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Comparison of 3 Methods for Preventing Perianesthetic Hypothermia in Callimicos (*Callimico goeldii*)

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Perianesthetic hypothermia is one of the most common complications in veterinary anesthesia, especially in small patients with a large body surface area to mass ratio. During anesthesia, body heat can be lost through 4 mechanisms—radiation, convection, conduction, and evaporation—but anesthetists frequently address only one mechanism at a time. Here we sought to evaluate 3 methods of preventing perianesthetic hypothermia in callimicos (*Callimico goeldii*). In our experience, these small NHP routinely become hypothermic under even brief inhalant anesthesia. To address multiple routes of heat loss, animals received 1 of 3 treatments: 1) placement of a reflective blanket over the patient to limit radiative heat loss to the surrounding environment; 2) placement of a reflective blanket and use of a heated anesthetic circuit, which warmed the inspired air to 104 °F (40 °C), and 3) placement under the patient of a forced-air warming blanket set at 109.4 °F (43 °C). Sources of radiative heat loss were assessed by using infrared thermography. Each animal was anesthetized with isoflurane and maintained in sternal recumbency in a temperature-controlled room (65 °F; 18.3 °C); esophageal core body temperature was monitored every 5 min for a total of 30 min. The rate of heat loss did not differ between the use of a reflective blanket with or without a heated anesthetic circuit. Animals provided the forced-air warming blanket experienced a slight increase in average body temperature. According to these findings, an underbody warm-air blanket provided the best protection against hypothermia for callimicos in sternal recumbency.

Perianesthetic hypothermia is one of the most common complications in veterinary anesthesia. Anesthetic drugs often cause blunting of normal physiologic thermoregulation, such as shivering.[8] Many anesthetics, especially inhalants, cause direct vasodilation, thus increasing heat loss from the skin.[2,10] Most body heat is lost through the skin, making cutaneous insulation or warming critical for preventing heat loss.[14,15] This prevention is particularly important in small patients that have a large body surface area to mass ratio. Perianesthetic hypothermia can increase recovery time[9] and risk of wound infection[1] as well as contribute to arrhythmias[13] and coagulation defects.[11,12]

During anesthesia, body heat is lost through 4 mechanisms: radiation, convection, conduction, and evaporation. Radiation is the loss of heat through infrared emission to the environment surrounding the patient; this mechanism does not include heat lost through direct contact with a cold surface. Radiation accounts for 60% to 70% of heat loss in anesthetized humans.[4,13] Convection is the loss of heat to air currents around the body. Most hospital situations involve conditioned air that is moved through ventilation systems with a high turnover rate, resulting in a continuous loss of heat to the air.[2] Conduction comprises the direct loss of heat to surfaces in contact with a patient. These surfaces include the operating table as well as intravenous fluids, ultrasound gel, and water on the patient. Evaporation is the loss of warm, humid air from the respiratory tract, skin, or an open surgical wound. Alcohol application can accelerate evaporative cooling from the skin.

Many commercial devices are available for perianesthetic warming, ranging from passive devices, such as conventional blankets, to active devices, such as circulating warm-water, electric, and forced-air blankets.[3,6] In many situations, an anesthetist might address only 1 of the 4 mechanisms at a time, although multimodal strategies to prevent heat loss (passive warming) and to provide supplemental heat (active warming) may be more effective. In some cases, the treatment method may not address the primary route of heat loss. For example, a patient in dorsal recumbency that is losing heat from a ventral midline celiotomy may not receive much benefit from underbody warming.

The goal of the present study was to evaluate 3 methods of perianesthetic hypothermia prevention in callimicos (*Callimico goeldii*). These small South American monkeys belong in the family Callitrichidae and weigh 400 to 800 g. The animals have a thick hair coat over the chest and dorsum but are only sparsely haired over the ventral abdomen and inguinal area (Figures 1 and 2). These NHP are anesthetized routinely for preventive healthcare, diagnostic, and therapeutic procedures, and in our experience, they frequently become hypothermic under even brief inhalant anesthesia.

In this study, we compared 3 different heat-loss prevention strategies, attempting to address multiple routes of heat loss. Determining the most effective method for reducing perianesthetic heat loss is important for patient safety and may guide routine use during anesthesia for small primates. Our hypotheses were that the rate of heat loss would be significantly lower with active heating methods compared with a passive method

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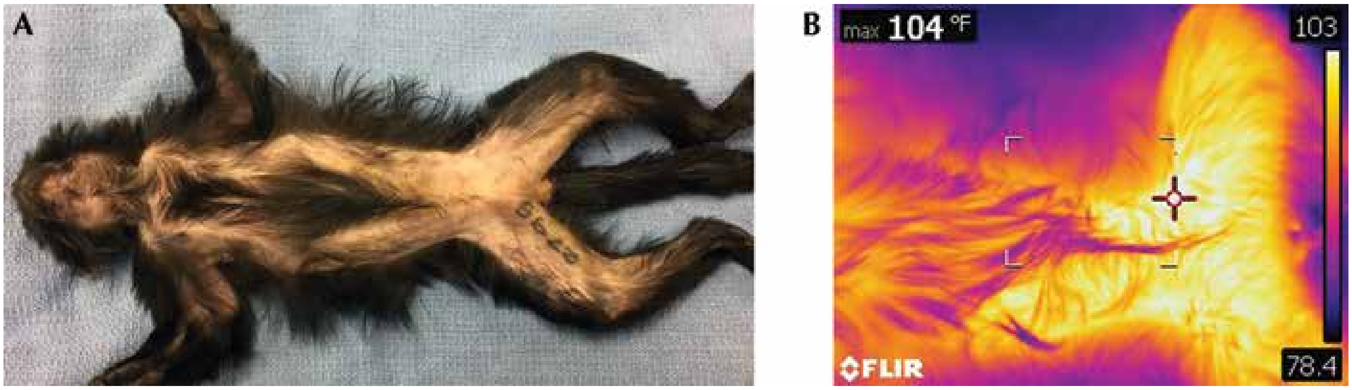

Figure 1. (A) Standard and (B) thermal images of the ventrum of an anesthetized callimico. Warm areas are white; cool areas are blue to black. The warmest area on the animal and the site of greatest cutaneous heat loss is the nonhaired inguinal area.

Figure 2. (A) Standard and (B) thermal images of the dorsum of an anesthetized callimico.

and that the rate of heat loss would not differ between active heating methods.

Materials and Methods

Animals. The experimental protocol was approved by the IACUC of the Chicago Zoological Society. The study population comprised 12 adult callimicos (*Callimico goeldii*; 8 female, 4 male; age, 1.2 to 17.1 y [median, 8.1 y]); weight [mean ± 1 SD], 544 ± 97 g. Animals were assigned to 1 of 3 treatment groups: 1) radiative barrier only; 2) radiative barrier with heated anesthetic circuit; and 3) forced-air warming blanket under the patient. For the radiative barrier, a reflective blanket (Emergency Mylar Thermal Blanket, Quiverr Collective, Carlsbad, CA) was placed over the patient to limit radiative heat loss to the surrounding environment. The heated anesthetic circuit was a commercially available device designed for veterinary use (Darvall Heated Breathing Circuit, Advanced Anesthesia Specialists, Gladesville, New South Wales, Australia), consisting of an active air-heating mechanism that warms the inspired air in the anesthetic circuit to 104 °F (40 °C). The unit contains a thermistor probe and a feedback loop to prevent overheating of the inspired air. The forced air-warming unit was set at 109.4 °F (43 °C) and was attached to a disposable underbody air-delivery blanket measuring 91 cm × 122 cm (Bair Hugger, 3M, Maplewood, MN), which was placed under the entire patient. These methods were chosen because each offers different advantages in terms of cost, ease of use, and access to the patient's body during anesthesia. Each therapeutic intervention was initiated after instrumentation with anesthetic monitoring devices.

Anesthesia. Each callimico was manually restrained for brief examination and mask induction with isoflurane at a vaporizer setting of 5% in oxygen, delivered at 2 L/min through a Mapleson type-D nonrebreathing circuit until muscle and jaw tone were relaxed. A catheter (24 gauge, 19 mm; Surflash, Terumo Medica, Somerset, NJ) was placed in an external saphenous vein, but no fluids were administered until the conclusion of the sampling period. During the sampling period, anesthesia was maintained by using a snug-fitting facemask with isoflurane at a vaporizer setting of 2% in oxygen, delivered at 1 L/min through the pediatric circle system designed for the heated anesthetic circuit. The same anesthetic circuit was used for all animals, but the heating mechanism was used only for the animals undergoing that treatment.

Thermographic imaging. Sources of radiative heat loss were assessed using an infrared thermography camera (model no. T420, FLIR Systems, North Billerica, MA). Whole-body images of the ventrum and dorsum of each animal were obtained prior to and immediately after induction of general anesthesia. Images were used for subjective identification of body regions that were losing the most heat to the environment and thus had a higher surface body temperature (Figures 1 and 2).

Monitoring. After thermography, the NHP were moved to a temperature-controlled room set at 65 °F (18.3 °C) and were maintained in sternal recumbency on the blanket for the forced-air warming system, which was placed on a vinyl covered, plastic encased, foam padded table for a computed tomography scanner. The same model of blanket was used for all animals, but the forced air warming mechanism was used only for the animals undergoing that treatment. For treatments with and without the heated anesthetic circuit, the patient was covered with a reflective blanket; for the forced-air warming blanket, the patient remained uncovered. Room temperature was measured before and after each patient.

All objective monitoring was performed by using a multiparameter veterinary monitor (model Max12-HD, Cardell, Midmark, FL). Esophageal core body temperature was measured by using a thermistor probe that was positioned with the tip at the level of the heart. The position of the probe tip was confirmed radiographically. The core temperature at the time the intervention was initiated was considered baseline (time 0), and core body temperature was monitored every 5 min for a 30 min period. During the study period, the NHP underwent computed tomography as a component of a routine preventative medicine examination. During the sampling time, the subjects were not handled, moved, or uncovered. Heart rate was measured by electrocardiography, and respiratory rate was measured by visually counting chest movements.

Data analysis. All statistical analysis was performed by using PRISM statistics software (GraphPad Software, San Diego, CA). Normality of data was determined by using the Shapiro–Wilk test. Differences in weight between groups were tested by using unpaired t tests; a P value less than 0.05 was considered significant. The body temperature at each time point was subtracted from the baseline temperature to determine the decrease from baseline; these values were plotted against time. Regression lines of temperature decrease compared with time were compared by using analysis of covariance; a P value less than 0.05 was considered significant.

Results

The surface temperature (assessed via thermographic imaging) of the nonhaired ventral skin in the inguinal area of our callimicos ranged from 103 to 105 °F (39.4 to 40.5 °C), compared with 95 to 96 °F (35 to 35.5 °C) on the haired dorsum. Weight did not differ between groups. The rate of heat loss did not differ between using the reflective blanket alone or with the heated anesthetic circuit. Animals placed on the forced-air warming blanket experienced a slight increase in average body temperature ($P < 0.05$) (Figure 3). According to these findings, an underbody warm-air blanket provided the best protection against hypothermia in sternally recumbent anesthetized callimicos.

Discussion

Like other small-bodied animals, callitrichids have many opportunities for significant heat loss during anesthesia. Due to their high surface area to body mass ratio, they can experience high cutaneous heat loss with little potential for metabolic heat production. In our current study, a forced-air warming blanket placed under an anesthetized, sternally recumbent patient was more effective at preventing hypothermia than was a reflective blanket alone or when combined with a heated anesthetic circuit in anesthetized callimicos. This method of warming might be particularly useful for advanced imaging studies, such as CT or MRI. During those studies, subjects are maintained sternally recumbent for extended periods of time in a room that is air-conditioned because of equipment needs and that is typically much cooler than the animals' preferred optimal thermal neutral zone.

A reflective blanket is a simple, passive means of reducing radiative loss, but it does not allow for any active heating of the patient. Forced-air warming blankets are reportedly one of the most effective methods of warming in veterinary anesthesia.[3,5,6,7] For small animals, such as callitrichids, a large warming blanket over the patient reduces access to the subject for examination, ultrasound imaging and sample collection. One advantage of heated anesthetic circuits over forced-air warming blankets is that the heated circuits can be used without obstructing access to the patient.

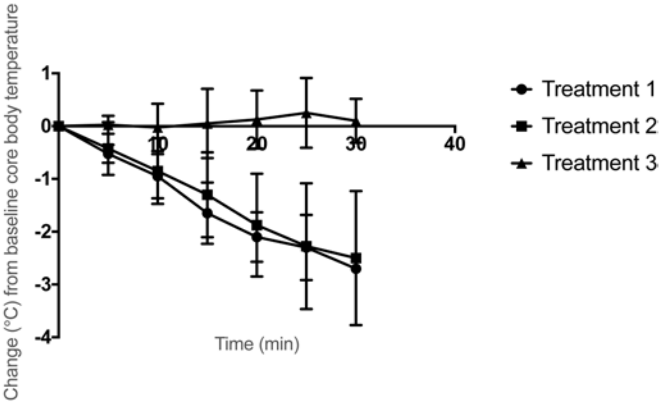

Figure 3. Change in esophageal core body temperature (°C; mean ± 1 SD) over time of callimicos provided a radiative barrier only (treatment 1), a radiative barrier and heated anesthetic circuit (treatment 2), or a forced-air warming blanket (treatment 3). Regression equations are: treatment 1, $y = -0.09469x - 0.06213$; treatment 2, $y = -0.08732x - 0.008036$; and treatment 3, $y = 0.006429x - 0.02143$. The rate of temperature change differed significantly ($P < 0.05$) when comparing treatment 1 or 2 with treatment 3 but not when treatment 1 was compared with treatment 2.

In humans, most of the heat lost during anesthesia is radiative heat loss from the skin, followed by convective heat loss to air currents in the room.[13] Most veterinary patients have the benefit of insulating fur, which can limit cutaneous heat loss by trapping air and limiting the effect of convective currents.[4] Callimicos, unlike many other callitrichids, are sparsely haired over the ventrum, especially the inguinal area, thus allowing for significant cutaneous heat loss by both radiation and convection. This route of heat loss was confirmed with thermographic imaging in this study. In addition, the abdomen might undergo additional evaporative cooling due to the presence of alcohol for phlebotomy or to conductive cooling from ultrasound gel or a cold table.

During anesthesia, heat loss due to vasodilation and cutaneous losses, as well as the limited heat production resulting from decreased metabolic activity, significantly contribute to hypothermia in patients. Passive mechanisms such as blankets, might limit heat loss, but they do not address decreased heat production by the animal. Neither cloth nor reflective blankets allow for active warming of the patient. Passive warming devices alone cannot prevent perianesthetic hypothermia in a clinical setting, and active warming devices must be used.[3]

In the current study, using the heated anesthetic circuit with the reflective blanket offered no benefit over the reflective blanket alone. The heated circuit is designed to be used with intubated patients, and the patients in our study were maintained by mask. Because relatively little heat is lost from the respiratory system of small patients, a heated circuit may have less of an effect in this species than in larger NHP. Furthermore, NHP likely have little respiratory heat loss compared with dogs, which lose much of any excess body heat through the respiratory system during panting.[8]

The forced-air warming blanket has been shown to be effective in several veterinary species and in humans.[5,6,7] This device actively provides supplemental heat to the patient, and it limits convective heat loss to the room when used over the patient. Although the forced-air warming blanket provided the most protection against hypothermia in our current study, it may not be as effective in a different clinical setting. According to thermal imaging, our callimicos lost much of their body heat from the inguinal area, so that placing them in sternal recumbency on the warm-air blanket was the most physiologically appropriate method to prevent heat loss. In clinical practice, however, these animals are often maintained in dorsal recumbency when they are anesthetized to facilitate examination and diagnostic procedures, such that the blanket is primarily in contact with the hair, potentially making it less efficacious.

Our findings are limited to callimicos not undergoing surgery or abdominal ultrasonography. During a typical physical examination under anesthesia, the animal might lose metabolic body heat primarily through radiation but also through conduction to cold surfaces and liquids, which rapidly cool the patient. The large surface area to body mass ratio and hairless ventrum of callimicos contribute to the high rate of heat loss in this species, but these factors also may facilitate active heating mechanisms, because there is less tissue to warm and less hair that insulates the body from the heating mechanism. Effective thermoregulation under anesthesia may require rethinking warming strategies and common clinical practices. Over-body forced-air warming during ultrasound examinations might be achieved by placing the forced-air blanket over both the animal and the ultrasonographer's hand. Evaporative heat loss can be minimized by limiting the use of water or alcohol on the skin surface, and conductive heat loss could be controlled by using prewarmed ultrasound gel. Although many of these other treatments need to be evaluated objectively, in many clinical settings it will be advantageous to provide heat in a way that addresses the relevant routes of heat loss.

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