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ORIGINAL ARTICLE

What is the predictor of the intraoperative body temperature in abdominal surgery?

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Abstract

Purpose Inadvertent hypothermia is a relatively common intraoperative complication. Few studies have investigated predictors of body temperature change or the effect of the blanket type used with a forced-air warming device during the intraoperative period. We investigated the predictive factors of intraoperative body temperature change in scheduled abdominal surgery.

Methods We retrospectively reviewed the data from 2574 consecutive adult patients who underwent scheduled abdominal surgery in the supine position. Temperature data were collected from anesthesia records. Multiple regression analysis was performed at 60, 120, and 180 min after the surgical incision to identify the factors influencing body temperature change. We conducted nonlinear regression analysis using the equation $\Delta T = \alpha\,(e^{-\gamma t}—1) + \beta t$, where ΔT represented the change in intraoperative core temperature (°C), t represented the surgical duration (minutes), and α, β, and γ were constants.

Results The intraoperative core temperature change was explained by the equation $\Delta T = 0.59\,(e^{-0.018t} - 1) + 0.0043t$. Younger age, higher body mass index (BMI), male sex, laparoscopic surgery, and use of an underbody blanket were associated with increased core temperature at 1 or 2 h after surgical incision. Male sex and an underbody blanket remained strong predictive variables even 3 h after surgical incision, whereas BMI had little explanatory power at this timepoint. The difference in the heating effect of an underbody versus an overbody blanket was 0.0012 °C per minute.

Conclusions The blanket type of the forced-air warmer, age, sex, laparoscopic surgery, and BMI are predictors of intraoperative core temperature change.

Keywords Body temperature · Forced-air warming · Inadvertent hypothermia

Introduction

Inadvertent hypothermia is a relatively common intraoperative complication. In homeothermic species, body temperature is well maintained under normal conditions by regulating the blood flow of the superficial vessels [1]. However, peripheral vasodilation caused by many anesthetic agents, including volatile anesthetics, propofol, and opioids, can promote heat loss [2, 3]. Core hypothermia develops rapidly after induction of general anesthesia mainly due to the core-to-skin redistribution of body heat by peripheral vasodilation and a cold ambient temperature in the operating room [4, 5]. Hypothermia can result in a variety of adverse effects, including cardiac events [6], shivering, increased intraoperative blood loss and transfusion [7, 8], surgical site infection [9], and reduced clearance of various drugs [10]. Thus, patients who experience intraoperative hypothermia may have a higher mortality and longer hospital stay [11].

Previously reported risk factors for hypothermia include a small body weight-to-body surface area ratio [12], age, height and weight, preoperative systolic blood pressure [13], and abdominal surgery [14]. However, few studies have investigated the intraoperative body temperature change itself.

A forced-air warming device is widely used to keep patients warm during the intraoperative period. This device comprises a warming unit and a disposable blanket. An underbody blanket that is placed under the patient has become available in recent years. The heating area of the underbody blanket is restricted to the side of the body, as

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the area compressed by the body is not effectively warmed. However, few studies have evaluated the warming effect of the underbody blanket.

We, therefore, investigated the predictive factors of intraoperative body temperature in scheduled abdominal surgery, including the blanket type used in the forced-air warming device.

Methods

Study subjects

This study was approved by the Ethical Committee for Clinical Studies of the Kyushu University School of Medicine. The 3918 patients who underwent abdominal surgery under general anesthesia at Kyushu University Hospital from January 2013 to December 2016 were identified using hospital records. Inclusion criteria were: age over 20 years, American Society of Anesthesiologists Physical Status class I–III, intraoperative supine position, esophageal body temperature monitoring, and operation time > 90 min. Patients with severe cardiovascular disease, peripheral vascular disease, preoperative hypothermia or hyperthermia, and excessive surgical bleeding that required blood transfusion were excluded. Patients undergoing emergency surgery were also excluded. A final total of 2574 patients were included in the data analysis.

Induction and maintenance of anesthesia

Epidural puncture was performed in 55% of patients, mainly via the paramedian approach. After performing the aspiration test to verify correct epidural catheter placement, 3 ml of 1% mepivacaine was injected through the epidural catheter. Epidural anesthesia is never used for maintenance of anesthesia in our hospital. All patients recruited in the current study underwent general anesthesia. Anesthetic, hemodynamic, and fluid management were at the discretion of the attending anesthesiologists. Most patients received intravenous fentanyl followed by propofol and rocuronium for induction. Anesthesia was typically maintained with sevoflurane, desflurane, or propofol. Remifentanil and rocuronium were administered intravenously as an analgesic or a muscle relaxant, respectively.

Temperature management

In our hospital, a forced-air warming device was routinely used during abdominal surgeries to prevent hypothermia unless contraindicated. Thermal care, including the choice of disposable blanket type (3M Bair Hugger® underbody blanket Model 585 or overbody blanket Model 522), was at the discretion of the attending anesthesiologist. Although Model 585 is labelled for use with the patient in the lithotomy position, the IRB of Kyushu University Hospital approved the off-label use of the Model 585 warming blanket with the patient in the supine position (approval number: 30-234). Furthermore, the manufacturer of Model 585 stated that this blanket can be used for any position, including the supine position (personal communication). Patients did not receive pre-warming to prevent intraoperative hypothermia. After intubation, a temperature probe (Smiths Medical, Rockland, MA) was inserted into the distal esophagus to measure the core body temperature. Body warming by the forced-air warmer was started at the surgical incision in almost all study subjects. The initial set temperature of both the underbody blanket (model 585) and the overbody blanket (model 522) was 38 °C. The ambient operating room temperature was set at 26 °C with a humidity of 40% during surgery under normal circumstances. Intravenous fluids were warmed to near body temperature via a fluid warmer (HOTLINE® Smiths Medical, Rockland, MA).

Measurement of intraoperative temperature changes

Basic patient information was obtained from the hospital records. The temperature was recorded every minute, and was downloaded by digital file from the anesthesia records. To detect the predictive factors for body temperature change, the outcome measurements were performed at 60, 120, and 180 min after the surgical incision. The type of forced-air warming blanket was detected via a QR code-based medical material identification system.

Measurement of the estimated heating area of the blankets

A brief study on the estimated body surface area exposed to the air warmed by each blanket was conducted in 10 healthy volunteers. We applied a soft cloth to each subject's body and marked the estimated heating area of each blanket. We did not include the area of the blanket beneath the body in the underbody blanket group, as there is no heating effect in the areas compressed by the body. The body surface area on the ventral side from the anterior axillary line was also excluded, as warmed air is trapped by the surgical drapes. Marked cloth was photographed and used for analysis. Image analysis was performed using Adobe Photoshop CC (Adobe Systems, San Jose, Calif) and Image J software (National Institute of Health Bethesda, MD).

Nonlinear regression analysis

Nonlinear regression analysis was conducted to develop a model to explain the transition of the intraoperative body temperature. We assumed that the transition of the body temperature could be calculated as the sum of the redistribution hypothermia and the warming effect.

Primarily, the following equation was selected to develop this model:

$$\Delta T = a\left(e^{-bt} - 1\right) + c\left(1 - e^{-dt}\right)$$

where ΔT is the response variable (changes in body temperature), t represents the number of minutes. Anesthesia-induced redistribution hypothermia results in an initial rapid decrease in core temperature, with the decrease in body temperature eventually reaching a plateau [15]. Hence, we applied the downwardly convex curve to the formula used to calculate redistribution hypothermia: a ($e^{-bt} - 1$). We initially applied the upwardly convex curve to the formula used to calculate the warming effect, as we assumed that the elevation in core temperature caused by the forced-air warmer would plateau over time: c ($1 - e^{-dt}$).

By performing non-linear regression analysis, we obtained the following formula for the transition of the intraoperative core temperature from the time of the surgical incision:

$$\Delta T = 0.58\left(e^{-0.019t} - 1\right) + 4.84\left(1 - e^{-0.00096t}\right)$$

(Coefficient of determination (R^2) = 0.917, residual standard deviation = 0.0094, sum of the squared errors of prediction = 0.018).

We found that the formula showing the warming effect was almost linear, as the coefficient "d" was an extremely small value (0.00096). We, therefore, adopted the equation $\Delta T = \alpha$ ($e^{-\gamma t} - 1$) + βt as a model to explain the transition of the intraoperative core temperature.

Statistical analysis

We initially conducted a multiple linear regression analysis using the Bayesian information criterion in a stepwise forward selection method with the following variables: age, sex, BMI, American Society of Anesthesiologists physical status, bleeding volume, urine volume, blanket type of the forced-air warmer, laparoscopic surgery, upper or lower abdominal surgery, time between anesthetic induction and surgical incision, initial body temperature at the time of the surgical incision, and infusion volume. The variables that the variance inflation factor (VIF) was < 5 were excluded to avoid multicollinearity of the equation. The following five variables were selected from the 12 candidate variables at 1 or 2 h after the surgical incision and were entered in a stepwise model: age, BMI, sex, laparoscopic surgery, and the blanket type of the forced-air warmer. Similarly, the same four variables (excluding BMI) at 3 h after the surgical incision were selected for use in a stepwise model. We, therefore, used these five variables for regression analysis to enable easy comparison of data.

The estimated warming area of an overbody or underbody blanket was compared using the Wilcoxon signed-rank test.

All statistical analyses were conducted using JMP Pro (ver. 12) software (SAS Institute Inc., Cary, NC, USA). A P value of < 0.05 was considered statistically significant. Data are presented as mean ± standard deviation or median [Q1, Q3].

Results

The demographics and perioperative variables of the study subjects are shown in Table 1, and the intraoperative changes in body temperature are shown in Fig. 1. The core

Table 1 Demographic and clinical characteristics

Characteristic	$n = 104$
Age (years)	57 ± 11
Height (m)	1.61 ± 0.08
Weight (kg)	59.4 ± 11.0
BMI (kg/m^2)	22.9 ± 3.2
Sex, *n* (%)	
Female	68 (65%)
Male	36 (35%)
ASAPS, *n* (%)	
Category 1	42 (40%)
Category 2	62 (60%)
Time to incision (min)	37 ± 6
Operative time (min)	235 ± 62
Baseline body temperature (°C)	36.4 ± 0.4
Blood loss (g)	55 ± 65
Urine output (ml)	716 ± 560
WHR	0.88 ± 0.07
Fat measurement with ultrasound	
Preperitoneal fat (mm)	8.1 ± 3.7
Subcutaneous fat (mm)	9.6 ± 3.6
Fat measurement with CT	
Cross sectional area (cm^2)	474 ± 109
Visceral fat (cm^2)	94 ± 53
Subcutaneous fat (cm^2)	150 ± 70

Time to incision: time between anesthetic induction and surgical incision. Baseline body temperature: temperature at the time of the surgical incision. Data are presented as number (%) or mean ± standard deviation

BMI body mass index, *WHR* waist to hip ratio, *ASAPS* American Society of Anesthesiologists physical status score

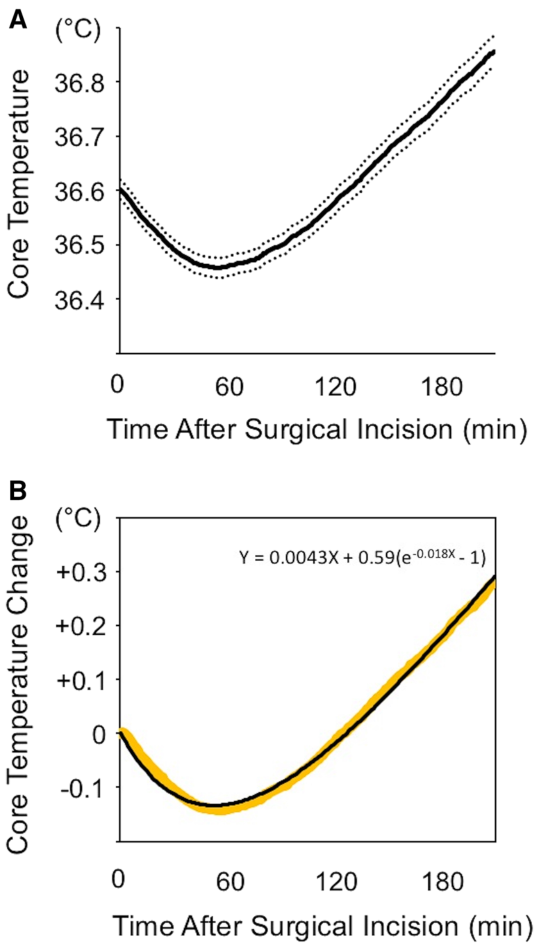

Fig. 1 Core temperature during scheduled abdominal surgery. **a** Core temperature (with 95% confidence intervals) from the time of the surgical incision. During the first hour, core temperature decreased by about 0.15 °C. Core temperature then plateaued and subsequently increased. The body temperature returned to the base temperature about 2 h after the surgical incision. **b** Change in core temperature from the time of the surgical incision. Non-linear regression analysis was used to derive the formula shown in the figure

temperature decreased for about 1 h from the time of the surgical incision, and subsequently increased. The body temperature returned to the base temperature about 2 h after the surgical incision, and thereafter increased linearly.

Using non-linear regression analysis, we obtained the following formula for intraoperative core temperature change (Fig. 1):

$$\Delta T = 0.59\left(e^{-0.018t} - 1\right) + 0.0043t$$

(Coefficient of determination (R^2) = 0.996, residual standard deviation = 0.0081, sum of the squared errors of prediction = 0.008).

Multiple regression analysis was conducted to determine the factors correlated with intraoperative body temperature change. Younger age, higher BMI, male sex, laparoscopic surgery, and use of an underbody blanket were significantly associated with increased core temperature at 1 h after the surgical incision (Table 2). Sex and the use of an underbody blanket remained strong predictive variables even 2 or 3 h after the surgical incision, whereas BMI had no explanatory power at 3 h after the surgical incision (Tables 3, 4). The difference in the heating effect of an underbody blanket versus an overbody blanket was assumed to be 0.0012 °C per minute, considering that the warming effect was approximately linear.

We also conducted multiple linear regression analysis to determine the effect of these five independent variables on the intraoperative change in body temperature in a minute-by-minute manner. The variables that had explanatory power from several minutes after the surgical incision were BMI, sex, laparoscopic surgery, and the blanket type of the forced-air warmer; whereas age only had sufficient explanatory power from about 30 min after the surgical incision (Table 5). Furthermore, BMI rapidly lost explanatory power from 2 h after the surgical incision.

We next investigated the estimated patient body surface area exposed to the warmed air.

The heating area of the underbody blanket was significantly larger than the overbody blanket when assessed by the Wilcoxon signed rank test (2868 [2601, 3096] vs 2412 [2059, 2478] cm^2, $P = 0.016$).

Table 2 Multiple regression analysis (60 min after the surgical incision)

	Coefficient [95% CI]	SE	*T*	*P* value
Age	− 0.002 [− 0.003, − 0.001]	0.000	− 5.37	< 0.001
BMI	0.011 [0.008, 0.014]	0.002	6.53	< 0.001
Male	0.085 [0.061, 0.108]	0.012	6.95	< 0.001
Laparoscopic surgery	0.100 [0.076, 0.124]	0.012	8.27	< 0.001
Underbody	0.099 [0.076, 0.122]	0.011	8.33	< 0.001

Dependent variable: temperature. Data are presented as number (%) or mean ± standard deviation

CI confidential interval, *SE* standard error, *BMI* body mass index

Table 3 Multiple regression analysis (120 min after the surgical incision)

	Coefficient [95% CI]	SE	*T*	*P* value
Age	− 0.004 [− 0.005, − 0.002]	0.001	− 5.46	< 0.001
BMI	0.010 [0.005, 0.015]	0.003	3.91	< 0.001
Male	0.132 [0.095, 0.169]	0.019	7.05	< 0.001
Laparoscopic surgery	0.106 [0.070, 0.143]	0.018	5.76	< 0.001
Underbody	0.184 [0.149, 0.219]	0.018	10.22	< 0.001

Dependent variable: temperature. Data are presented as number (%) or mean ± standard deviation

CI confidential interval, *SE* standard error, *BMI* body mass index

Table 4 Multiple regression analysis (180 min after the surgical incision)

	Coefficient [95% CI]	SE	*T*	*P* value
Age	− 0.004 [− 0.005, − 0.002]	0.001	− 3.91	< 0.001
BMI	0.006 [− 0.001, 0.013]	0.004	1.69	0.092
Male	0.134 [0.083, 0.186]	0.026	5.11	< 0.001
Laparoscopic surgery	0.080 [0.030, 0.130]	0.026	3.13	0.002
Underbody	0.227 [0.178, 0.276]	0.025	9.15	< 0.001

Dependent variable: temperature. Data are presented as number (%) or mean ± standard deviation

CI confidential interval, *SE* standard error, *BMI* body mass index

Table 5 The time period when the *P* value of each independent variable was below 0.001 in 180 min from the surgical incision

	Time period (min)
Age	34–180
BMI	6–126
Male	7–180
Laparoscopic surgery	16–178
Underbody	14–180

BMI body mass index

Discussion

The current study evaluated the variables affecting intraoperative core temperature change during scheduled abdominal surgery. The factors significantly associated with increased core temperature at 1 h after the surgical incision were the use of an underbody blanket, male sex, younger age, laparoscopic surgery, and higher BMI; sex and the use of an underbody blanket remained strong predictive variables even 2 or 3 h after the surgical incision.

The strongest predictor of intraoperative core temperature change was the blanket type of the forced-air warmer, with the underbody blanket resulting in a greater increase in core temperature than the overbody blanket. The difference in the heating effect produced by each blanket type may be mainly due to the difference in the body surface area exposed to the warmed air, as the heating area of the blanket is the most important factor that determines the heating effect [16]. However, there was only a small difference between the blanket types in the heating effect per minute, and it, therefore, seems unnecessary to use an underbody blanket during short surgeries.

Sex was also a strong predictor of core temperature until 3 h after the surgical incision, with males showing a higher intraoperative core temperature than females. The precise mechanism of the sex difference is uncertain, but it may be because females have lower conductance than males due to a greater thickness of the subcutaneous tissues [17]; furthermore, compared with females, males naturally have greater skeletal muscle mass, which is an important site of non-shivering thermogenesis [18].

Age was inversely correlated with intraoperative body temperature in the present study, similarly to the results reported in a small-size prospective study [19]. However, age was not associated with the body temperature until 30 min after the surgical incision. The formula $\Delta T = \alpha (e^{-\gamma t} - 1) + \beta t$ indicates that age mainly affects the warming effect rather than redistribution hypothermia. The core temperature required to trigger thermoregulatory vasoconstriction is reportedly lower in older adult patients than in younger patients [20].

Patients who underwent laparoscopic surgery had a higher intraoperative core temperature than those who underwent open surgery. This contrasts with the findings of previous studies that found no significant association between laparoscopic surgery and core temperature [21, 22]. This difference in results may be due to the much smaller sample size of these previous studies compared with our study, and/or because the previous studies did not use an electrothermal bipolar vessel sealing system that easily generates heat [23]. In our hospital, the CO_2 gas used to establish pneumoperitoneum was not warmed or humidified; warmed CO_2 gas may result in an even greater intraoperative core temperature difference between those undergoing laparoscopic versus open surgery.

Patients with a higher BMI had a higher intraoperative core temperature than those with a lower BMI during the first hour of abdominal surgery; however, this effect was no longer present at 3 h after the surgical incision. The reason that the BMI no longer affected the core temperature at 3 h after surgical incision may be because the subcutaneous tissue has a high adiabatic effect, and therefore, patients with excess fat may exhibit small core temperature decreases due to redistribution hypothermia and the small heating effect of a forced-air warming device.

We established the equation $\Delta T = \alpha\ (e^{-\gamma t} - 1) + \beta t$ as a model to explain the change in the intraoperative core temperature. The formula showed that the warming effect, βt, was almost linear. This implies that the heating effects of various warming devices may be easily compared, as the heating effect of each device can be shown as the amount per minute for up to 3 h after the surgical incision. Furthermore, this equation shows that the intraoperative core temperature is mainly affected by redistribution hypothermia in the early period after anesthesia induction, whereas the core temperature is strongly affected by the heating effect at several hours after induction.

The risk of hypothermia is reportedly reduced by preoperative amino acid administration [24]. None of the present patients were administered amino acids preoperatively, although some patients received amino acids intraoperatively. Amino acid infusions started after the development of intraoperative core hypothermia reportedly have no effect on rewarming [25]. In our hospital, amino acids are administered to patients only after the development of hypothermia. However, amino acid administration seems to have had little influence on our results.

The present study had some limitations. First, although the air conditioning was set at 26 °C with 40% relative humidity in all operating rooms, the retrospective nature of the present study means that there is no guarantee that the temperature of the operating room was constant for all patients. Previous research has reported a positive relationship between ambient operating room temperature and patient core temperature [14, 26, 27]. Second, none of the study subjects were warmed preoperatively. Further research is needed to clarify whether the equation for the change in body temperature in pre-warmed patients differs from our equation. Third, the underbody blanket used in the present study (model 585) is intended for use with the patient in the lithotomy position. However, the blanket is likely to have a lesser heating effect with the patient in the lithotomy position than in the supine position, as the lower limb is included in the heating area of the underbody blanket using the supine position. Thus, it is unlikely that the use of the model 585 underbody blanket affected our results. Fourth, the formula $\Delta T = 0.59\ (e^{-0.018t} - 1) + 0.0043t$ may not apply in operations with a duration of 3 h or more, as the increase in body temperature may cease due to thermoregulation such as sweating during a long operation. Finally, our results can only be applied to patients undergoing abdominal surgery in the supine position, and the coefficients of the body temperature equation obtained from our study cannot be directly applied to other operating rooms.

In conclusion, the present findings suggest that older adult female patients undergoing abdominal surgery of long duration will benefit from the use of an underbody blanket, as this population is most susceptible to intraoperative decreases in core temperature. Further prospective research is needed to confirm these findings.

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