

A descriptive study of the relationship between preoperative body temperature and intraoperative core temperature change in adults under general anaesthesia

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Background: Despite numerous guidelines on perioperative temperature management, perioperative hypothermia remains common. Prewarming to prevent redistribution hypothermia is supported by evidence, but not widely practised. We investigate the measurement of preoperative mean body temperature as a potential tool for individualising the practice of prewarming.

Methods: We hypothesised that patients who experience intraoperative hypothermia have a lower preoperative mean body temperature. A longitudinal study was conducted in adult patients presenting for ophthalmological surgery under general anaesthesia, to describe the relationship between the incidence of hypothermia within the first hour of anaesthesia and preoperative mean body temperature.

Results: Sixty-five patients were enrolled. Twelve participants (18%) presented to the operating theatre hypothermic (core temperature < 36.0 °C). A further 28 (43%) became hypothermic during the procedure. All hypothermia events occurred within 60 minutes after induction of anaesthesia, and half of the events occurred within 19 minutes. The difference in preoperative mean body temperature between those with and without intraoperative hypothermia was only -0.2 °C (95% CI -0.4, 0.1). This is neither clinically relevant nor statistically noteworthy. In Cox proportional hazards analysis, BMI and ASA status compounded the observed association between preoperative mean body temperature and the incidence of intraoperative hypothermia. A higher BMI and ASA are associated with a lower incidence of hypothermia.

Conclusion: We conclude that intraoperative hypothermia is common and occurs early after induction of anaesthesia. We observed no useful difference in preoperative mean body temperature to help distinguish between patients who become hypothermic and those who do not. Without a useful risk prediction tool, a generic approach to prewarming remains appropriate. Preoperative screening for pre-existing hypothermia should be practised, even in cases considered as low risk.

Keywords: inadvertent perioperative hypothermia, redistribution hypothermia, mean body temperature, mean skin temperature

Introduction

Inadvertent perioperative hypothermia is defined as an unplanned core temperature of less than 36 °C occurring during the perioperative period.^{1,2} It is associated with numerous adverse patient outcomes³⁻⁵ including increased surgical site infection rates,^{4,6} blood loss,^{5,7} length of hospital stay⁶ and cost of care.^{1,8-10} Despite the ubiquity of guidelines to prevent perioperative hypothermia, the reported incidence ranges between 20% and 90%.^{3,11}

In the non-anaesthetised person, peripheral thermoregulatory vasoconstriction maintains the core temperature by limiting blood flow to the skin which interfaces with the cold environment. This creates a heat exchange system with a core-to-peripheral temperature gradient, allowing the core temperature to be maintained despite mean body temperature changes.^{12,13}

Mean body temperature is the average temperature of the body. Under normal thermoregulation, peripheral temperature changes to allow either heat conservation or heat loss for the purpose of maintaining a constant core temperature. With

heat conservation, the gradient between the core and the skin is high and the mean body temperature is lower compared to a heat loss state, where the gradient between the core and the skin is low and the mean body temperature is higher. Anaesthesia obliterates this mechanism by causing peripheral vasodilatation and lowering the hypothalamic thresholds at which thermoregulatory vasoconstriction and shivering responses are initiated.¹⁴ Redistribution hypothermia will occur even in the presence of intraoperative warming.¹⁵ The heat gain from intraoperative warming is not enough to prevent the core temperature from decreasing to hypothermic levels due to the pre-existing temperature gradient between the core and the peripheries.¹⁶ During the first thirty minutes of general anaesthesia, close to 90% of the decrease in core temperature is due to redistribution of heat from the core to the periphery. From thirty to sixty minutes, 66% of the ongoing decrease in core temperature is attributable to heat redistribution.¹⁷ In the absence of prewarming, re-establishing normothermia after redistribution can take longer than an hour.¹⁸ Prewarming supplies heat to the peripheries, reducing the core-to-peripheral gradient prior to anaesthesia-induced heat redistribution.¹⁷

Mechanistically, adverse outcomes are not only related to a single temperature measurement at the end of surgery or on arrival in the postoperative recovery area, but to the duration of hypothermia exposure.¹⁸ Inadvertent hypothermia should be prevented at all times, making prewarming the logical gold standard.

Numerous guidelines are available on perioperative temperature management.^{1,2,19,20} Prewarming is commonly recommended. Despite evidence supporting the efficacy of prewarming periods as short as 10 minutes,²¹ the practice has not been widely adopted. Poor adoption has been attributed to a lack of buy-in from practitioners,¹¹ increase in expenses, and lack of knowledge.¹¹ Some day-case surgery centres claim a low incidence of hypothermia with short procedures and do not want to accrue the extra expense of an active warming device.²²

In an age of precision medicine, guidelines should strive to be patient specific. Although some guidelines include preoperative hypothermia risk assessment, this does not translate to any specific prewarming recommendations,¹ with the exception that those found to be hypothermic preoperatively be warmed prior to induction of anaesthesia. We seek a more individualised approach to prewarming of surgical patients.

The primary objective of this study was to describe the difference in preoperative mean body temperature between patients who develop intraoperative hypothermia, and those who do not. Secondary aims included testing the effect of measured confounders on the association between preoperative body temperature and intraoperative hypothermia. Risk factors associated with inadvertent hypothermia include low ambient temperature, large surface area exposure, open body cavities, cold intravenous fluids, extremes of age, and low body mass index (BMI).¹ We hypothesised that estimated preoperative mean body temperature predicts the extent of initial core temperature decrease post induction of general anaesthesia, with patients

who develop intraoperative hypothermia before sixty minutes having a lower preoperative mean body temperature than those who do not develop intraoperative hypothermia.

Methods

Study design, setting and participants

With approval of the Human Research Ethics Committee of the University of Cape Town (HREC772/2018) and the written informed consent of participants, this study was conducted at a tertiary level hospital in Cape Town, South Africa. We employed a longitudinal study design with repeated measurement of temperature over time. We used consecutive sampling of adult patients presenting for elective ophthalmic surgery requiring general anaesthesia, where the surgery had an expected duration of at least an hour. Ophthalmic surgery was selected due to minimal environmental exposure of the patients, and the lack of blood loss and fluid shifts. This was done as a method of restricting these known confounding factors from biasing the observed effect of heat redistribution after induction of general anaesthesia.

Patients were deemed eligible if they were 18 years or older. Patients with a recent fever or known sepsis were excluded. Recruitment and informed consent took place in the ward, typically on the day prior to surgery.

Variables and methods of measurement

The primary outcome was preoperative mean body temperature. Secondary outcomes were preoperative mean skin temperature and zero heat flux (ZHF) temperature. Mean skin temperature is the average temperature of the skin. Different skin regions have different temperatures which are related to blood flow and adipose distribution. In this study the mean skin temperature was calculated using the Ramanathan method.²³ ZHF temperature is a non-invasive core temperature measurement. It consists of a sensor placed on the forehead

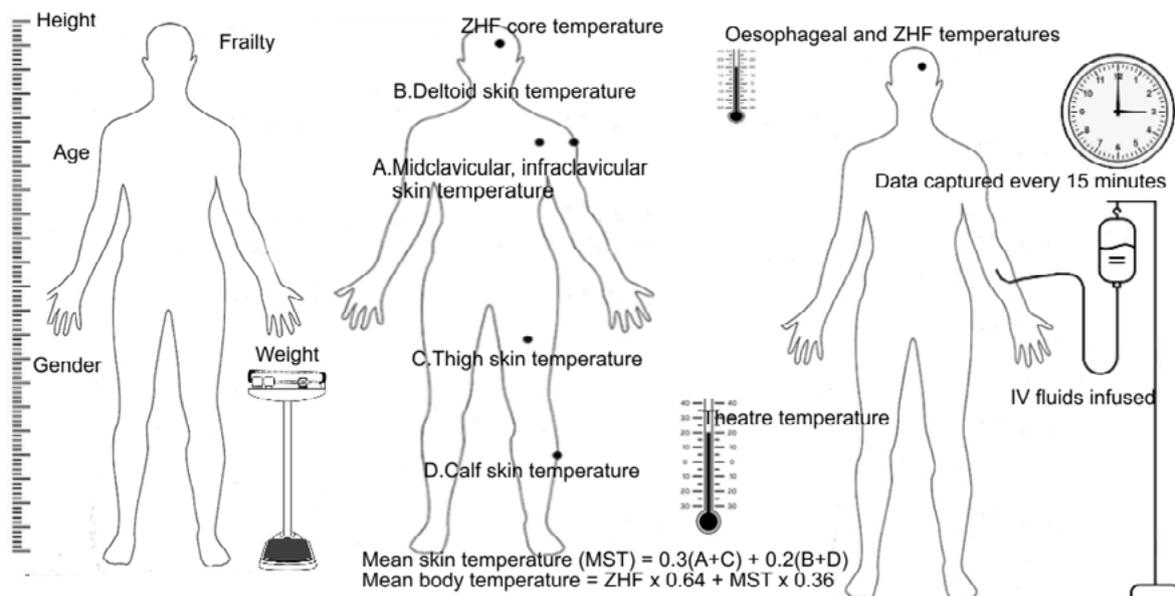


Figure 1: Measured variables. Zero heat flux (ZHF), intravenous (IV)

which creates a zone of insulation that eliminates heat loss to the environment. An isothermic pathway is formed which allows core temperature to be measured at the skin surface.²⁴

Baseline variables were collected in the ward during the recruitment visit, and in the induction room of the operating theatre prior to anaesthesia. Skin temperature was measured in the induction room, using a handheld thermocouple thermometer with a surface probe (Thermapen™, Electronic Temperature Instruments Ltd., West Sussex, United Kingdom). Operating room temperature and core temperature according to a ZHF monitor (3M™ SpotOn™, St. Paul, Minnesota, USA) were recorded immediately prior to induction. Thereafter, from the time the participant was connected to monitoring in the operating theatre until the time of tracheal extubation, body core temperature was measured continuously using both the ZHF monitor and a thermistor placed in the mid-oesophagus or nasopharynx. After induction of general anaesthesia, the patient's core temperature was documented every 15 minutes. The time-to-hypothermia interval was recorded in one-minute increments. Data collection procedures during the study as well as the body sites and calculation used are described in Figure 1.

Other recorded baseline variables were patient demographics: ASA status, Edmonton frailty scale,²⁵ sex, age, BMI, and case-related variables: airway management (endotracheal tube or supraglottic airway), volume of intravenous fluid administered during the procedure, and duration of the procedure from induction of anaesthesia to emergence. All fluids were warmed preoperatively in a fluid warmer set at 40 °C.

Four pre-identified body sites based on the Ramanathan method,²³ were used to calculate mean skin temperature.²⁶ Mean body temperature was calculated using a weighted formula involving both the mean skin temperature and the core temperature (Figure 1).²³ The thermometer used for skin temperature measurements has an accuracy of 0.4 °C, within the range of -49.9 °C to 299.9 °C. During and after these measurements, the patient was covered as much as possible with a cotton blanket to prevent heat loss. The temperature sensor was applied to the skin for two minutes to allow equilibration of each reading. The ZHF sensor was attached to the forehead above the non-operative eye. The ZHF sensor has an accuracy of 0.23 °C.

The choice of anaesthetic technique and agents was left to the discretion of the attending anaesthesiologist. After endotracheal intubation, an oesophageal thermistor was placed orally at 20 cm from the teeth. The thermistor has a range of 25–45 °C and an accuracy of 0.1 °C. In cases where a supraglottic airway was used, the thermistor was placed in the nasopharynx. Intravenous fluids were limited to as little as necessary, and the volumes were recorded at the end of the case.

A forced-air warming blanket was placed over each patient but not switched on. Active warming of the patient was initiated if the core temperature dropped below 36 °C. At this point,

the time to hypothermia was documented, and temperatures recorded subsequently were excluded from analysis.

Classification of hypothermia was based on oesophageal temperature, except when a supraglottic airway was used, in which case the ZHF temperature was considered a more accurate method of determination. During pilot data collection it was observed that the thermistor placed in the nasopharyngeal position in the presence of a supraglottic airway device frequently produced spurious readings. Oesophageal readings were favoured over the ZHF readings as it is a more widely used modality and its accuracy is well established. When oesophageal temperature readings were recorded below 36.0 degrees from the start of the case (baseline), the case was classified as preoperative hypothermia (left censored) and excluded from the primary analysis.

Study size

The incidence of hypothermia was unknown in this population, and no previous studies pertaining to the correlation between preoperative mean body temperature and perioperative hypothermia could be found. Therefore, a pilot study was conducted to inform our sample size calculation. The pilot study was conducted over 10 consecutive theatre days (11 February to 2 March 2019). Seventeen patients were investigated, of whom eight (57%) became hypothermic.

We used the pilot study data to estimate the required sample size for a two-sample t-test. Given an effect size of 0.3 °C difference in mean body temperature between groups (SD 0.37), to obtain power of 0.8 at a two-sided level of significance of 0.05, required a sample size of 50 patients with a ratio of 1:1. Based on this estimate it was determined *a priori* that recruitment would be continued until the smallest comparison group (with or without an incident of hypothermia) included 25 participants.

Statistical method

Baseline and outcome variables were described using summary statistics; mean (SD) for continuous variables, median (interquartile range) for ordinal variables and count (percentage) for categorical variables.

The primary objective (difference in preoperative mean body temperature between those who develop hypothermia in the first 60 minutes of anaesthesia compared to those who do not) and secondary objectives (difference in preoperative mean skin temperature and ZHF temperature between those who develop hypothermia in the first 60 minutes of anaesthesia compared to those who do not) were assessed using a two sample t-test.

A survival analysis using Kaplan-Meier estimation and Cox proportional hazards analysis was conducted to explore effects of all measured variables on the experience of hypothermia and the association between preoperative mean body temperature and hypothermia. Model building used the likelihood ratio test and Bayesian information criterion (BIC) in sequential models with increasing number of variables and first order interactions

to identify the model that best fits the data. Proportional hazards, overall fit, outliers, influential observations and functional form of variables were assessed in model diagnostics.

Statistical analysis was conducted with R (R Core Team, 2020. R Foundation for Statistical Computing, Vienna, Austria). The survival analysis made use of the 'survival'²⁷ and 'survminer'²⁸ packages. This manuscript was prepared in accordance with the STROBE statement.²⁹

Results

Participants

Of the patients approached during recruitment, three did not consent and were not enrolled. A total of 65 participants were enrolled in the study during the period from 24 June until 1 August 2019.

Mean participant age and BMI were 49 years and 26.1 kg.m⁻² respectively. Fifty-four per cent (35/65) of the participants were female. Median ASA grade was 2. Table I reports additional details of participant and case characteristics.

Missing data: One participant's oesophageal temperature sensor produced ("non-physiological") readings; for this case data from the ZHF sensor was substituted for analysis. Data for calculating BMI was not recorded in four participants, IV fluid administered was not recorded for eight participants and the room temperature was not recorded for four participants.

Outcome data

Of the 65 enrolled participants, 12 (18.5%) were hypothermic at baseline, 28 (43%) became hypothermic after induction

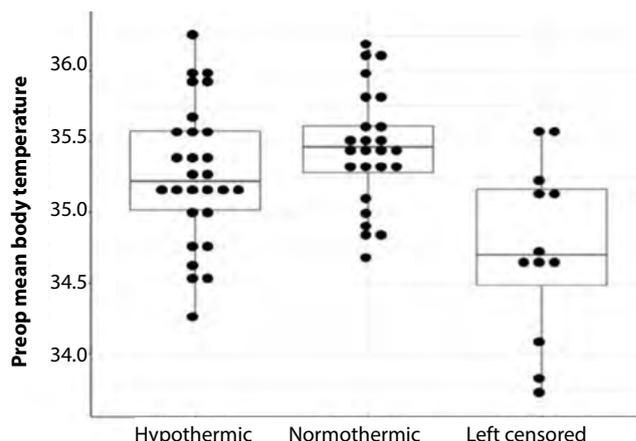


Figure 2: Box and dot plot of preoperative mean body temperature distribution by core temperature outcome during the first 60 minutes of anaesthesia. Left censored data are those participants who were hypothermic at baseline and therefore excluded from the primary outcome

of anaesthesia, and only 25 (38.5%) did not experience hypothermia. (Table II). The difference (95% confidence interval) in preoperative mean body temperature between those who developed hypothermia after induction of anaesthesia and those who did not was -0.2 °C (-0.4, 0.1) (Figure 2). The differences in ZHF temperature and mean skin temperature were -0.1 °C (-0.4, 0.1) and -0.2 (-0.7, 0.3).

Further analysis of the change in core temperature over time using a Kaplan-Meier estimate demonstrated median time (95% CI) to hypothermia as 19 (13, 23) minutes after induction of anaesthesia (Figure 3). Hypothermia events occurred early after induction of anaesthesia: 86% (24 of 28 events) occurred within 30 minutes and no events occurred after the first hour.

Table I: Participant and case characteristics reported as mean (SD) for continuous variable, median (IQR) for ordinal variables, and frequency (proportion) for dichotomous variables

	Hypothermia at baseline (n = 12)	Hypothermia during anaesthesia (n = 28)	No hypothermia observed (n = 25)
Age (years)	49.8 (14.8)	46.0 (17.1)	52.5 (15.9)
Body mass index (BMI) [§]	26.0 (3.6)	24.0 (4.2)	28.4 (4.7)
Sex: Female	6/12 (0.50)	15/28 (0.54)	14/25 (0.56)
ASA status*	2 (2.3)	2 (1.2)	3 (2.3)
Edmonton frailty score‡	2 (1.4)	3 (2.5)	3 (2.4)
Duration of anaesthesia (min)	97 (24)	110 (45)	107 (38)
IV fluid volume (l) ^Δ	0.883 (0.252)	0.743 (0.306)	0.684 (0.279)
Room temperature (°C) [¶]	21.2 (1.1)	20.5 (1.1)	20.8 (1.3)
SGA (cp. Endotracheal tube)	1/12 (0.08)	4/28 (0.14)	2/25 (0.08)

* Maximum observed ASA status = 3. ‡ Maximum observed frailty score = 8. ASA – American Society of Anesthesiologists Physical Status Classification, IV – intravenous, SGA – supraglottic airway device. § BMI data was missing for 1 and 3 participants in the 'hypothermic before anaesthesia' and 'hypothermia during anaesthesia' groups. Δ IV fluid volume was not recorded for 1, 4 and 3 participants in the groups 'hypothermic before anaesthesia', 'hypothermia during anaesthesia' and 'no hypothermia'. ¶ Room temperature was not recorded for 3 and 1 participants in the 'hypothermia during anaesthesia' and 'no hypothermia' groups.

Table II: Preoperative body thermometry, mean (SD), grouped by participant experience of hypothermia during the first 60 minutes of anaesthesia

	Hypothermia at baseline (n = 12)	Hypothermia during anaesthesia (n = 28)	No hypothermia observed (n = 25)
Preoperative ZHF temperature (°C)	36.2 (0.8)	36.8 (0.5)	36.9 (0.4)
Preoperative mean skin temperature (°C)	32.8 (0.8)	32.6 (0.9)	32.8 (0.9)
Preoperative mean body temperature (°C)	34.7 (0.6)	35.3 (0.5)	35.4 (0.4)

ZHF – zero heat flux forehead reading

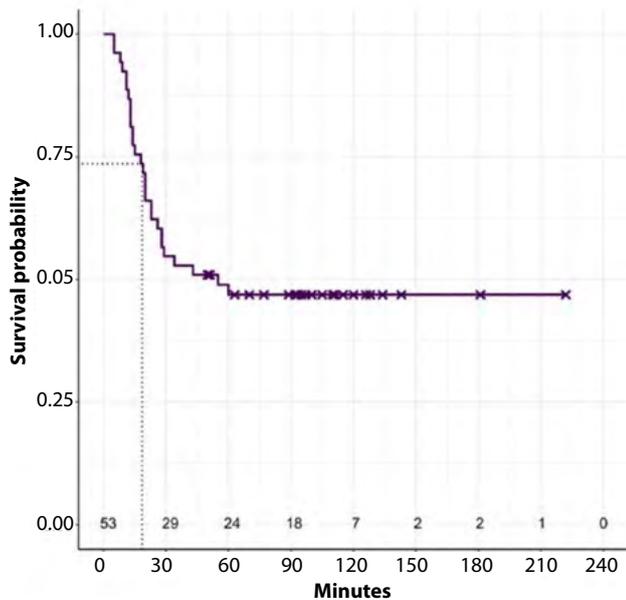


Figure 3: Kaplan-Meier plot of time to hypothermia in patients with starting core temperature greater than 36.0 °C. Median time to hypothermia is 19 minutes. Number at risk indicated at bottom of plot area along with corresponding time in minutes. Censoring events indicated with a 'x'. Survival probability on the y-axis is the cumulative probability of NOT developing intraoperative hypothermia

The results of the Cox proportional hazards analysis are summarised in Table III. Of the variables considered for inclusion in the model – preoperative mean body temperature, age, ASA, BMI, Edmonton frailty score, room temperature and volume of IV fluid infused – only preoperative mean body temperature, BMI and ASA were included in the final model as the other variables were not independently associated with the development of hypothermia or did not improve the model when comparing sequential models. Inclusion of first-order interactions did not improve the model and were not included in the final model reported here.

Table III: Final multivariable Cox proportional hazard model

	HR	95% CI	p-value
Preoperative mean body temperature (°C)	0.23	0.07–0.77	0.017
Body mass index (BMI)	0.83	0.74–0.94	0.002
ASA (reference: 1)			
ASA: 2	0.71	0.29–1.77	0.467
ASA: 3	0.19	0.06–0.62	0.006

The relationship between BMI and hypothermia is demonstrated in the Supplemental Figure – the hazard of hypothermia was lower in those with a higher BMI and higher in those with a lower BMI ($p = 0.002$; log-rank test).

Discussion

Key results

There was no statistically notable nor clinically relevant difference in the preoperative mean body temperature between the group who became hypothermic and the group who

remained normothermic (mean [SD] 35.3 [0.5] °C and 35.4 [0.4] °C respectively). The same held true for preoperative mean skin temperature and preoperative core body temperature. Even in our relatively healthy study population of patients with nearly no body surface exposure, inadvertent perioperative hypothermia was very common (a prevalence of 62%), with an incidence of hypothermia after induction of anaesthesia of 43%.

Study limitations

The study was conducted at only one institution. By design, the observed decrease in core temperature is believed to be mainly representative of redistribution hypothermia. However, the amount of heat loss to the environment was not measured. Our outcome of primary interest was preoperative mean body temperature, but there was no practical way to measure this directly in our study. Our calculation of this variable, although previously validated, could be a source of measurement error. Our data cannot be used to estimate the drop in core temperature in other types of surgery, as the amount of heat loss will be significantly higher in surgeries with more surface exposure. Although the number of enrolled participants was sufficient to address our primary objective, it remains too small to adequately explore other predictors of redistribution hypothermia. Our time-to-event analysis suggests the importance of BMI and possibly ASA status as predictors, but other measured variables cannot be excluded as determinants due to the limited sample size and restricted observed ranges of participant characteristics.

Interpretation

The high incidence of inadvertent perioperative hypothermia in our study is in keeping with findings of other researchers, such as Moola and Lockwood, Inal et al. and Sun et al.^{3,11,18} We demonstrate this to be true even in surgery that is considered low risk, where exposure is limited, and there is minimal blood loss. The importance of preoperative screening for hypothermia has been highlighted in this study, with 19% of patients arriving at theatre hypothermic. This supports the guidance of the National Institute of Health and Care (NICE) in the UK, which states that patients should be screened preoperatively in the ward and should not be allowed to go to the operating theatre if they are hypothermic, but should instead be actively warmed until they are normothermic (except in the case of an emergency).¹

Our study demonstrates a limitation in the understanding of redistribution hypothermia. Prewarming increases peripheral heat content and therefore decreases the core to peripheral gradient. This mechanism has repeatedly been shown to prevent redistribution hypothermia.^{3,4,9,11,16,20} Our failure to demonstrate a relationship between the mean preoperative body temperature, the mean skin temperature and the core temperature to the incidence of redistribution hypothermia suggests that other important determinants exist and are commonly at play, or that these measures are not a true reflection of the core to peripheral gradient

The observed short time to development of hypothermia is noteworthy. Redistribution of heat occurs rapidly, with most of the observed events in our study occurring within 30 minutes following induction of anaesthesia. Literature typically report the incidence of hypothermia in the first hour of anaesthesia^{18,30} or the absolute core temperature decrease in the first hour,^{13,31} rather than time to hypothermia.

Short procedures should not be seen as low-risk for hypothermia. No hypothermic events occurred after an hour of anaesthesia, which suggests that redistribution takes less than an hour. It also suggests that the study was successful in observing only redistribution as a reason for decrease in core temperature. Other literature reports hypothermic events after an hour.^{13,18,30} These studies, however, include surgeries where ongoing heat losses played a role. In these studies, the rate of temperature decrease changes at about one hour, which is further evidence that redistribution is complete at this time and that continued decrease in temperature is due to ongoing heat loss to the environment.^{13,18}

Further exploration of our data using time-to-event analysis generated hypotheses about other determinants of redistribution hypothermia. Although preoperative mean body temperature was not predictive of hypothermia when assessed across the whole study sample, a lower BMI was a notable risk factor for development of hypothermia, while a higher BMI appears to have been protective. The observed data fits the hypothesis that preoperative mean body temperature becomes an important determinant of the intraoperative development of hypothermia in those with a lower BMI. This observation is in keeping with the research of Ozer et al. and Fernandes et al.^{32,33}

An association with unexpected direction was observed between ASA status and the development of hypothermia, whereby those with an ASA status of 3 experienced a lower hazard of hypothermia compared to those with an ASA status of either 1 or 2. This unexpected association may be spurious, due to the relatively small dataset and restricted spectrum of participants, and interrater variability in ASA classification. The association did not appear to be solely explained by any association between BMI and ASA status. Numerous studies have looked at the relationship between ASA status and the development of perioperative hypothermia. The results are incongruent, with some studies demonstrating that ASA has an impact on the development of hypothermia,³⁴⁻³⁶ while other studies found no such correlation.^{37,38} We are not aware of any studies that show a protective element with higher ASA scores. One reason for a true discrepancy may be that our design effectively studied heat redistribution, while in other studies, heat loss to the environment is the dominant determinant of body temperature.

Conclusion

Inadvertent perioperative hypothermia is common, even in low-risk patients and low-risk procedures. Our findings underpin the importance of screening for preoperative hypothermia

as described in the current NICE guidelines.¹ Hypothermia resulting from heat redistribution occurs early after induction of anaesthesia (within the first hour), so that prewarming (even for short procedures) should strongly be considered. Future work should explore BMI and ASA status along with other determinants of hypothermia, striving towards a patient-specific approach to perioperative warming that is informed by a better understanding of perioperative thermal physiology.

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Conflict of interest

The authors declare no conflict of interest.

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Ethical approval

With approval of the Human Research Ethics Committee of the University of Cape Town (HREC772/2018) and the written informed consent of participants, this study was conducted at a tertiary level hospital in Cape Town, South Africa.

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Supplemental figure

Kaplan-Meier plot of the probability of not experiencing hypothermia stratified by tertiles of body mass index (BMI) with *p*-value for the log-rank test. Upper yellow tertile (27; 39), middle teal tertile (23; 27), lower purple tertile (18; 23). Survival probability on the y-axis is the cumulative probability of NOT developing intraoperative hypothermia.

