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Relationship between perfusion index and central temperature before and after induction of anesthesia in laparoscopic gastrointestinal surgery

A prospective cohort study

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Abstract

The perfusion index (PI) cutoff value before anesthesia induction and the ratio of PI variation after anesthesia induction remain unclear. This study aimed to clarify the relationship between PI and central temperature during anesthesia induction, and the potential of PI in individualized and effective control of redistribution hypothermia. This prospective observational single center study analyzed 100 gastrointestinal surgeries performed under general anesthesia from August 2021 to February 2022. The PI was measured as peripheral perfusion, and the relationship between central and peripheral temperature values was investigated. Receiver operating characteristic curve analysis was performed to identify baseline PI before anesthesia, which predicts a decrease in central temperature 30 minutes after anesthesia induction, and the rate of change in PI that predicts the decrease in central temperature 60 minutes after anesthesia induction. In cases with a central temperature decrease of ≥ 0.6°C after 30 minutes, the area under the curve was 0.744, Youden index was 0.456, and the cutoff value of baseline PI was 2.30. In cases with a central temperature decrease of ≥ 0.6°C after 60 minutes, the area under curve was 0.857, Youden index was 0.693, and the cutoff value of the PI ratio of variation after 30 minutes of anesthesia induction was 1.58. If the baseline PI is ≤ 2.30 and the PI 30 minutes after anesthesia induction is at least 1.58-fold the PI ratio of variation, there is a high probability of a central temperature decrease of at least 0.6°C within 30 minutes after 2 time points.

Abbreviation: PI = perfusion index.

Keywords: baseline perfusion index, central temperature decrease, laparoscopic gastrointestinal surgery, perfusion index, perfusion index ratio of variation

1. Introduction

Unplanned perioperative hypothermia involves a decrease in core temperature to ≤ 36°C.[1] It results in an increased rate of surgical site infection, hemorrhagic tendency, and ischemic heart disease,[2–5] making it a serious perioperative complication. Therefore, their occurrence should be prevented. Warm-air heaters are commonly used to control perioperative body temperature, and their preventative effects on unplanned perioperative hypothermia have been demonstrated.[6]

Redistribution hypothermia is a decrease of 1°C to 3°C in the central temperature caused by the impairment of central thermos gulatory control due to sympathetic nerve blockade and peripheral blood vessel dilation by anesthetic administration.[7,8] Its extent is influenced by the peripheral temperature central temperature difference, that is, the degree of peripheral blood vessel contraction.[9] Differences in the degree of peripheral

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All data generated or analyzed during this study are included in this published article [and its supplementary information files].

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vascular constriction immediately before anesthesia induction (i.e., differences in blood perfusion) could influence the degree of redistribution hypothermia, although there are currently no studies exploring this.

A pulse oximeter is a widely used, noninvasive medical device used in perioperative management that measures oxygen saturation and can simultaneously measure the perfusion index (PI), the ratio between pulsatile and non-pulsatile blood volume. PI changes measured in the upper limbs are closely correlated with hemodynamics under general anesthesia.[10] PI is useful for monitoring changes in peripheral perfusion due to anesthesia in real time, and changes in PI can help determine the effects of body temperature redistribution, vasodilation, and their association with anesthesia. Previous prospective pilot studies have shown that patients with a low PI before anesthesia induction are more likely to develop intraoperative hypothermia.[10,11] However, the pre-anesthesia induction cutoff PI and ratio after anesthesia induction of PI variation that is effective in preventing redistribution hypothermia have not been clarified. We hypothesized that there is a cutoff value between PI before anesthesia induction and PI volatility after anesthesia induction related to redistribution hypothermia. This study aimed first to clarify the relationship between PI and the decrease in central temperature during anesthesia induction, and second the potential of PI for individualized and effective control of redistribution hypothermia.

2. Methods

2.1. Study design and ethical considerations

This single center, prospective observational study was conducted at a medical operating center, and was approved by the Ethics Committee of the University Graduate School of Medicine, Dentistry, and Pharmaceutical Sciences (No. 21070803) and the Ethics Committee of the Medical Center (No. 2021063) where the research was conducted. All patients or their legal guardians were fully informed regarding the inclusion of the participants in the study and their full understanding was confirmed before providing written informed consent, which was obtained after confirming that their participation in the study was guaranteed. The study design adhered to The Strengthening the Reporting of Observational Studies in Epidemiology Statement guidelines.[12] A statistical plan was established before the data were accessed, and data analysis was performed after the data were accessed.[13]

2.2. Study setting and population

This study was conducted between August 2021 and February 2022 in the operating rooms of the National Hospital Organization. All participants were at least 20 years old at the time of gastrointestinal laparoscopic surgery under general anesthesia. The exclusion criteria were emergency surgery, presumably affecting the central temperature and peripheral blood flow, drug hypersensitivity such as allergies, and a history of trauma or myocardial infarction. In a previous study conducted on the correlation between PI and blood pressure changes before the introduction of anesthetics, the correlation coefficient was 0.30.[14] Because this study aimed to determine the cutoff value of PI, the purpose and direction were the same; therefore, we used the same correlation coefficient (0.3). The sample size was calculated by performing an uncorrelated test (both sides) with a significance level of 0.05 and a power of 0.8, indicating that a minimum of 85 cases were needed. Accordingly, the target number of cases was set to 100, considering the number of discontinued and excluded cases.

2.3. Outcome and data collection

The primary endpoint was the central temperature, and the secondary endpoint was the peripheral temperature. The following parameters from entry to discharge from the operating room were assessed: PI was recorded using a Radical-7® Pulse CO-Oximeter® (Masimo Corporation, Irvine, CA); the central temperature was recorded using the 3M™ Bear Hugger™ deep temperature monitoring system (Arizant Healthcare Inc., Prairie, MN) attached to the right side of the forehead, and the peripheral temperature was recorded by attaching a body temperature probe® HBP-TEMP-409J (FUKUDA COLIN Co., Ltd., Japan) to the palm of the upper limb contralateral to that on which noninvasive blood pressure was measured. A PI-measuring probe was placed on the second finger of the upper limb. The temperature probe was unaffected by the air heater.

2.4. Anesthesia procedure and warming methods

A 3M™ Bear Hugger™ Patient Warming Model 675 (Arizant Healthcare Inc., Prairie, MN) was used as the air heater. The operating table was warmed using 3M™ Bear Hugger™ Underbody Blanket 585 (Arizant Healthcare Inc., Prairie, MN). The temperature was increased to 43°C 30 minutes before the patient entered the operating room. The participants' bodies were warmed to 43°C in the supine position from entry until just before the initiation of surgical positioning. To heat the thighs, strips on either side of the lower body blanket were tied to the thighs of the participants. The hot air heater was activated after the surgical position was fixed and before the start of the surgery to ensure that the hot air was not cutoff during surgery. The heater functioned from the entry into the operating room until the exit.[15] The infusion of carbon dioxide was either not heated or humidified.

Before the start of surgery, the operating room temperature was maintained at 26°C. The infusion used was Physio® 140 (Otsuka Pharmaceutical Co., Ltd., Japan), which was warmed in an operating room warming cabinet (set at 37°C). After entering the operating room, the electrocardiogram leads, blood pressure cuff, and pulse oximeter were fixed with the patient in the supine position. The anesthesiologist in charge administered 0.6 to 1.0 mg/kg propofol, 3.0 to 5.0 mg/kg thiamylal sodium, or 0.15 to 0.30 mg/kg midazolam, 0.3 μg/kg/minute remifentanil, and 0.6 mg/kg rocuronium to induce anesthesia. After sufficient muscle relaxation was achieved, the tracheal tube was inserted into the main bronchus via direct or video laryngoscopy. Anesthesia was maintained using sevoflurane, desflurane, remifentanil, or rocuronium, at the discretion of the anesthesiologist in charge. Total intravenous anesthesia with propofol was administered in a few cases. Intraoperative ventilator settings were set at a tidal volume of 6 to 8 mL/kg, positive end expiratory pressure of 4 to 8 cm H_2O, respiratory rate of 10 to 14 cycles/minute, and fraction of inspired oxygen of 0.4. An open arterial pressure line was secured in the radial arteries of all participants. At our surgery center, the open arterial pressure line was measured during laparoscopic gastrointestinal surgery. The anesthesiologist administered ephedrine, phenylephrine, dopamine, and 6% hydroxyethyl starch to ensure a mean blood pressure > 60 mm Hg.

Before the end of the surgery, 15 mg/kg acetaminophen and 50 mg nonsteroidal anti-inflammatory drugs were administered for analgesia. Fentanyl was administered to ensure that the effective site concentration at the time of awakening was 1 to 2 ng/mL, and 4 mg/kg sugammadex was administered before extubation, after stabilization of spontaneous ventilation and recovery from muscle relaxation. After extubation, the patient was transferred to the postoperative observation room or the intensive care unit.

2.5. Statistical analysis

Patient medical history as well as surgical and anesthetic factors are presented as medians (interquartile ranges). Data for PI and central and peripheral temperature values were continuously collected from 1 minute before the anesthetic injection (baseline). To minimize potential bias and accuracy issues, we used a mean of 10 seconds before and after (e.g., 1 minute later:50 seconds to 1 minute 10 seconds for a total of 11 data). Figure 1 shows the anesthesia induction process. Data were obtained immediately after the injection of the anesthetic 30 minutes later. Only the central temperature was measured for up to 60 minutes after the central temperature was unaffected by the outside air during surgical positioning. Variation was defined as the difference between the value after injection of the anesthetic (60 minutes after the induction of anesthesia for central temperature and 30 minutes after the induction of anesthesia for peripheral temperature) and baseline. The ratio of variation was used in the analysis of PI and was defined as the ratio of the baseline PI to the value after injecting the anesthetic. The PI and central and peripheral temperatures after anesthesia induction were analyzed using repeated-measures analysis of variance. Analysis of baseline PI and the PI ratio of variation can prove that peripheral blood perfusion before and after anesthesia induction correlates with central temperature. Furthermore, it can be linked to body temperature management interventions using the PI as an index. The primary endpoint was analyzed using Spearman correlation analysis between the variation in central temperature and PI. The secondary endpoints were analyzed using Spearman correlation analysis between the variation in the peripheral temperature and PI. In the present study, the maximum intraoperative core temperature decrease was – 0.4 ± 0.2°C, which was within normal physiological variation in temperature (approximately – 0.5°C).[16] Therefore, in this study, the decrease in body temperature associated with general anesthesia was defined as a decrease in central temperature of ≥ 0.6°C from the time of anesthesia induction. Receiver operating characteristic curve analysis was performed to predict the decrease in central temperature due to general anesthesia, and the cutoff values of baseline PI and ratio of variation were obtained. Differences with a significance level of 5% were considered statistically significant. Statistical software JMP ® 15 (SAS Institute Inc., Cary, NC) was used.

3. Results

3.1. Participant demographics

Among the 106 patients scheduled for surgery during the study period, 100 were enrolled. Patients who did not provide consent (n = 3) or underwent emergency surgery (n = 3) were excluded. None of the patients were lost to follow up (Fig. 2). Patient characteristics are shown in Table 1.

3.2. Changes in each parameter before and after anesthesia induction

Figures 3–5 show the changes in the PI and the peripheral and central temperatures. Compared with those at baseline, the PI ($P < .01$) and peripheral temperature increased after 30 minutes ($P < .01$), whereas the central temperature decreased after 60 minutes ($P < .01$).

3.3. Relationship with baseline PI

The baseline PI showed a significant association with the amount of variation in peripheral and central temperatures 30 minutes after anesthesia induction ($r = -0.239$, $P < .01$; $R = 0.437$, $P < .01$, respectively; Fig. 6).

3.4. Relationship with the PI ratio of variation

The PI ratio at 30 minutes was significantly associated with the amount of variation in peripheral and central temperatures at 30 and 60 minutes after anesthesia induction ($R = 0.443$, $P < .01$; $r = -0.535$; $P < .01$; Fig. 7), respectively.

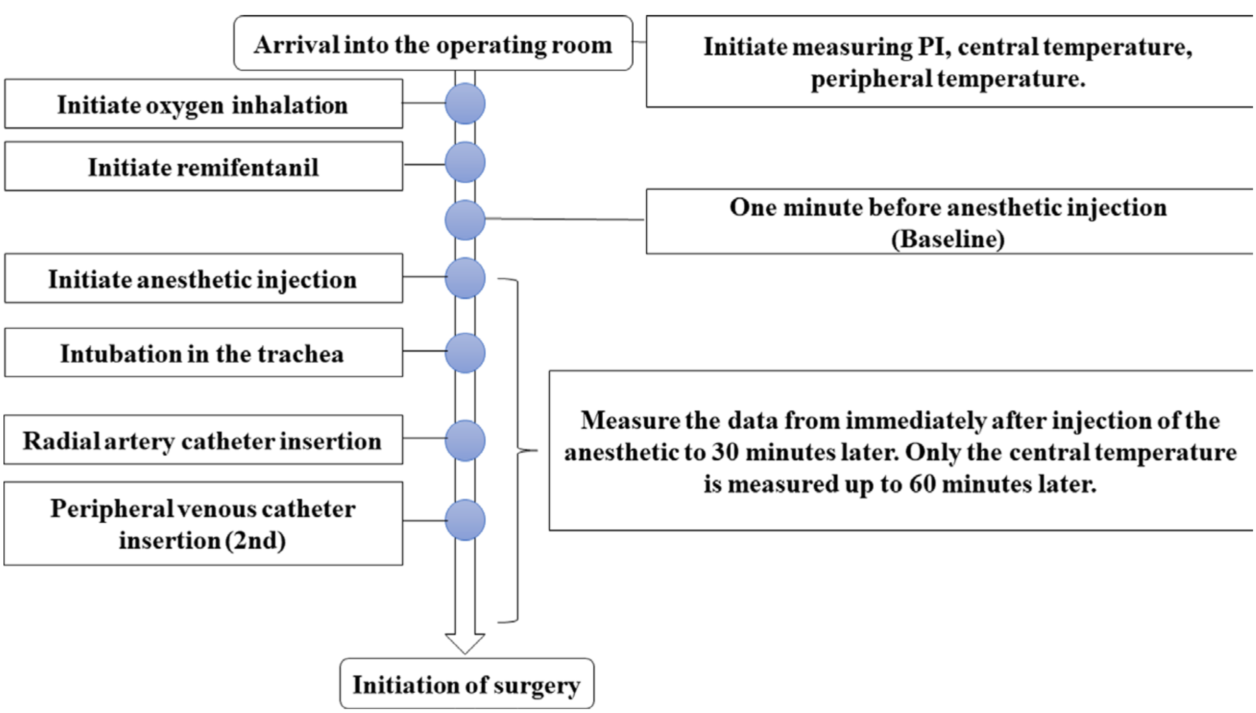

Figure 1. Flow and analysis from entry in the operating room to the initiation of surgery. The flow chart shows the content and timing of medical interventions and data collection from the time of entry into the operating room.

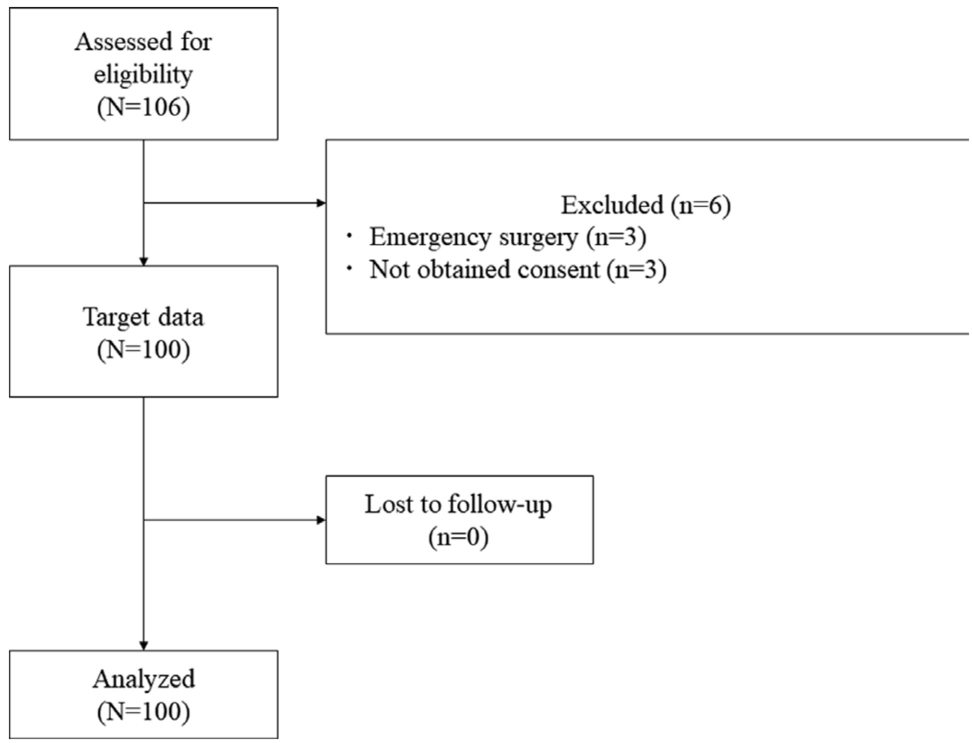

Figure 2. Trial STROBE diagram. Among the 106 patients scheduled for surgery during the study period, 100 patients provided consent. Patients who did not provide consent (n = 3) and those who had undergone emergency surgery (n = 3) were excluded. STROBE = The Strengthening the Reporting of Observational Studies in Epidemiology Statement.

3.5. Prediction of central temperature decrease by baseline PI

Receiver operating characteristic curve analysis was performed to predict the decrease in central temperature 30 minutes after anesthesia induction based on baseline PI. Considering the central temperature decrease by at least 0.6°C after 30 minutes to be a positive result, area under curve and Youden index were 0.744 and 0.456, respectively. Thus, the PI cutoff value was set at 2.30 (Fig. 8).

3.6. Prediction of the central temperature decrease by the PI ratio of variation

Receiver operating characteristic curve analysis was used to predict the decrease in central temperature 60 minutes after anesthesia induction based on the PI ratio of variation after 30 minutes. Considering the central temperature decrease by at least 0.6°C after 60 minutes to be a positive result, the area under curve and Youden index were 0.857 and 0.693, respectively. Thus, the cutoff value for PI ratio of variation was set at 1.58 (Fig. 9).

4. Discussion

Induction of general anesthesia results in the redistribution of heat from the central to the peripheral parts of the body, followed by heat loss exceeding metabolic heat production. Moreover, general anesthesia can markedly impair body temperature regulation and cause peripheral vascular contraction and shivering after the termination of anesthesia. Therefore, monitoring the central temperature during general or local anesthesia and maintaining a normal body temperature are necessary.[17] In this study, we recorded the change in body temperature from before to after anesthesia induction by measuring the central and peripheral body temperatures immediately after the patient entered the operating room. Similarly, regarding the PI, it was possible to accurately record all data from the patient's entry to discharge from the operating room and analyze the relationship with body temperature. The results of the present study demonstrate that anesthesia induction tends to increase the PI. The PI before and after anesthesia induction showed significant correlations with the central temperature decrease and peripheral temperature increase, which supported the study hypothesis. This is consistent with previous reports, which state that PI is associated with central temperature and correlated with intraoperative peripheral temperature and the peripheral central temperature gradient during cesarean section.[10,18–20] Thus, it may be possible to estimate and prevent redistribution hypothermia at 30 and 60 minutes after anesthesia induction by managing body temperature according to the baseline PI before and PI ratio of variation at 30 minutes before and after anesthesia induction, respectively. This result regarding perioperative body temperature management can be considered novel, and we aim to formulate a body temperature management protocol to be followed during the induction of general anesthesia.

The decrease in the central temperature 30 minutes after anesthesia induction was associated with the PI 1 minute before anesthesia induction, which was the baseline in this study. The results of this study suggest that the PI value before anesthesia induction may be an effective tool for predicting the decrease in central temperature at an early stage during general anesthesia. Patients with a low baseline PI have a low peripheral temperature and a large central peripheral temperature difference; thus, preoperative warming may prevent perioperative hypothermia. Preoperative warming aims to prevent body temperature redistribution by increasing the patient's peripheral temperature before anesthesia induction and reducing the central-peripheral temperature difference. Accordingly, the body periphery must be kept warm before the patient's entry into the operating room to maintain the PI at ≥ 2.30 before anesthesia induction. Preoperative heating refers to active heating from a point before the patient's entry into the operating room to

Table 1

Patient characteristics (N = 100).

Age (yr)	71 (61–78)
Sex	
Male	57 (57.0%)
Female	43 (43.0%)
Height (cm)	161.0 (153.0–167.3)
Weight (kg)	57.1 (69.5–46.9)
Body mass index (kg/m^2)	22.0 (18.8–25.4)
Anesthesia time (min)	414.5 (330.0–472.0)
Operative time (min)	335.5 (261.0–400.8)
Amount of bleeding (mL)	20.0 (10.0–58.8)
Urine volume (mL)	300.0 (105.0–457.5)
Total fluid volume (mL)	2515.5 (2000.5–2907.5)
Infusion warming apparatus	
Used	93 (93.0%)
Not used	7 (7.0%)
Intraoperative blood transfusion	
Required	8 (8.0%)
Not required	92 (92.0%)
Postoperative shivering	
No	97 (97%)
Score 1	1 (1%)
Score 2	2 (2%)
Preoperative total protein (g/dL)	6.7 (6.1–7.0)
Preoperative albumin (g/dL)	3.9 (3.4–4.3)
Preoperative hemoglobin (g/dL)	11.8 (10.6–13.6)
Hypertension	
Yes	19 (19.0%)
No	81 (81.0%)
Diabetes mellitus	
Yes	6 (6.0%)
No	94 (94.0%)
Angina pectoris	
Yes	7 (7.0%)
No	93 (93.0%)
American society of anesthesiologists-physical status class	
1	5 (5.0%)
2	89 (89.0%)
3	6 (6.0%)
Stages of cancer	
Stage I	44 (44.0%)
Stage II	29 (29.0%)
Stage III	27 (27.0%)

Values are presented as median (interquartile range) or number (percentage).

a point immediately before anesthesia induction. Preoperative heating using a warm air heater effectively prevents redistribution hypothermia.[21–24] Preoperative warming methods include the use of a warming wrap, warm air heater, infusion warming, and room temperature adjustment.[25–27] Additionally, in recent years, a gown type warm air heater that can be used before the patient enters the operating room has been reported to be effective.[28] Furthermore, operating table warming, room temperature adjustment, and infusion warming, which were used in this study, should be standard practice for general anesthesia patients.[29] As a warm air heater warms the entire body, the use of a carbon fiber–based heater that can only warm the peripheries is also effective. Therefore, to maintain and increase the PI, it is necessary to assess its use in combination with a warm air heater.[27] Anesthesiologists must confirm that PI can be maintained appropriately before anesthesia induction to prevent redistribution hypothermia. However, additional research is required to validate these findings.

The ratio of variation in PI 30 minutes after anesthesia induction was associated with a decrease in central temperature 60 minutes later. If the PI increases by 1.58-fold 30 minutes after anesthesia induction compared with the baseline PI 1 minute before anesthesia induction, this will lead to a decrease in the central temperature 60 minutes after anesthesia induction. The increase in peripheral PI after anesthesia induction reflects general anesthetic induced vasodilation, the extent of which affects the temperature redistribution. Thus, maintenance of peripheral vascular resistance following anesthesia induction is expected to prevent peripheral vasodilation and decrease the central temperature. The use of vasoconstrictors from the time of general anesthesia induction decreases the magnitude of redistribution hypothermia.[30] Additionally, the occurrence of hypothermia after 60 minutes can be predicted by obtaining the PI ratio 30 minutes after anesthesia induction, so that additional body temperature management intervention can be performed. As an additional heating method, warm air heating is the most effective. Therefore, in addition to considering the use of an over body blanket with an underbody blanket, heating of the infusion solution should also be considered.

In terms of the limitations and difficulties of this study, it is necessary to implement a perioperative body temperature management protocol, with the PI cutoff value obtained from our results as an index to ascertain whether redistribution hypothermia can be predicted. Furthermore, we did not use standardized

	PI
Baseline	3.07 (1.39–4.63)
Induction	2.98 (1.55–4.76)
1 min	2.97 (1.41–4.55)
5 min	3.57 (1.94–5.88)
10 min	4.37 (2.51–5.97)
15 min	3.93 (2.48–5.97)
20 min	4.01 (2.59–6.14)
25 min	3.97 (2.80–5.87)
30 min	4.00 (2.79–6.14)

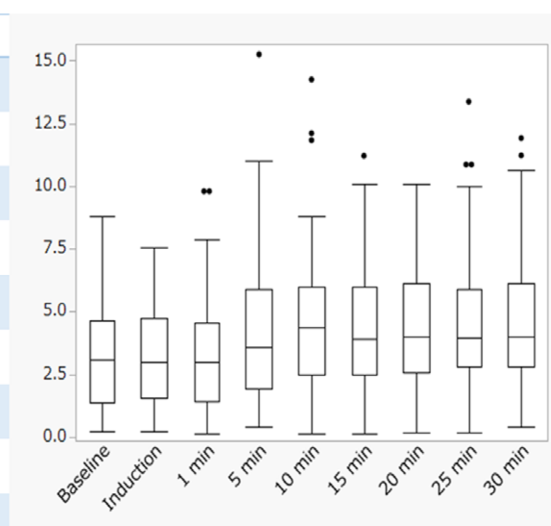

Figure 3. Progress and changes in the perfusion index (PI). After anesthesia induction, PI increased over time ($P < .01$).

	Peripheral temperature
Baseline	32.5 (30.9–34.3)
Induction	32.9 (31.1–34.4)
1 min	32.9 (31.2–34.4)
5 min	33.4 (31.9–34.6)
10 min	33.5 (31.9–34.5)
15 min	33.7 (32.4–34.5)
20 min	34.0 (32.5–34.9)
25 min	34.2 (33.1–35.3)
30 min	34.7 (33.3–35.6)

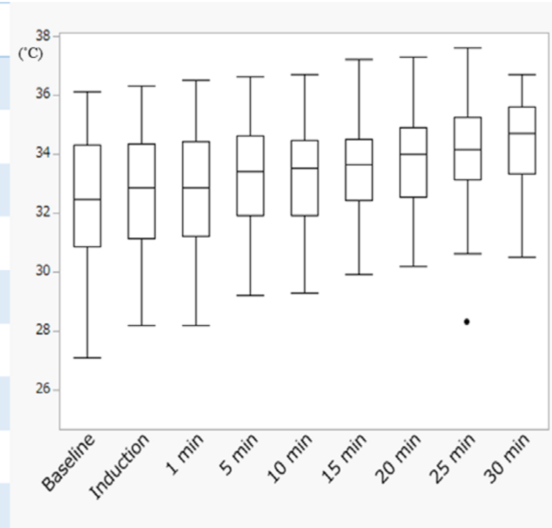

Figure 4. Progress and changes in the peripheral temperature. After anesthesia induction, the peripheral temperature increased over time ($P < .01$).

	Central temperature
Baseline	37.1 (36.7–37.3)
Induction	37.1 (36.7–37.3)
1 min	37.2 (36.7–37.3)
5 min	37.2 (36.7–37.3)
10 min	37.1 (36.6–37.3)
15 min	37.0 (36.5–37.2)
20 min	36.9 (36.5–37.1)
25 min	36.8 (36.4–37.1)
30 min	36.7 (36.4–36.9)
60 min	36.7 (36.3–36.9)

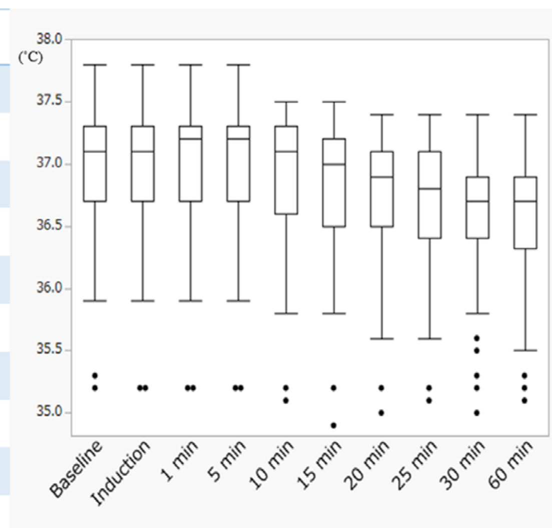

Figure 5. Progress and changes in the central temperature. After anesthesia induction, the central temperature increased over time ($P < .01$).

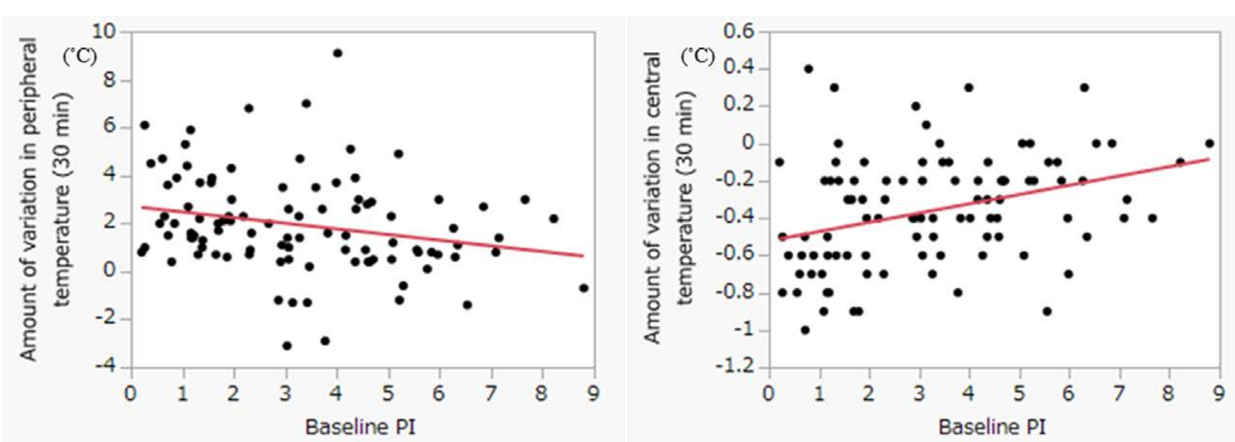

Figure 6. Relationship with the baseline perfusion index (PI). The baseline PI showed a significant association with the amount of variation in peripheral temperature at 30 minutes after anesthesia induction ($R = 0.239$; $P < .01$) and the amount of variation in central temperature at 60 minutes after anesthesia induction ($R = 0.437$; $P < .01$).

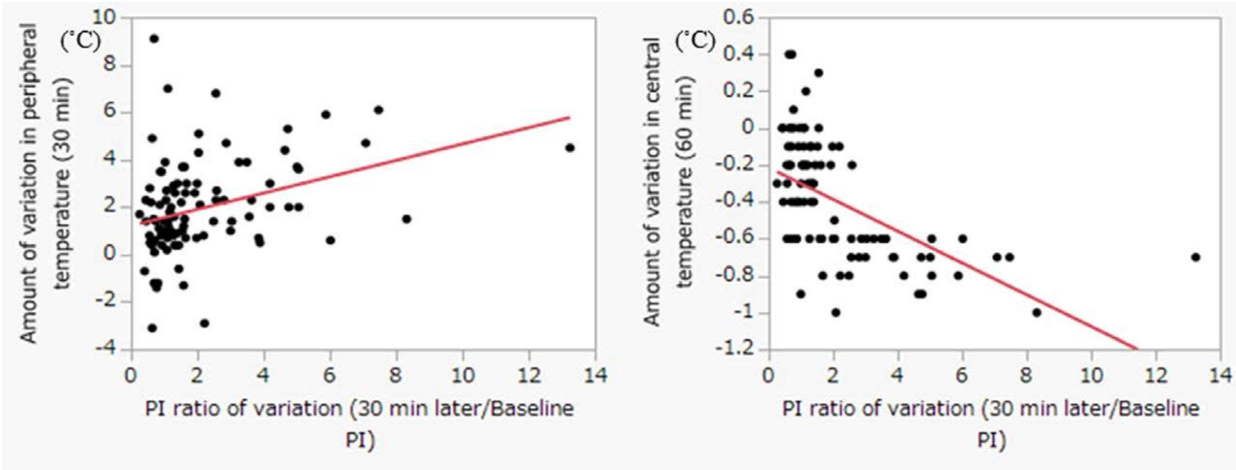

Figure 7. Relationship with the perfusion index (PI) ratio of variation. The PI ratio of variation at 30 minutes, when it was the maximum, was significantly associated with the amount of variation in peripheral temperature at 30 minutes after anesthesia induction (R = 0.443; P < .01) and the amount of variation in central temperature at 60 minutes after anesthesia induction (R = 0.535; P < .01).

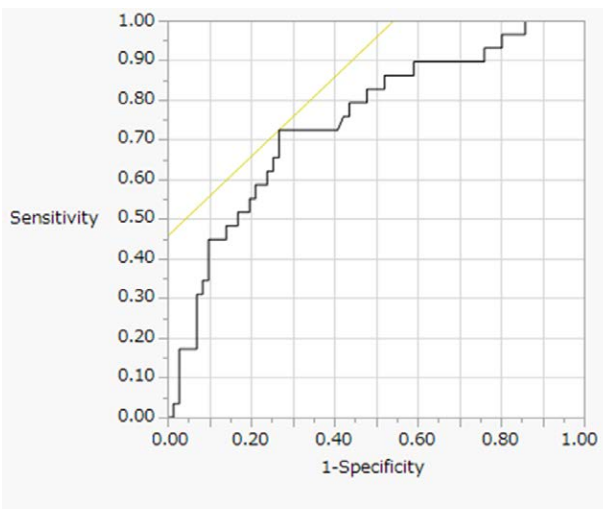

Figure 8. Receiver operating characteristic curve analysis of central temperature decrease after anesthesia induction. This figure shows the changes in central temperature measured 30 minutes after anesthesia with baseline perfusion index (PI). Considering central temperature decrease by at least 0.6°C after 30 minutes to be a positive result, the area under the receiver operating characteristic curve and Youden index were 0.744 and 0.456, respectively. On this basis, the PI cutoff value was set at 2.30.

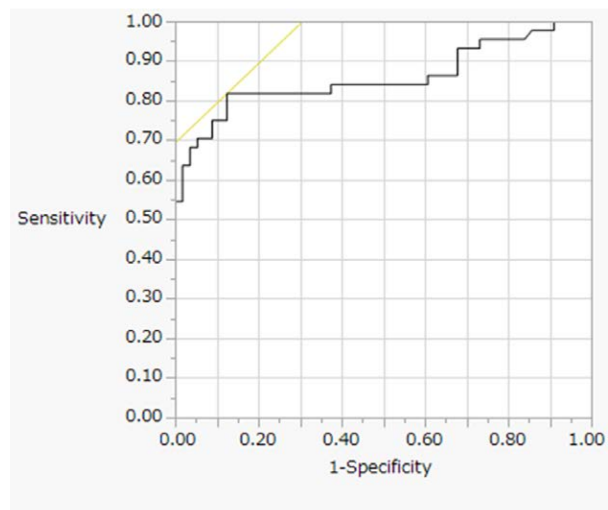

Figure 9. Receiver operating characteristic curve analysis of perfusion index (PI) rate of variation and central temperature decrease. This figure shows the results of the analysis of the PI rate of variation 30 minutes after anesthesia induction and central temperature decrease 60 minutes after anesthesia induction. Considering central temperature decrease by at least 0.6°C after 60 minutes, the area under the receiver operating characteristic curve and Youden index were 0.857 and 0.693, respectively. On this basis, the cutoff value for the PI ratio of variation was set at 1.58.

anesthetics and preoperative warming in this study because the same anesthetic or preoperative heating was not used in all patients. By not standardizing these, measuring the baseline PI and PI ratio of variation – regardless of which anesthetic is used – will help predict a decrease in central temperature. However, if further analysis is performed in the future, it will be necessary to standardize and analyze each individual anesthetic without preoperative warming. Additionally, this was a single center, prospective, observational study of patients scheduled for surgery. A prospective, observational study including patients who have undergone emergency surgery and have difficulty in body temperature management should be performed to strengthen perioperative body temperature management. Although the participants of this study were adults, it has been reported that PI increases with anesthesia induction, even in children.[31] Therefore, even in pediatric surgery patients, an increase in PI may lead to changes in body temperature, necessitating the need to expand the scope of this research. Additionally, in this study, a decrease of ≥ 0.6°C in the central temperature was defined as a decrease in body temperature due to general anesthesia. However, setting the standard for lowering body temperature to 0.6°C limited our data collection because intraoperative body temperature control is thorough in Japan, and there was almost no severe decrease in body temperature up to 1°C to 3°C at the time of general anesthesia induction. However, in some studies, unplanned perioperative hypothermia resulted in a decrease of 1°C to 3°C at the central temperature.[7,8] Furthermore, as there was very little data regarding patients with hypothermia below 36°C in this study, analysis of such extreme cases was not possible. Therefore, the PI cutoff value may change when severe redistribution hypothermia is used as the criterion for lowering body temperature. To solve this problem, joint research with other multinational institutions is necessary.

In conclusion, PI has a significant relationship with central and peripheral temperatures. This suggests that if the baseline

PI (1 minute before induction of anesthesia) is ≤ 2.30 and the PI 30 minutes after induction of anesthesia is at least 1.58-fold the baseline PI, there is a high probability of the central temperature decreasing by at least 0.6°C by 30 minutes after each of the time points (30 minutes and 60 minutes after anesthesia induction). Therefore, PI provides a useful scientific basis for perioperative management with the aim of preventing a decrease in the central temperature.

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