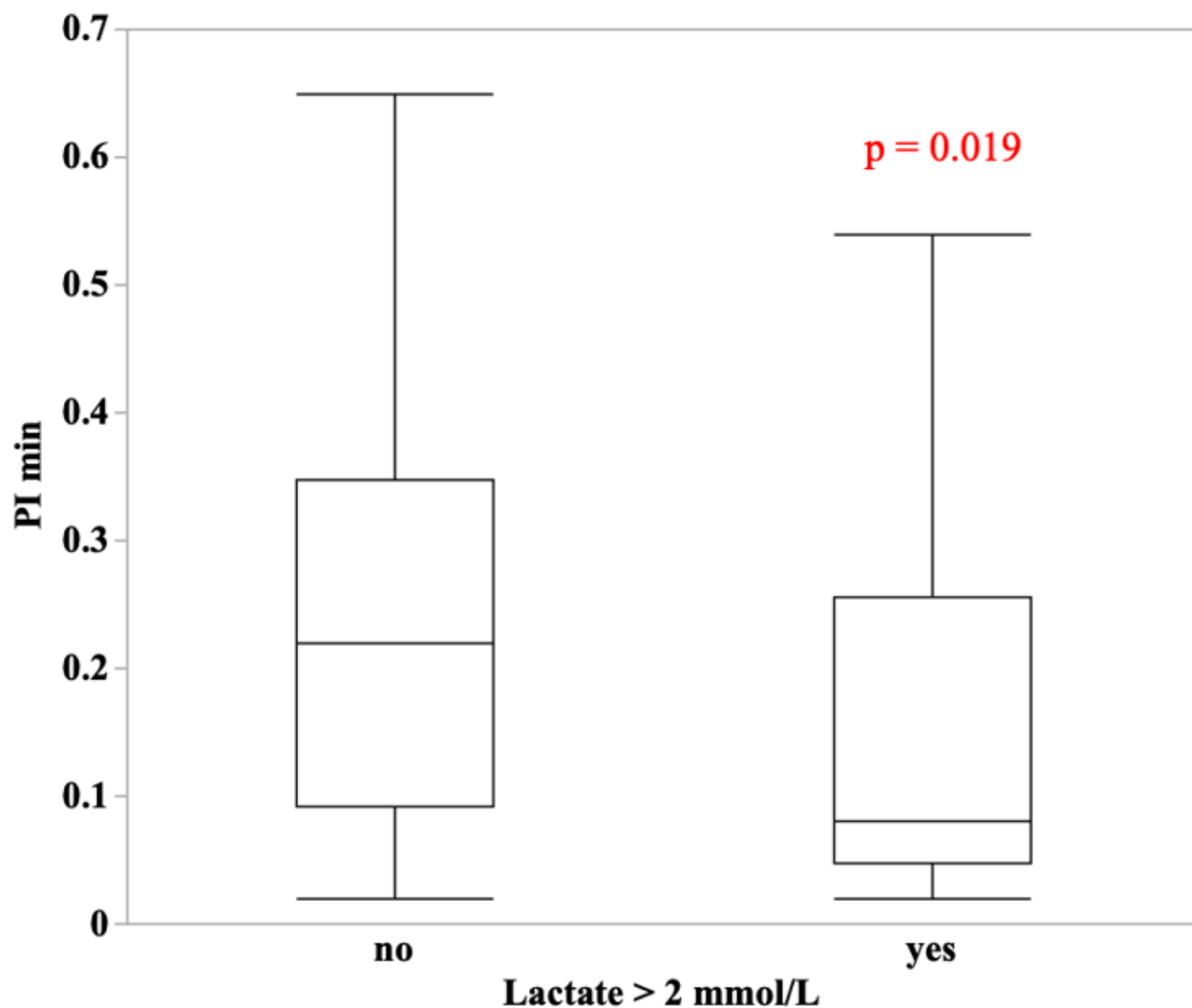


Figure 1

Minimum intraoperative perfusion index according to end-of-surgery hyperlactatemia. Box-and-whisker plot comparing PI min between patients with and without end-of-surgery hyperlactatemia, defined as lactate levels >2.0 mmol/L. The two-sided Mann–Whitney U test was used. PI min, minimum intraoperative perfusion index.

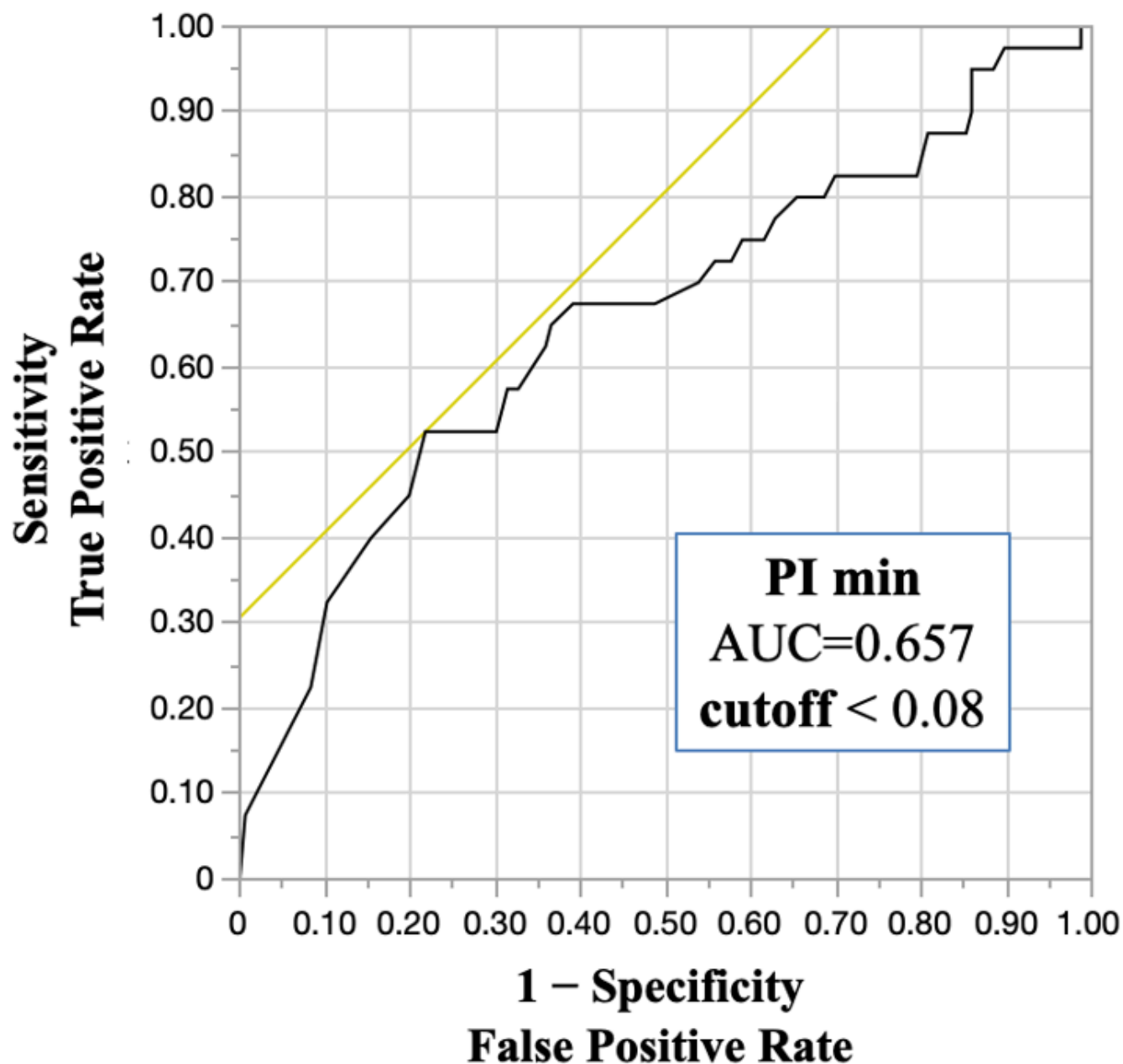


Figure 2

Receiver operating characteristic curve for PI min to discriminate end-of-surgery hyperlactatemia. ROC analysis was performed with end-of-surgery hyperlactatemia defined as lactate levels >2.0 mmol/L. PI min yielded an AUC of 0.657, with an optimal cutoff of <0.08. AUC, area under the curve; PI min, minimum intraoperative perfusion index; ROC, receiver operating characteristic.

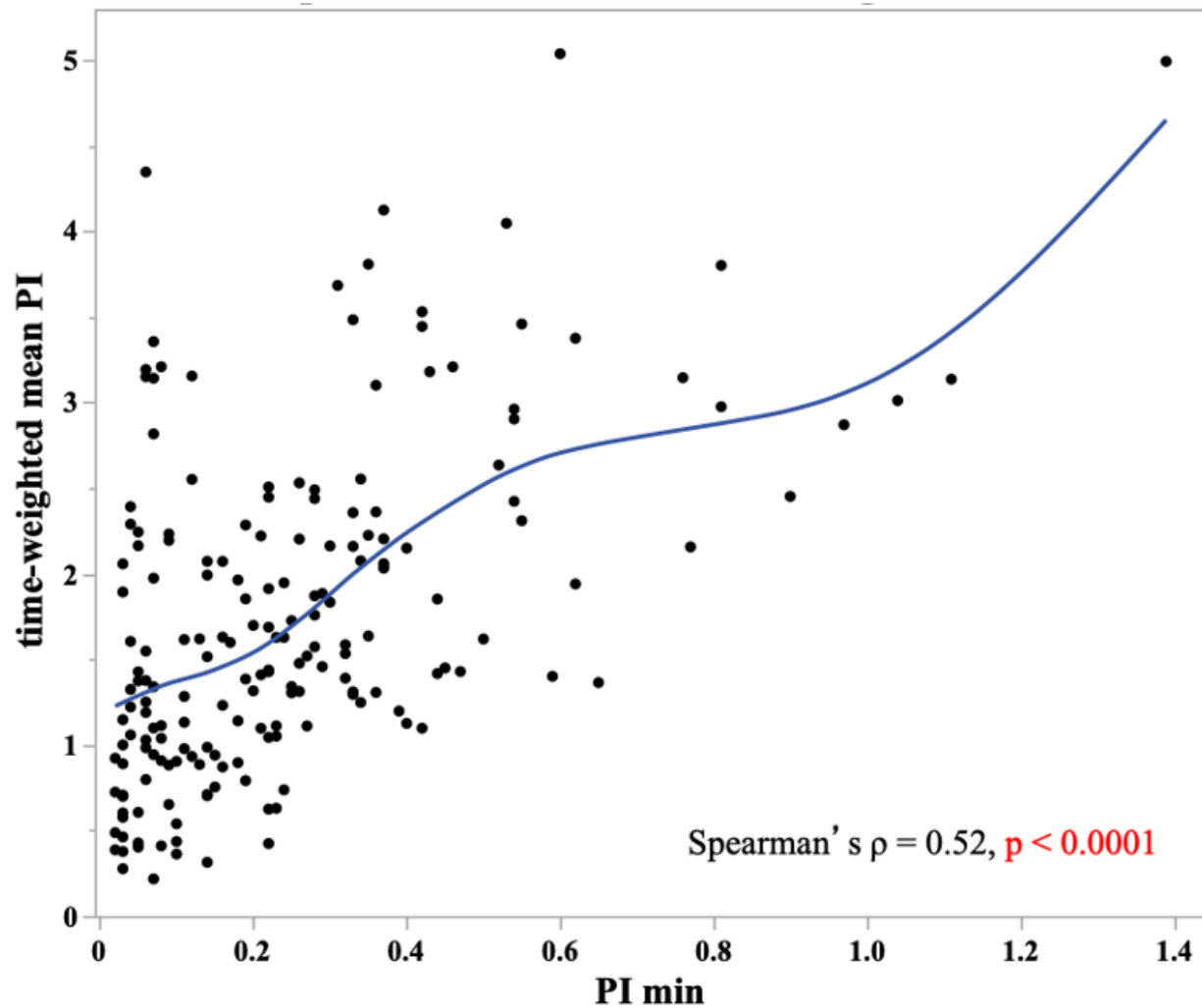


Figure 3

Relationship between PI min and TWM-PI. Scatter plot showing the association between PI min and TWM-PI across individual patients. PI min and TWM-PI demonstrated a significant positive correlation (Spearman's rho = 0.52, $p < 0.0001$). PI min, minimum intraoperative perfusion index; TWM-PI, time-weighted mean perfusion index.