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Effects of a Heated Anesthesia Breathing Circuit on Body Temperature in Anesthetized Rhesus Macaques (*Macaca mulatta*)

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This study evaluated the effects of using a heated anesthesia breathing circuit in addition to forced-air warming on body temperature in anesthetized rhesus macaques as compared with forced-air warming alone. Hypothermia is a common perianesthetic and intraoperative complication that can increase the risk of negative outcomes. Body heat is lost through 4 mechanisms during anesthesia: radiation, conduction, convection, and evaporation. Typical warming methods such as forced-air warming devices, conductive heating pads, and heated surgical tables only influence radiative and conductive mechanisms of heat loss. A commercially available heated breathing circuit that delivers gas warmed to 104 °F can easily be integrated into an anesthesia machine. We hypothesized that heating the inspired anesthetic gas to address the evaporative mechanism of heat loss would result in higher body temperature during anesthesia in rhesus macaques. Body temperatures were measured at 5-min intervals in a group of 10 adult male rhesus macaques during 2 anesthetic events: one with a heated anesthesia breathing circuit in addition to forced-air warming, and one with forced-air warming alone. The addition of a heated breathing circuit had a significant positive effect on perianesthetic body temperature, with a faster return to baseline temperature, earlier nadir of initial drop in body temperature, and higher body temperatures during a 2-h anesthetic procedure. Use of a heated anesthesia breathing circuit should be considered as a significant refinement to thermal support during macaque anesthesia, especially for procedures lasting longer than one hour.

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Hypothermia is a common complication during veterinary anesthesia that can lead to serious secondary side effects during surgery, such as coagulation disorders, increased risk of wound infection, altered pharmacokinetics of anesthetic drugs, and increased time to recovery.[3,8,9] Body heat is lost during anesthesia through 4 mechanisms: radiation of heat through infrared emission to the environment, convection of heat to air currents flowing over the body, conduction of heat directly to surfaces touching the patient, and evaporation of water from the respiratory tract, skin, or open surgical site.[2] In addition, the initial fall in core body temperature during the first hour of anesthesia is attributed to vasodilation caused by general anesthetics and the redistribution of body heat from the core to the periphery, and is difficult to prevent without prewarming a patient.[3,16] The drop in body temperature can be further exacerbated by clipping of hair and the patient undergoing surgical preparation with isopropyl alcohol or other skin antimicrobial solutions without being covered.[14,15] The thermoregulatory centers in the hypothalamus are also impaired during anesthesia.[3] To offset the loss of body heat to the environment, warming methods such as forced-air warming blankets, conductive heating pads, and heated surgical tables are often used in veterinary medicine to warm the patient during procedures. These intraoperative warming methods only address radiation and conduction and do not account for other mechanisms of heat loss.[2] If difficulty arises in maintaining adequate body temperature during anesthesia, options are limited, and discontinuation of the procedure may be necessary to rewarm the patient.

Multimodal prevention of hypothermia is analogous to the strategy of multimodal analgesia. Multimodal analgesia attempts to manage pain by using therapies that target multiple pain and inflammatory pathways.[1] Similarly, the multiple mechanisms of heat loss can be specifically targeted to prevent perianesthetic hypothermia. At our institution, we use nonhuman primates (NHPs) extensively for infectious disease research that often requires implantation of telemetry devices and central venous catheters to minimize handling for data and sample collection. These surgeries can be lengthy and require the use of various intraoperative warming methods to maintain or recover body temperature, thereby reducing the risk of the negative effects of hypothermia. In our experience, even expedient surgical preparation and the use of forced-air warming and convective warming blankets cannot prevent macaques from often becoming considerably hypothermic during surgical procedures.[10] Normal macaque body temperature ranges from 98.6 to 103.1 °F (37 to 39 °C); animals with temperatures below this range would be considered hypothermic.[5]

This study investigated the efficacy of a heated anesthesia breathing circuit that warms inspired anesthetic gas to mitigate the evaporative mechanism of heat loss and its effects on body temperature in anesthetized rhesus macaques as compared with forced-air warming alone. Body temperatures were measured during 2 anesthetic events: one with a heated breathing circuit in addition to forced-air warming, and one with forced-air

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warming alone. Forced-air warming is as effective as other warming methods, is relatively inexpensive, and is available at many research institutions.[4,11] A heated breathing circuit would not be expected to replace forced-air warming or other external active warming as a sole warming method, but it may have benefits when used in conjunction with forced-air warming.[6] The addition of a heated breathing circuit would potentially limit evaporative heat loss from the respiratory tract, while radiative and conductive heat losses could still be managed with forced-air warming. This combination may be particularly beneficial during procedures lasting longer than 75 min.[8]

A commercially available, inexpensive, low-maintenance heated breathing circuit device designed for use in veterinary medicine is available and easily integrated into any anesthesia machine as a free-standing unit (Darvall Heated Breathing Circuit, Advanced Anesthesia Specialists, Gladesville, New South Wales, Australia). The breathing circuit warms the inspired anesthetic gas to 104 °F, has a feedback loop to prevent overheating, and is easily cleaned and disinfected between patients. The efficacy of this heated breathing circuit has been previously studied in much smaller NHPs, specifically callimicos (*Callimico goeldii*) that weighed 544 ± 97 g; little to no benefit in core temperature was demonstrated.[2] However, the authors attributed this to the small size of the animal, the high body surface area-to-mass ratio, and the relatively minimal amount of heat lost via the respiratory tract as compared with radiative and conductive heat losses.[2] A heated breathing circuit may have a greater effect in larger species of NHPs such as rhesus macaques, as has been found in dogs, cats, and humans.[6,12,13] If so, using a heated breathing circuit as an additional warming method in research macaques could reduce the risk of adverse effects associated with inhalation anesthesia hypothermia and serve as a valuable refinement.

We hypothesized that the use of a heated anesthesia breathing circuit to provide heated gas to anesthetized rhesus macaques when used in conjunction with forced-air warming would result in less heat loss and a higher body temperature as compared with forced-air warming alone, especially in procedures longer than one hour.

Materials and Methods

Animals. Animal research was conducted under a United States Army Medical Research Institute of Infectious Diseases (USAMRIID) IACUC-approved protocol in compliance with the Animal Welfare Act, PHS Policy, and other Federal statutes and regulations relating to animals and experiments involving animals. Animals were housed in an AAALAC International accredited facility that adheres to principles stated in the *Guide for the Care and Use of Laboratory Animals*, National Research Council, 2011.[7] The study group was 10 male rhesus macaques selected to be of approximately similar size and body condition (*Macaca mulatta*; age, 5.7 to 6.9 y [median 5.8 y]; weight [mean ± 1 SD] 6.98 ± 0.78 kg). Blood was collected for complete blood count and comprehensive blood chemistry panel within 30 d prior to anesthetic events. All animals used in this study were considered to be healthy. Anesthetic events were conducted in a surgical suite with a temperature set point of 71 °F. Room temperature was measured and recorded at the start of each procedure and was within ± 2 °F of set point at each procedure. While assigned to the study, the animals were provided food twice daily (Teklad 2050, Envigo, Madison, WI) and water ad libitum via an automatic drinking valve. They were checked at least twice daily, and provided enrichment in the form of toys and dietary enrichment. Animals were housed in modular primate caging (Lab Products, Seaford, DE) in ABSL2 rooms at 64 to 84 °F, 30% to 70% relative humidity, and 12:12-h light/dark cycle. Macaques were acclimated at the facility for at least 90 d prior to study.

Anesthesia and warming. Each rhesus macaque was sedated with 5 mg/kg tiletamine/zolazepam (Tiletamine–zolazepam, Zoetis, Parsippany-Troy Hills, NJ) administered intramuscularly for 2 separate anesthetic events, and then intubated with a size-appropriate cuffed endotracheal tube. Intubation was guided by laryngoscope and proper placement confirmed by auscultation of bilateral breath sounds during positive pressure ventilation. An area (approximately 10 × 10 cm) of the ventral abdomen was clipped of hair followed by a sterile surgical scrub of alternating chlorhexidine and alcohol, mimicking the sterile prep that precedes surgical procedures. After intubation and scrub, each macaque was connected to the breathing circuit. The mean time from the sedation injection to connection to breathing circuit was 23.8 min, with no more than 6 min difference between the 2 treatment events for any NHP. Isoflurane anesthesia (Baxter; Deerfield, IL) was administered at 1 to 3% to maintain surgical anesthetic depth using a semiclosed breathing circuit and an isoflurane vaporizer (Ugo Basile; Gemonio, VA, Italy) on a veterinary anesthesia machine (Midmark, Versailles, OH). Maintenance of surgical depth of anesthesia was assessed by loss of palpebral reflex and minimal jaw tone and monitoring for an increase in respiratory rate. The Darvall Heated Breathing Circuit was used for all patients. A peripheral venous catheter was placed to provide unwarmed IV fluid administered at 10 mL/kg/hour (0.9% NaCl, Baxter; Deerfield, IL). During the 2 anesthetic events, each macaque was connected to the breathing circuit for 2 h. The macaque was placed in dorsal recumbency on an unheated stainless steel surgical table with an absorbent pad and a forced-air warming blanket set to 109.4 °F underneath the patient (Bair Hugger, 3M; Saint Paul, MN). Each patient was covered with a disposable surgical drape, leaving only the head and a 10 × 10 cm fenestration over the abdomen exposed.

In one of the anesthetic events, the heated breathing circuit was prewarmed for 10 min prior to connection to the patient and remained on for the duration of the anesthesia to continually deliver warmed inspired anesthetic gas at approximately 104 °F. In the other anesthetic event, the breathing circuit was not turned on and delivered unheated anesthetic gas. The order of the anesthetic events was randomly assigned for each NHP, with five NHPs undergoing the heated event first, and five undergoing the unheated event first. The 2 anesthetic events were conducted 14 d apart and occurred at approximately the same time of day.

After each 2-h anesthetic event, the anesthesia gas vaporizer was turned off and each animal received 100% oxygen for at least 5 min and then was extubated, recovered, and returned to cage. The heated breathing circuit unit was cleaned between procedures according to manufacturer's recommendations.

Temperature monitoring. An esophageal thermometer probe was inserted to the level of the heart, with positioning confirmed radiographically. The esophageal probe was plugged into the Darvall Heated Breathing Circuit unit, which displayed both the temperature of the thermometer probe and the temperature of the anesthetic gas delivered to the patient at the end of the breathing circuit. A rectal thermometer probe was inserted approximately 10 cm into the rectum and monitored via a veterinary patient monitor (Biomet BM5 Vet; Tustin, CA). Other vital signs including heart rate, respiratory rate, SpO_2, and $EtCO_2$, were measured using the same monitor for the duration of the anesthetic event.

Body temperature was measured and recorded every 5 min from both the esophageal and rectal thermometer probes. Baseline temperature was designated as the body temperature measured when the patient was initially connected to the breathing circuit and monitoring equipment ("time 0"). Other vital signs were recorded every 5 min. No animals were removed from study prior to completion and no data were excluded from the statistical analysis performed. Because each animal underwent an anesthetic event with and without the heated breathing circuit added, each animal served as its own control.

Data analysis. Temperature data were assessed for the difference between the temperatures measured during the 2 120-min anesthetic events, the nadir time at which the body temperature began to rise after the initial drop, the magnitude of the nadirs, and the time at which the body temperatures returned to baseline. Repeated measures ANOVA did not find a significant effect of treatment sequence. Therefore, the effect of treatment was tested by paired *t* test. No adjustment was applied for multiple comparisons. Statistical significance is defined as $P < 0.05$. The *P*-values indicate the result of a paired *t* test, unless indicated otherwise. Results are summarized as mean and SE, or mean difference and 95% CI. Analysis was performed using SAS version 9.4 (SAS Institute, Cary, NC).

Results

Rhesus macaques maintained on a heated anesthesia breathing circuit in combination with forced-air warming had a statistically significant reduction in time for recovery to baseline temperature as compared with forced-air warming alone. Return to baseline was 40.5 min faster ($P < 0.05$) as measured by esophageal temperature and 29.0 min faster ($P < 0.05$) as measured by rectal temperature (Table 1 and Figures 1 and 2). Temperature loss from baseline to nadir was greater in the unheated group as measured at the esophagus ($P < 0.05$), but was not statistically different at the rectum (Table 1). Macaques

Table 1. Comparison of deviation from baseline esophageal and rectal body temperatures at nadir, time to nadir, and recovery from nadir with and without use of a heated anesthesia breathing circuit.

	Mean temperature or time ±SE		
	Without heated breathing circuit (n = 10)	With heated breathing circuit (n = 10)	Difference (95% CI)
Esophageal Temperature.			
Baseline temperature (°F)	97.92 ± 0.25	97.88 ± 0.47	0.04 (-1.09, 1.16)
Deviation from baseline at nadir (°F)	−1.8 ± 0.18	−0.7 ± 0.10	−1.1 (-1.95, -0.24)[b]
Time to nadir (min)[a]	57.0 ± 6.11	48.0 ± 6.80	9.0 (-10.87, 28.87)
Time to return to baseline (min)[a]	101.0 ± 9.21	60.5 ± 13.05	40.5 (14.35, 66.64)[b]
Rectal Temperature.			
Baseline temperature (°F)	98.5 ± 0.26	98.3 ± 0.40	0.2 (-0.67, 1.09)
Deviation from baseline at nadir (°F)	−1.1 ± 0.20	−0.9 ± 0.19	−0.2 (-0.81, 0.35)
Time to nadir (min)[a]	44.5 ± 3.91	30.0 ± 3.25	14.5 (4.90, 24.11)[b]
Time to return to baseline (min)[a]	94.5 ± 8.18	65.5 ± 10.01	29.0 (5.29, 52.71)[b]

[a]Time after placement on breathing circuit (min)
[b]$P < 0.05$ by paired *t* test
SE - Standard Error. CI - Confidence Interval.

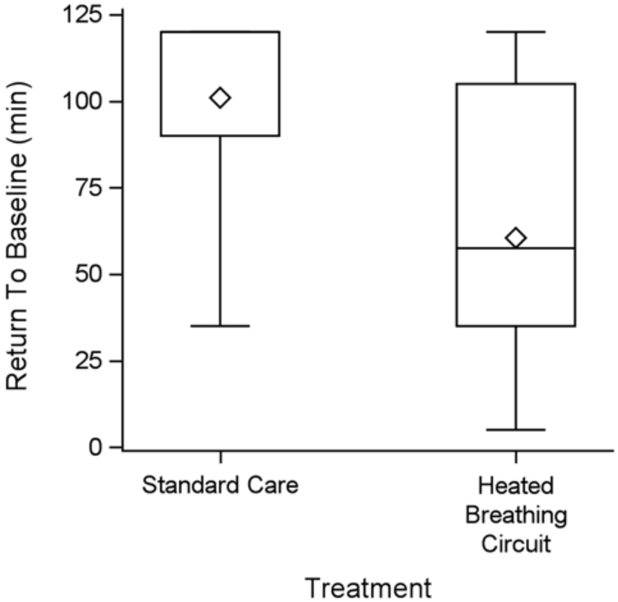

Figure 1. Box plot of time to return to baseline for esophageal temperatures comparing anesthetic events with a heated breathing circuit, and with only forced air warming ("standard care"). Body temperature returned to baseline significantly faster with the warming unit (mean 60.5 compared with 101.0 min, $P < 0.05$). Box and whiskers indicate interquartile range, min, and max. Line and diamond indicate median and mean, respectively.

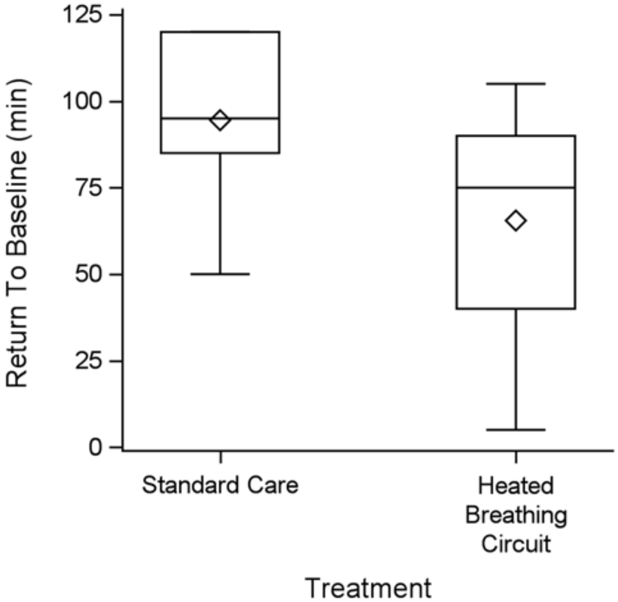

Figure 2. Box plot of time to return to baseline for rectal temperatures comparing anesthetic events with a heated breathing circuit, and with only forced air warming ("standard care"). Body temperature returned to baseline significantly faster with the warming unit (mean 65.5 compared with 94.5 min, $P < 0.05$). Box and whiskers indicate interquartile range, min, and max. Line and diamond indicate median and mean, respectively.

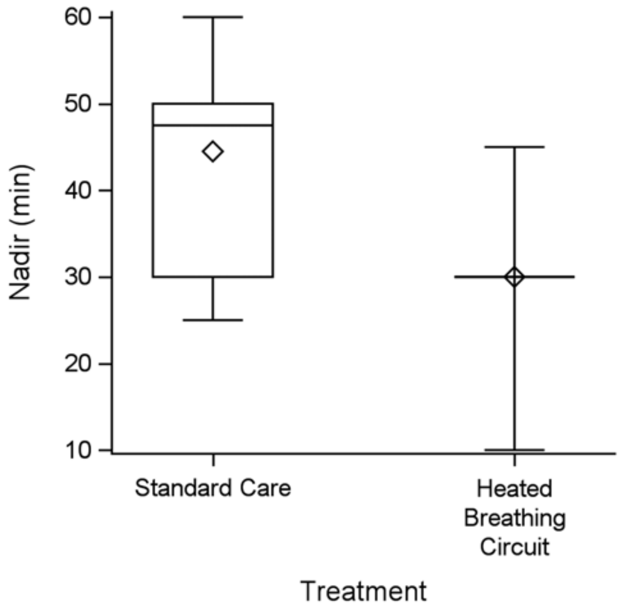

Figure 3. Box plot of time of nadir for rectal temperatures comparing anesthetic events with a heated breathing circuit to only forced air warming ("standard care"), with a significantly earlier nadir when using the heated breathing circuit (mean 30 compared with 45.5 min, $P < 0.05$). An earlier nadir indicates that the patient began to recover temperature and return toward baseline sooner. Box and whiskers indicate interquartile range, min, and max. Line and diamond indicate median and mean, respectively.

on the heated breathing circuit reached nadir faster and began to return toward baseline sooner, with the difference in time statistically significant only when based on rectal temperature ($P < 0.05$) (Table 1 and Figure 3). As measured by rectal temperature at 5-min intervals, macaques on the heated breathing circuit had higher body temperatures during the interval from 70 to 120 min of anesthesia time as compared with their nonheated values ($P < 0.05$) (Table 2 and Figure 4). Based on esophageal temperature measured at 5-min intervals, macaques on the heated breathing circuit had higher body temperatures during the interval from 20 to 120 min of anesthesia as compared with nonheated values ($P < 0.05$) (Table 3 and Figure 5). Two-way repeated measures ANOVA showed that the order in which the 2 procedures were conducted had no statistically significant effect.

Other measured vital signs showed no significant differences when measured with or without the heated breathing circuit. No significant differences were found in the amount of isoflurane used to maintain surgical depth of anesthesia or in length of recovery times after anesthesia.

Discussion

These results support our hypothesis that compared with forced-air warming alone, the use of a heated anesthesia breathing circuit results in less heat loss and higher body temperature when used in conjunction with forced-air warming, especially in longer procedures. The use of a heated breathing circuit can be a valuable addition to multimodal thermal support during anesthesia. The most significant effect of the heated breathing circuit was the reduction in time needed for a patient to return to baseline temperature. Combining a heated breathing circuit with forced-air warming to address evaporative heat loss during anesthesia resulted in a return to baseline temperature nearly 30 min faster based on rectal temperature and 40 min faster based on esophageal temperature.

Table 2. Comparison of deviation from baseline rectal body temperatures following placement on a heated or unheated breathing circuit recorded at 5-min intervals.

	Mean temperature deviation ± SE from baseline (°F)		
Time (min)[a]	Without heated breathing circuit (n = 10)	With heated breathing circuit (n = 10)	Difference (95% CI) (°F)
5	−0.20 ± 0.10	−0.24 ± 0.08	0.04 (−0.31, 0.37)
10	−0.54 ± 0.12	−0.63 ± 0.11	0.09 (−0.32, 0.50)
15	−0.75 ± 0.16	−0.76 ± 0.15	0.01 (−0.50, 0.52)
20	−0.89 ± 0.19	−0.84 ± 0.19	−0.05 (−0.65, 0.55)
25	−0.94 ± 0.21	−0.84 ± 0.19	−0.10 (−0.74, 0.54)
30	−0.96 ± 0.25	−0.83 ± 0.20	−0.13 (−0.83, 0.57)
35	−0.90 ± 0.25	−0.69 ± 0.21	−0.21 (−0.91, 0.49)
40	−0.94 ± 0.25	−0.63 ± 0.22	−0.31 (−1.03, 0.41)
45	−0.91 ± 0.27	−0.57 ± 0.23	−0.34 (−1.10, 0.42)
50	−0.84 ± 0.28	−0.45 ± 0.23	−0.39 (−1.15, 0.37)
55	−0.75 ± 0.27	−0.36 ± 0.24	−0.39 (−1.15, 0.37)
60	−0.82 ± 0.24	−0.20 ± 0.23	−0.62 (−1.25, 0.01)
65	−0.72 ± 0.25	−0.09 ± 0.22	−0.63 (−1.31, 0.05)
70	−0.62 ± 0.25	0.05 ± 0.22	−0.67 (−1.33, -0.01)[b]
75	−0.48 ± 0.25	0.22 ± 0.26	−0.70 (−1.36, -0.04)[b]
80	−0.44 ± 0.25	0.31 ± 0.24	−0.75 (−1.35, -0.15)[b]
85	−0.31 ± 0.27	0.41 ± 0.24	−0.72 (−1.42, -0.02)[b]
90	−0.22 ± 0.26	0.54 ± 0.23	−0.76 (−1.41, -0.11)[b]
95	−0.11 ± 0.27	0.67 ± 0.23	−0.78 (−1.47, -0.09)[b]
100	−0.07 ± 0.26	0.75 ± 0.24	−0.82 (−1.46, -0.18)[b]
105	0.03 ± 0.27	0.90 ± 0.24	−0.87 (−1.55, -0.19)[b]
110	0.11 ± 0.26	1.00 ± 0.21	−0.89 (−1.54, -0.24)[b]
115	0.15 ± 0.25	1.05 ± 0.20	−0.90 (−1.54, -0.26)[b]
120	0.22 ± 0.24	1.13 ± 0.18	−0.91 (−1.50, -0.33)[b]

Mean ± SE baseline rectal body temperatures (°F): Unheated: 98.5 ± 0.26, Heated: 98.3 ± 0.40

[a]Time after placement on breathing circuit (min)

[b]$P < 0.05$ by paired t test

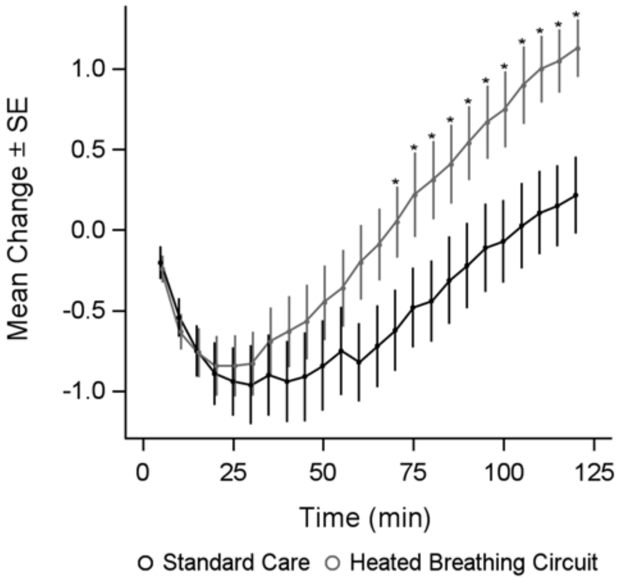

Figure 4. Mean change ± SE of rectal temperatures relative to baseline comparing anesthetic events with a heated breathing circuit, and with only forced air warming ("standard care"), with higher body temperatures from 70 to 120 min of anesthesia time (*$P < 0.05$).

Table 3. Comparison of deviation from baseline esophageal body temperatures following placement on a heated or unheated breathing circuit recorded at 5-min intervals.

Time (min)[a]	Mean temperature deviation ± SE from baseline (°F) Without heated breathing circuit (n = 10)	With heated breathing circuit (n = 10)	Difference (95% CI) (°F)
5	−0.54 ± 0.16	−0.25 ± 0.09	−0.29 (−0.76, 0.10)
10	−1.24 ± 0.26	−0.68 ± 0.17	−0.56 (−1.29, 0.17)
15	−1.40 ± 0.28	−0.74 ± 0.19	−0.67 (−1.44, 0.11)
20	−1.62 ± 0.32	−0.68 ± 0.18	−0.94 (−1.73, −0.14)[b]
25	−1.57 ± 0.32	−0.68 ± 0.18	−0.88 (−1.70, −0.06)[b]
30	−1.62 ± 0.27	−0.63 ± 0.21	−0.99 (−1.71, −0.27)[b]
35	−1.57 ± 0.31	−0.58 ± 0.23	−0.99 (−1.80, −0.18)[b]
40	−1.57 ± 0.31	−0.47 ± 0.26	−1.10 (−1.99, −0.21)[b]
45	−1.57 ± 0.27	−0.45 ± 0.26	−1.12 (−1.95, −0.28)[b]
50	−1.57 ± 0.33	−0.45 ± 0.26	−1.12 (−1.99, −0.25)[b]
55	−1.51 ± 0.32	−0.29 ± 0.27	−1.22 (−2.13, −0.32)[b]
60	−1.51 ± 0.32	−0.18 ± 0.29	−1.33 (−2.30, −0.37)[b]
65	−1.40 ± 0.32	−0.13 ± 0.30	−1.28 (−2.32, −0.23)[b]
70	−1.13 ± 0.33	0.04 ± 0.31	−1.17 (−2.14, −0.20)[b]
75	−1.03 ± 0.31	0.14 ± 0.26	−1.17 (−2.00, −0.34)[b]
80	−0.92 ± 0.30	0.25 ± 0.32	−1.17 (−2.04, −0.30)[b]
85	−0.92 ± 0.31	0.31 ± 0.30	−1.22 (−1.99, −0.46)[b]
90	−0.81 ± 0.31	0.36 ± 0.33	−1.17 (−2.08, −0.26)[b]
95	−0.70 ± 0.32	0.52 ± 0.33	−1.22 (−2.22, −0.23)[b]
100	−0.70 ± 0.30	0.63 ± 0.34	−1.33 (−2.37, −0.30)[b]
105	−0.54 ± 0.27	0.74 ± 0.34	−1.28 (−2.25, −0.31)[b]
110	−0.54 ± 0.27	0.79 ± 0.32	−1.33 (−2.28, −0.38)[b]
115	−0.54 ± 0.27	0.85 ± 0.29	−1.39 (−2.27, −0.51)[b]
120	−0.49 ± 0.28	0.95 ± 0.28	−1.44 (−2.42, −0.46)[b]

Mean ± SE baseline esophageal body temperatures (°F): Unheated: 97.92 ± 0.25, Heated: 97.88 ± 0.47

[a]Time after placement on breathing circuit (min)

[b]$P < 0.05$ by paired t test

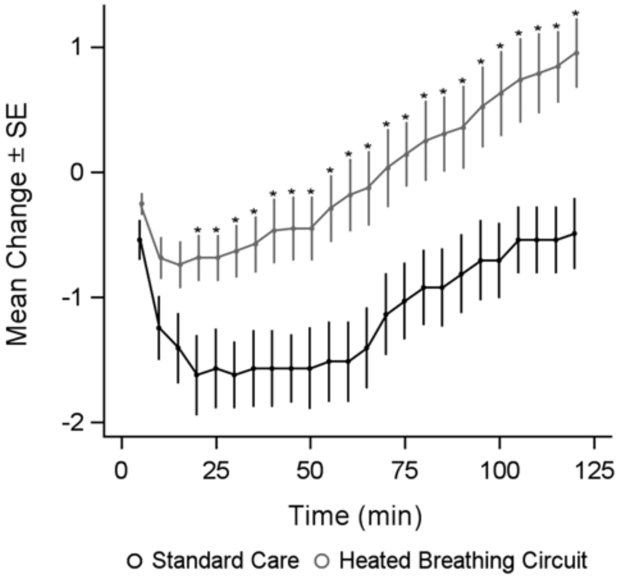

Figure 5. Mean change ± SE of esophageal temperatures relative to baseline comparing anesthetic events with a heated breathing circuit, and with only forced air warming ("standard care"), with higher body temperatures from 20 to 120 min of anesthesia time (*$P < 0.05$).

The effect was especially apparent for longer anesthetic events. When we used a heated breathing circuit in conjunction with forced-air warming, patients had significantly higher rectal body temperatures from 70 to 120 min after initiation of anesthesia as compared with forced-air warming alone. Based on our results, clinicians should consider adding a heated breathing circuit to the standard of care for multimodal thermal support during longer surgical or other anesthetic procedures in rhesus macaques and similar-sized NHPs.

We speculate that the warmed airway may have affected surrounding tissues in a way that contributed to the earlier significant difference found in esophageal as compared with rectal temperatures. However, both the esophageal and rectal temperature findings support our hypothesis. Both temperature measurements had a mean return to baseline after one hour of anesthesia time with the heated breathing circuit, while body temperature took 94.5 to 101 min to return to baseline without the heated breathing circuit. Results showed statistically significant increases in both rectal and esophageal temperature measurements at 70 min and later. Therefore, we concluded that the heated breathing circuit has the greatest benefit in procedures lasting longer than one hour. However, some benefit also occurs for shorter procedures, as the nadir of rectal temperature occurred earlier, and the magnitude of body temperature lost at the esophageal temperature nadir was smaller. An earlier nadir indicates that the patient began to recover temperature and return toward baseline sooner with the addition of the heated anesthesia circuit.

We opted to perform this study without concurrent surgical procedures because surgical time, size of incision, variable blood loss, and other factors may have been additional confounding variables in the evaluation of this warming method. Eliminating the variable of heat loss from an open incision and blood loss during surgery focused the study on the evaporative heat loss from the respiratory tract during anesthesia. Anesthesia, procedure preparation, time in place on the surgical table, and other factors such as draping were consistent between patients, so the heated breathing circuit was the only significant difference between anesthetic events.

The heated breathing circuit is a semiclosed breathing circuit. A heated Bain or similar open circuit is not available for use in smaller animals, as the rate of flow in those types of circuit is higher and the gas cannot be fully warmed by the time it reaches the patient. Our results suggest that intubated patients who can be placed on a semiclosed breathing circuit are most likely to benefit from the heated breathing circuit.

In conclusion, we suggest that use of a heated anesthesia breathing circuit should be considered to provide thermal support to macaques during anesthesia, especially for procedures that last longer than one hour.

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Opinions, interpretations, conclusions, and recommendations are those of the author and are not necessarily endorsed by the U.S. Army.

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