Resistive-Heating or Forced-Air Warming for the Prevention of Redistribution Hypothermia

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BACKGROUND: We evaluated the efficacy of resistive-heating or forced-air warming versus no prewarming, applied before induction of anesthesia for prevention of hypothermia.
METHODS: Twenty-seven patients scheduled for laparoscopic colorectal surgery were randomized into 1 of 3 groups: no prewarming; 30 minutes of prewarming with a carbon fiber total body cover at 42°C; or 30 minutes of preoperative forced-air warming at 42°C. The forced-air warming cover excluded the shoulders, ankles, and feet. The prewarming period was exactly 30 minutes. At the 31st minute, a total IV anesthesia technique was initiated, and all patients were actively warmed with a lithotomy blanket. Tympanic and distal esophageal temperatures were measured. Categorical data were analyzed using χ^2 test, and continuous data were analyzed with analysis of variance. $P < 0.05$ was considered statistically significant.
RESULTS: The mean esophageal temperatures differed significantly between the control and the carbon fiber group from 40 to 90 minutes of anesthesia. After 50 minutes of anesthesia, the mean esophageal temperatures in the control, carbon fiber, and forced-air groups were 35.9°C ± 0.3°C, 36.5°C ± 0.4°C, and 36.2°C ± 0.3°C, respectively. No statistically significant difference was found between the forced-air and control groups. After 30 minutes of prewarming with resistive heating, patients had an esophageal temperature that was significantly higher than the control group.
CONCLUSIONS: Prewarming should be considered part of the anesthetic management when patients are at risk for postoperative hypothermia. (Anesth Analg 2010;110:829–33)

Core hypothermia developing immediately after induction of anesthesia results largely from an internal core-to-peripheral redistribution of body heat.[1,2] The extent to which redistribution decreases core temperature depends on the anesthetic-induced inhibition of tonic thermoregulatory vasoconstriction and the magnitude of the core-to-peripheral tissue temperature gradient. Because even mild perioperative hypothermia may have adverse effects, prevention is indicated in most cases.[3]

Thirty minutes of forced-air warming before the induction of anesthesia in volunteers increased peripheral tissue heat content more than is normally redistributed during the first hour of anesthesia.[4] Several studies have shown that prewarming may prevent redistribution hypothermia in anesthetized patients.[4–8] Moreover, prewarming is the only technique that has generally been shown to be effective for reducing intraoperative hypothermia during procedures lasting <1 hour.[9] Without prewarming, the intraoperative use of circulating water, forced-air, and resistive-heating techniques is often unable to prevent the decrease in core temperature during the first hour of anesthesia.[10,11]

Several reusable resistive-warming systems have been developed recently.[10,12–16] They are based on carbon fiber technology and have a low-voltage, direct current power supply. In this study, we assessed the efficacy of a resistive-heating system or a forced-air warming system for 30 minutes of prewarming in comparison with a control group that received the current standard of care.

METHODS

With approval of the IRB, written informed consent was obtained from 27 adult patients scheduled for elective laparoscopic colorectal surgery with a normal body weight as defined by the body mass index (weight [kg]/height [m^2]), range of 18.0–28.0 kg/m^2, extremes included. The criteria for exclusion were a history of alcohol or drug abuse, older than 80 years, evidence of current infection, pregnancy, thyroid disease, the intake of a calcium channel blocker within 24 hours before induction of anesthesia, antiemetic, opioid, antihistaminic, neuroleptic or anticholinergic medication, or the use of cannabinoids or corticosteroids.

Treatment Protocol

Patients were randomly assigned to 1 of 3 groups: (1) no prewarming, (2) prewarming with resistive heating, or (3) prewarming with forced air. Randomization consisted of drawing lots (a numbered, opaque, and sealed envelope, destroyed after being drawn) by a random individual. For resistive heating, a Geratherm® (Medical AG, Geschwenda, Germany) "presurgical" whole body cover was applied for exactly 30 minutes before induction of anesthesia, with the control unit set at 42°C. The Geratherm cover measures 205 × 135 cm and has 5 active warming carbon fiber elements of 40 × 20 cm incorporated with an intermediate distance of 10 cm, powered by a 15 V direct current. Forced-air warming was performed with an Arizant Healthcare (Eden Prairie, MN) Model 110 Perioperative Blanket along with the Model 750 Temperature Management Unit calibrated at 42°C by our technician. The inflatable part of the Model 110 forced-air warming blanket is rectangular and measures 40 × 105 cm. It has a foot drape that is not inflated ("to minimize the risk of thermal injury,"

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as stated by the manufacturer) and is used with booties that are not warmed. The blanket may be used with the patient in a seated, semireclined, or supine position. The inflating part of the Model 110 blanket can cover the full body surface in the supine position, with exception of the shoulders, ankles, and feet in a patient of average height. In the control group, each patient's entire body was covered with cotton blankets that were not warmed before induction of anesthesia, and at least 20 minutes of baseline measurements were obtained.

The start of prewarming was considered as elapsed time 0. To minimize diurnal variation in body temperature as a confounding factor, time 0 was at 7:30 AM (GMT + 1:00 or + 2:00 for summer time) ±5 minutes in all patients. The devices for prewarming were removed precisely at an elapsed time of 31 minutes. Intraoperative temperature management was then started (time 31) and consisted of forced-air warming in all patients, with the Temperature Management Unit set at 42°C and a Lithotomy Underbody Blanket Model 585 (Arizant Healthcare). After induction of anesthesia, the patient was changed from the supine to the lithotomy position. When esophageal temperature reached 36.8°C or copious sweating was observed, the blower was set at 38°C. Intravenous fluids were warmed to 42°C (Ranger, Arizant Healthcare), and ambient temperature was kept near 20°C.

Patients received 0.5 mg of alprazolam orally as premedication the night before surgery. All patients received a total IV anesthetic, initiated at 31 minutes. After a bolus of 1 μg/kg remifentanil administered IV, an infusion of 0.20–0.25 $\mu g \cdot kg^{-1} \cdot min^{-1}$ was continued. Propofol was administered by a plasma target-controlled infusion method (Diprifusor TCI System, AstraZeneca, Brussels, Belgium) using a target propofol concentration of 6 μg/mL for endotracheal intubation, followed by 2–4 μg/mL for maintenance of anesthesia at the discretion of the anesthesiologist. Rocuronium 0.6 mg/kg IV was administered to facilitate tracheal intubation. Patients' lungs were mechanically ventilated with 40% oxygen and air mixture to an end-tidal Pco_2 of approximately 35 mm Hg.

The use of phenylephrine 100 μg for restoration of mean arterial blood pressure >60 mm Hg was recorded. At the beginning of wound closure, the remifentanil and propofol infusions were discontinued, and ketorolac 0.5 mg/kg (maximum 30 mg) and paracetamol 1 g were administered IV. If detected by the anesthesiologist, residual paralysis was antagonized with neostigmine 2.5 mg and atropine 1.0 mg IV, and extubation of the trachea was performed.

Measurements

Vital signs, end-tidal Pco_2, and temperatures were monitored using Datex-Ohmeda AS/3 modules and recorded electronically at 5-minute intervals using Datex-Ohmeda S/5™ Collect software (GE Healthcare, Helsinki, Finland). All temperatures were measured using Mon-a-therm™ thermocouples (Tyco International Co., New York, NY) with a precision of ±0.01°C and an accuracy of ±0.1°C. Measurements started 10 minutes before prewarming and continued until discharge from the postanesthesia care unit (PACU). An off-line uninterruptible power supply powered the monitors during patient transport from the operating room to the PACU. Ambient temperature was measured at least 1 m from any heat-producing equipment. The core temperature was measured at the tympanic membrane with the aural probe occluded with cotton and taped into place.[10] Immediately after induction of anesthesia and loss of consciousness, an esophageal temperature probe was inserted 25 cm below the arytenoid cartilages. A nasogastric tube was then inserted, passively draining into a collecting bag. The esophageal temperature was the primary end point of this study. Because of the direct thermal effect of forced-air warming on the tympanic temperature, esophageal temperature was used to measure core temperature intraoperatively. The mean skin temperature (T_{skin}) was calculated from temperatures recorded at 4 cutaneous sites[17]: $T_{skin} = 0.3\ (T_{chest} + T_{arm}) + 0.2\ (T_{thigh} + T_{calf})$. The mean body temperature (MBT) was estimated from core and mean skin temperatures using the following formula[18]: $MBT = 0.64 \times T_{Core} + 0.36 \times T_{skin}$. Sweating was assessed qualitatively by touching a pH indicator strip to the forehead of the patient every 5 minutes.

Data Analysis

Our primary variable was intraoperative core temperature. We tested the null hypothesis that there is no difference in intraoperative esophageal temperature between the active treatment groups (prewarmed with resistive heating or forced air) and the control group. For sample size calculation, we wanted to detect a difference of means of 1.0°C and assumed that the SD for esophageal temperature was 0.5°C. With 80% power and a significance level of 0.05, each sample required 4 patients. To increase the power of our study and to cover for incomplete study data, we decided to double this sample size. After inclusion of at least 8 patients per group, the study was concluded. If all 8 subjects in each group completed the study, this would have allowed the detection of a difference of 0.7°C.

The mean skin temperature and the tympanic and esophageal temperatures were continuous and normally distributed variables. The changes in temperature were calculated using the temperature at elapsed time 35 minutes as a baseline. These variables were compared using an analysis of variance, a covariance analysis, and a Tukey-Kramer post hoc test. The covariate was the baseline temperature at 35 minutes. Categorical data were analyzed using a χ^2 test. The statistical analyses were performed using the Statistical Analysis System 9.1 (SAS Institute, Carey, NC). Data are expressed as mean values ± SD. In the figures, results are presented as means ± SEM. A P value <0.05 was considered statistically significant.

RESULTS

Nine patients were assigned to each active treatment group. One patient in the control group had a severe anaphylactic reaction after induction of anesthesia. For this patient, the surgery was postponed, and he was excluded from the analysis. Patient groups were comparable with respect to age, ASA physical status, and body mass index (Table 1). No differences were found among groups with respect to ambient room temperature, the administration of anesthetics and fluids, or mean arterial blood pressure. The duration of anesthesia ranged from 90 to 260 minutes, with an average duration of surgery that was not significantly different among the groups. An esophageal temperature probe was present in all patients for the first 90 minutes of anesthesia.

Table 1. Demographic Characteristics and Anesthetic and Surgical Variables

Variable	Group		
	Control	Carbon fiber	Forced air
Number of patients (*n*)	8	9	9
Age (y)	59 ± 10	64 ± 10	66 ± 12
Sex (male/female)	5/3	6/3	6/3
ASA physical status (I/II/III)	3/2/3	2/2/5	1/5/3
History of arterial hypertension (*n*)	2	4	3
Weight (kg)	69 ± 6	73 ± 10	65 ± 5
Height (cm)	166 ± 4	169 ± 7	168 ± 6
Body mass index (kg/m^2)	25 ± 2	25 ± 2	23 ± 2
Ambient temperature (°C)	19.8 ± 0.3	20.0 ± 0.3	20.0 ± 0.3
Duration of surgery (min)	128 ± 47	98 ± 48	114 ± 42
Duration of anesthesia (min)	182 ± 56	142 ± 50	158 ± 42
Mean arterial blood pressure (mm Hg)	80 ± 10	78 ± 13	75 ± 8
Phenylephrine use (μg)	125 ± 191	83 ± 100	144 ± 133
Propofol ($mg \cdot kg^{-1} \cdot h^{-1}$)	7.8 ± 0.9	7.0 ± 1.2	7.3 ± 1.1
Remifentanil ($\mu g \cdot kg^{-1} \cdot min^{-1}$)	0.24 ± 0.03	0.21 ± 0.03	0.22 ± 0.06
Neostigmine use (*n*)	1	1	0
Administered fluid ($mL \cdot kg^{-1} \cdot h^{-1}$)	9 ± 4	8 ± 3	10 ± 3
Blood loss (mL/kg)	1 ± 1	1 ± 1	2 ± 3

None of the values were significantly different among the treatment groups. Data are presented as means ± SD.
The induction doses of propofol and remifentanil are included in the calculation of drug consumption.

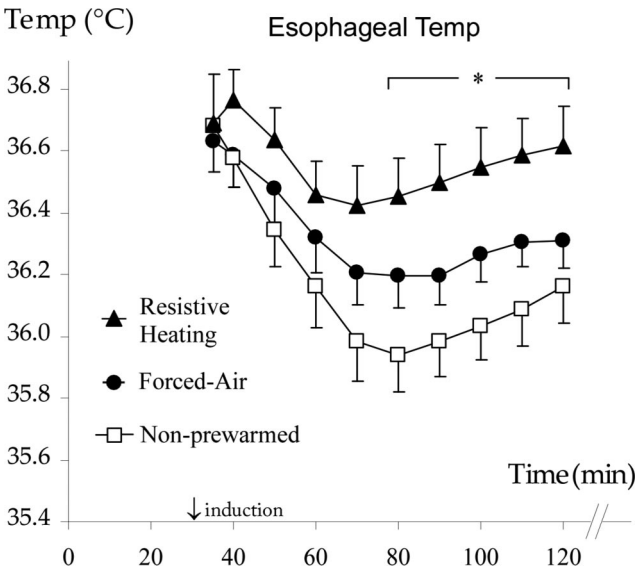

Figure 1. Intraoperative esophageal temperature. General anesthesia was induced at elapsed time 31 minutes. The esophageal temperature decreased for the first 40–50 minutes of anesthesia in each treatment group. After 50 minutes of anesthesia (i.e., elapsed time 80 minutes), the mean esophageal temperature in the control ($n = 8$), carbon fiber ($n = 9$), and forced-air ($n = 9$) groups was 35.9°C ± 0.3°C, 36.5°C ± 0.4°C, and 36.2°C ± 0.3°C, respectively. The mean core temperature differed significantly between the control and the carbon fiber group after 40–90 minutes of anesthesia ($P < 0.05$)*. Results are presented as means ± SEM.

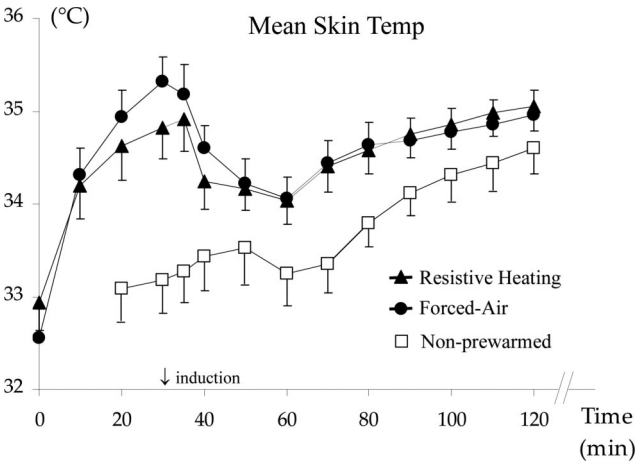

Figure 2. Mean skin temperature during anesthesia. The mean skin temperature was significantly lower ($P < 0.05$) in the control group compared with each of the active treatment (prewarming) groups until 70 minutes after the induction of anesthesia (i.e., elapsed time 100 minutes). Results are presented as means ± SEM.

At the end of the prewarming period, the core temperature measured at the tympanic membrane (T_{TYMP}) was 35.9°C ± 0.5°C in both the carbon fiber group and in the forced-air warming group. In the control group, after at least 10 minutes of baseline measurements and immediately before induction of anesthesia, the T_{TYMP} was 35.9°C ± 0.5°C. Despite prewarming and intraoperative warming, the esophageal temperature decreased for the first 40 minutes in each treatment group (Fig. 1). After 50 minutes of anesthesia, the mean esophageal temperature in the control, carbon fiber, and forced-air groups was 35.9°C ± 0.3°C, 36.5°C ± 0.4°C, and 36.2°C ± 0.3°C, respectively, being significantly different between the control and carbon fiber group. The mean esophageal temperature differed significantly between the control and carbon fiber group from 40 to 90 minutes of anesthesia. In this study, there was no statistically significant difference in esophageal temperature between the forced-air and control groups. The postoperative tympanic temperature decreased in all patient groups to a plateau approximately 1 hour after arrival in the PACU. At 60 minutes after arrival, the mean tympanic temperature did not differ significantly among the control, carbon fiber, and forced-air groups (35.4°C ± 1.0°C, 35.6°C ± 0.5°C, and 35.5°C ± 0.8°C, respectively).

The mean skin temperature was statistically lower ($P < 0.05$) in the control group compared with the other groups during prewarming and until 70 minutes after induction of anesthesia (Fig. 2). The MBT (Fig. 3) differed significantly between the control and carbon fiber group at 5 minutes after induction of anesthesia and from 30 minutes until 90 minutes of anesthesia. The MBT of the forced-air warming group differed significantly from controls at 5, 40, and 50 minutes after induction of anesthesia. In all groups, the mean skin temperature reached a plateau of 34.0°C after the patients were in the PACU for 150 minutes.

Because sweating was observed, the blower was set at 38°C for 3 patients in the carbon fiber group (respectively at

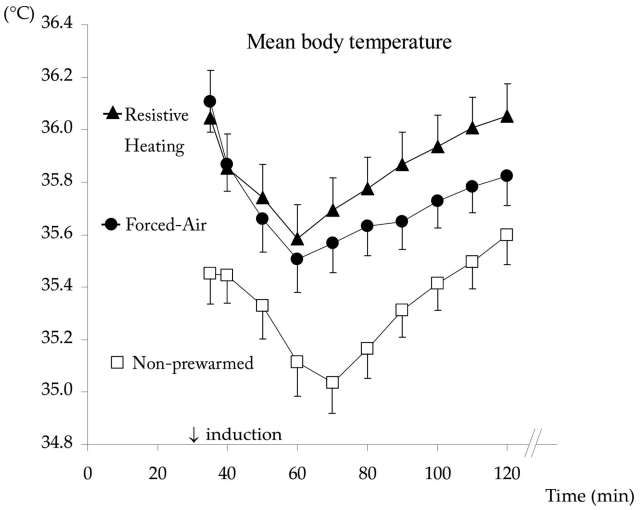

Figure 3. Mean body temperature (MBT) during anesthesia. The MBT during anesthesia was calculated from core and mean skin temperatures. The time elapsed after the start of prewarming is indicated. At 31 minutes, anesthesia was induced. No difference between the active treatment groups was found. The MBT differed significantly between the control group ($n = 8$) and the carbon fiber group ($n = 9$) at 5 minutes after induction of anesthesia, and from 30 minutes until 90 minutes of anesthesia ($P < 0.05$). The forced-air warming group ($n = 9$) significantly differed ($P < 0.05$) from the control group at 5, 40, and 50 minutes after induction of anesthesia. Results are presented as means ± SEM.

90, 106, and 237 minutes after induction of anesthesia) and for 1 patient in the forced-air warming group (at 97 minutes after induction of anesthesia). At the time of arrival in the PACU, 4 patients in the carbon fiber group and 1 patient in the forced-air group were sweating.

DISCUSSION

The intraoperative esophageal temperature changes suggest that redistribution of heat is partially prevented by 30 minutes of prewarming with both the carbon fiber cover and the forced-air warming blanket. Hypothermia, defined as a core temperature <36.0°C, did not occur in these 2 active treatment groups. Compared with the control group, only a significant difference in esophageal temperature was found with the carbon fiber group after 40 minutes of anesthesia and beyond (Fig. 1).

Redistribution of heat was still noticeable in our patients. The landmark study by Just et al.[8] in 1993 showed that 1–2 hours of prewarming prevented intraoperative hypothermia, even in patients undergoing prolonged abdominal surgery who were not warmed. Subsequently, the optimal duration of prewarming has been studied. Thirty minutes of full-body forced-air warming in volunteers increased peripheral tissue heat content by more than the amount normally redistributed during the first hour of anesthesia.[4] Combined with intraoperative warming, our clinical study confirms that hypothermia can be prevented by 30 minutes of prewarming using appropriate methods.

Some investigators found that resistive heating maintains intraoperative normothermia as well as forced-air heating.[10,15] In our study, we assessed the efficacy of 2 warming systems that are recommended for prewarming. The inflatable part of the forced-air cover (40 × 105 cm) approximately equals the total surface of the carbon fiber elements incorporated in the resistive heating blanket (5 × 40 × 20 cm). Because the blanket between the 5 carbon fiber elements (40 × 10 cm) is indirectly warmed, however, the total body surface area except the head can be covered with the warmed part of the blanket. The forced-air warming blanket was used with our study patients in a supine position (mean patient height 168 ± 6 cm), leaving the shoulders, ankles, and feet unheated. This may partially explain why only the carbon fiber group showed a statistically significant difference compared with the control group after 40 minutes of anesthesia. It is uncertain if the carbon fiber technique per se is more efficient. In an experimental model with a water dummy, the superiority of convective warming over resistive heating has been demonstrated.[14] In a recent study in healthy volunteers, heating efficacy and core rewarming rates were similar when using full-body forced-air and full-body resistive polymer heating.[16]

The group that did not undergo prewarming only presented with mild intraoperative hypothermia. The laparoscopic technique and the intraoperative use of the forced-air warming blanket could be responsible for this observation. In our control patients, the lowest intraoperative esophageal temperature barely decreased <36°C at 40–60 minutes after induction of anesthesia, and this was followed by an increase in temperature. In patients undergoing open abdominal surgery with a lower-body forced-air cover (the blower set on high, i.e., 42°C–43°C) and an ambient temperature near 22°C, the core temperature change was −1.0°C ± 0.6°C in the first 2 hours of surgery.[10]

There are a number of limitations to our study. First, the temperature differences between the active treatment groups and the control group were less than expected. One may question the need for prewarming in this clinical setting. For ethical reasons, we applied efficient intraoperative warming to all patients, which likely attenuated temperature differences among the groups. Furthermore, an alternative approach could have been to set up an equivalence trial to compare the 2 active treatment groups. In that approach, the 95% confidence interval of the difference between the 2 treatments would have been between $-\delta$ and $+\delta$. A temperature difference of 0.5°C between any intervention and control groups is considered physiologically significant in hypothermic patients. In this regard, the 95% confidence interval of the difference would have needed to be between −0.5°C and 0.5°C to consider both active treatments equivalent. In this study, the 95% confidence interval of the difference ranged from the lowest confidence interval (−0.6°C to 0.2°C) to the largest confidence interval (−0.1°C to 0.4°C). Setting up an equivalence trial would have required 18 patients in each active treatment group. In this study, the statistical power is too low to allow a proper comparison between the 2 active treatment groups.

Second, because the duration of anesthesia ranged from 90 to 260 minutes (colorectal surgery was sometimes combined with other procedures such as hernia repair), the postoperative data are difficult to interpret. All patients received intraoperative warming with forced-air, and several patients were sweating on arrival in the PACU. Because our assessment of sweating was qualitative, we may

have missed it in some patients. The mean core temperature in all groups as measured with the tympanic temperature probe in the PACU decreased in all patient groups to a plateau value that was 0.3°C–0.4°C lower than the perioperative baseline values, which is difficult to interpret. Finally, we used 2 methods to assess core temperature. Tympanic membrane temperatures are accurate so long as the thermocouple is properly positioned, the ear canal is occluded, and the face is protected from direct thermal manipulation.[18] For this reason, we used the tympanic probe preoperatively and postoperatively and an esophageal probe for intraoperative assessment of core temperature, resulting in temperatures that were correlated but were different.[19] In this study, the mean tympanic temperature at the end of the prewarming period was exactly the same in the experimental groups as in the control group (35.9°C ± 0.5°C), ensuring patients to be comparable with regard to their baseline core temperature. However, because near-simultaneous measurements of tympanic membrane and esophageal temperatures (recorded immediately after induction of anesthesia) differed by nearly a degree, we must concede the possibility of the tympanic membrane temperatures being falsely low due to technical problems.

In general, this clinical setting is inappropriate to study heat balance and the quantification of redistribution of heat. The use of thermal flux transducers and supplemental skin and muscle temperatures in volunteers is the best method to study the rapid core-to-peripheral transfer of heat and related thermoregulatory phenomena in humans.

For elective surgery, prewarming should be considered as part of the anesthetic management, especially when patients are at risk for postoperative hypothermia and its adverse outcomes.[3] In a randomized trial involving >400 patients, Melling et al.[20] demonstrated a significant reduction in postoperative wound infection rates from 14% to 5% in patients who were prewarmed for 30 minutes. When choosing among warming covers, the cost, effectiveness, and convenience should be major factors. Besides its effectiveness, the carbon fiber system has the advantage of being reusable. After use, it needs to be disinfected with a 70% alcohol spray. However, the forced-air cover is disposable, eliminating the risk of patient-to-patient transmission. In hospitals today, great attention is directed to controlling the increasing incidence of infections with multidrug-resistant organisms such as vancomycin-resistant *Enterococcus* or methicillin-resistant *Staphylococcus aureus*. As such, the safety of the reusable system with regard to the transmission of bacteria is unknown and should be determined in future studies. The meticulous disinfection of the carbon fiber cover after use is a sine qua non condition.

In conclusion, patients prewarmed with a resistive-heating system showed an esophageal temperature that was significantly higher compared with a control group between 40 and 90 minutes of anesthesia. Prewarming should be considered as part of the anesthetic management when patients are at risk for postoperative hypothermia.

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DISCLOSURE

The authors do not consult for, accept honoraria from, or own stock or stock options in any anesthesia-related company.

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