Prevention of Perioperative Hypothermia in Anesthetized Dogs Using a Novel Computerized Body Temperature Regulation System

Epstein, A.,* Avni, G., Laset, G. and Aroch, I.

Hebrew University Teaching Hospital and Koret School of Veterinary Medicine, Hebrew University of Jerusalem, P.O. Box 12, Rehovot, 76100, Israel

* **Corresponding author:** Dr. Ana Epstein, DVM. Address: Hebrew University Veterinary Teaching Hospital, Koret School of Veterinary Medicine, Hebrew University of Jerusalem, P.O. Box 12, Rehovot, 76100, Israel. Tel: +972-3-9688588. Fax: +972-3-9604079. E-mail: ana6@hotmail.com

ABSTRACT

The objective of this study was to evaluate the efficacy and safety of a novel computerized body temperature regulation system (CBTR) in preventing hypothermia during general gas anesthesia in dogs. A non-blinded, controlled, cross-over group study was carried that included six healthy adult beagles. Each dog was anesthetized twice for 150 minutes, serving as its own control. The second anesthesia was done 1 week after the first, using the same anesthetic protocol. Controls (week 1), received no thermal care (NTC; i.e., passive, non-heated blanket under the body). In the study group (week 2) body temperature was maintained using the CBTR, consisting of a water-channeled vest, covering the dogs' trunk and extremities. Vest temperature was maintained by a computerized feedback loop system, and skin and rectal thermosensors, with the temperature set at 37.8˚C. Rectal temperature, mean arterial blood pressure (MBP), complete blood count (CBC), serum chemistry and coagulation tests were measured before, during and after anesthesia in all dogs. At the end of anesthesia, mean rectal temperature in NTC group was 31.8±0.6˚C (a decrease of 6.4±0.9˚C from the beginning of anesthesia) versus 37.3±0.7˚C (a decrease of 0.57±0.83˚C) in the CBTR group (P<0.0001). MBP, leukocyte count and potassium concentration were higher (P<0.05), while times to extubation and to sternal recumbency were shorter (P<0.05) in the CBTR group compared to the NTC group. No adverse effects (e.g., overheating, burns) occurred in the CBTR group. It was concluded that the CBTR system was safe and effective in preventing perioperative hypothermia and minimizing undesirable effects.

Key Words: Canine, gas anesthesia, thermoregulation, hematology, coagulation, arterial blood pressure.

INTRODUCTION

Hypothermia is a state of decreased body temperature below the reference interval in homeothermic organisms (1). It develops when animals are unable to maintain normal body temperature due to impairment of the mechanisms responsible for maintenance of normothermia. The latter include behavioral (e.g., avoiding cold sources, curling and packing in groups) and metabolic (e.g., shivering and vasoconstriction) reactions. Hypothermia develops when an animal, for any reason, is unable to utilize these actions. It may result from various medical conditions, including hypothyroidism, hypoglycemia, head trauma, shock, burns, general anesthesia (GA), toxicoses (e.g., ethanol and alphachloralose), central nervous system (CNS) depression, prolonged immobility and spinal cord transsection (2). Hypothermia decreases basal metabolism, oxygen consumption and cerebral blood flow, and depending on its severity and duration, might lead to alkalosis, acidosis, vasodilatation, increased cardiac irritability that potentially results in atrial or ventricular fibrillation, decreased cardiac output, asystole, apnea and suspended CNS activity (3). It may result in significant changes in the complete blood count (CBC), including decreased white blood

cell (WBC) and platelet counts (2). Additionally, clotting times are prolonged during hypothermia (4) and intestinal motility decreases (2).

Perioperative hypothermia often occurs during surgery due to GA-induced impairment of thermoregulation (5). General anesthesia suppresses the normal physiological responses to decreased body temperature, resulting in iatrogenic hypothermia. Hypothermia has been associated with a number of post-operative complications, such as cardiovascular impairment, shivering, increased oxygen consumption, delayed wound healing, coagulopathy, decreased cerebral blood flow, hypotension, depression, acid-base balance disturbances, altered drug action and prolonged recovery (3,6). In dogs undergoing GA, rectal temperature usually decreases by 1˚C within 40 minutes from induction of anesthesia, and decreases progressively over time. After two hours of GA, a drop of 2.5˚C is expected (7). Most body heat loss during GA occurs through the skin surface by convection and radiation, and it is also affected by the type and dose of the anesthetic drugs, environmental temperature, anesthetic breathing system, oxygen flow, temperature of the intravenous fluids administered and time and extent of exposure of body cavities and viscera during surgery (7).

Hypothermia can be prevented and treated using several warming devices. In veterinary practice, various techniques are routinely used to prevent and treat GA-induced hypothermia. Passive blanket warming is cost-effective, simple and widely available, however, it is inefficient. Warm water bottles have limited usefulness, because their temperature decreases over time, and when they fall below the patient's temperature, they actually increase heat loss. In addition, their use has been associated with thermal burns (8). Oat bags have been used with slightly better results, but have similar limitations (8). Artificial warming devices such as electric heating pads and lamps must be used with extreme caution to avoid thermal burns or electrocution, especially near fluid sources. Warm intravenous fluids might aid in body temperature maintenance, but have limited effects (9). Forced warm air blowers are very popular and seem to be effective in prevention of hypothermia, however, a previous study has shown that their use might potentially increase the transmission of bacterial infections to the anesthetized patients (10). Warm water circulating blankets are effective and these are recommended to preserve the patient's body heat (8). These can be placed under or over the trunk, or be applied to or wrapped over different body parts. One of the most effective rewarming techniques is wrapping the distal extremities with warming blankets. This has been shown to be superior to placement of warming blankets only under the animal's trunk (11). This technique takes advantage of the wide network of arterio-venous shunts located in these body parts that account for as much as 80% of their blood flow, depending on the degree of vasodilatation (12).

The present study examined a new approach in prevention and treatment of perioperative hypothermia using a Computerized Body Temperature Regulation (CBTR) system (Allon 2001, M.T.R.E., Or-Akiva, Israel) during GA in healthy dogs. The CBTR system is a recently developed, compact device that potentially overcomes the limitations of currently used devises. It consists of a water-channeled fitted garment, worn by the patient, covering most body parts, including the extremities, but allowing surgical approach to the abdomen. It receives water from a heating/cooling circulating unit and is computer-controlled to be maintained and can be maintained at any set-point temperature between 19 and 41˚C. A feedback loop receives information of the patient's body temperature from cutaneous and rectal thermal sensors (thermistors) applied to the patient. Thus, the system's water temperature constantly changes according to the desired set-point temperature and the patient's actual temperature. In addition, the computer feedback software in this unit prevents overheating, thus limiting potential thermal burns. The vest is flexible and is available in several sizes. It can be applied to various body parts to maximize surface coverage without affecting surgical areas. The garment consists of a disposable liner, a reusable middle layer of water-channeled polyethylene and a reusable outer layer of insulating fabric. The heating/cooling unit is in a heat pump configuration and circulates water via an oscillating diaphragm pump.

This system has been tested in several studies in human patients, and proved to be highly safe and effective in preservation of normothermia in coronary artery bypass surgery (13), liver transplantation (14), abdominal surgery (15) and induced hypothermia during cardiac arrest or stroke (16). The objective of this study was to evaluate using a non-blinded, controlled, cross-over group study, the efficacy and safety of this CBTR sysetm in preventing hypothermia during general gas anesthesia in dogs.

MATERIALS AND METHODS

Animals and study design

This study included six healthy, adult, beagle dogs with a body weight range of 11 to 15 kg and age range of 2 to 3 years. They were determined to be healthy based on the history, physical examination, complete blood count (CBC), serum biochemistry, serum cortisol concentration and a coagulation profile (i.e., activated partial thromboplastin time (aPTT) and prothrombin time (PT)). The study design was a non-blinded cross-over, with each dog anesthetized twice, one week apart, using the same anesthetic protocol. Each dog served as its own control. During the first anesthesia no thermal care was applied, and dogs were placed on an unheated blanket (NTC), while during the second anesthetic, thermal care was maintained using the CBTR system. All dogs were anesthetized, one after another, on the same day in each treatment. The study was approved by the Ethics Committee for Animal Experimentation, Faculty of Agriculture, Food and Environment, Hebrew University of Jerusalem.

Anesthetic protocol

The dogs were premedicated with pethidine-HCl (4mg/kg, intramuscularly, Dolestine, Teva, Tel-Aviv, Israel) and acepromazine-maleate (0.05 mg/kg, intramuscularly, PromAce, Fort Dodge, IA, USA). After premedication, an intravenous catheter was introduced into a cephalic vein. Induction was performed using ketamine-HCl (10mg/kg, intravenously; Ketaset, Fort Dodge, IA, USA) and diazepam (1mg/kg, intravenously; Assival, Teva, Tel-Aviv, Israel) given to effect (usually, a third of the calculated dose). The dogs were then intubated, and anesthesia was maintained using 1% of halothane (Fluothane, AstraZeneca Limited, Auckland, NZ) in 2 L/minute flow of 100% oxygen, delivered by a circle absorber equipped with an F-anesthetic circuit.

During anesthesia, the dogs were placed in dorsal recumbency. Hartmann's solution (10 mL/kg/hr, intravenously, at room temperature) was given from induction of anesthesia to return to sternal recumbency. At 150 minutes post induction, halothane was terminated, while 100% oxygen in 2 L/minute flow through the anesthetic circuit was maintained for 10 additional minutes. Then, oxygen was discontinued and dogs were disconnected from the anesthetic circuit and allowed to breathe room air through the endotracheal tube while in lateral recumbency. Extubation was done upon regaining of the swallow reflex. The time from termination of GA to extubation (TTE) was recorded. A dog was considered to have recovered from GA when sternal recumbency was voluntarily regained. The time from turning off the halothane vaporizer to regaining of sternal recumbency (TTSR) was also recorded.

Thermal care protocol

From induction of GA to extubation, each dog was treated once by each one of the two following protocols; no thermal care (NTC, included a blanket under the dog) and the CBTR system, as previously described, with system's set-point for the dogs' rectal temperature set at 37.8°C. The CBTR was allowed to warm up for 30 minutes prior to induction of anesthesia of the first dog in this group. The CBTR system water-heated garment covered the trunk and all extremities, with exception of the abdomen (from 10 cm cranial to the xyphoid cartilage to the pubis) in order to simulate a midline celiotomy approach. In both treatments, from extubation to gain of sternal recumbency, dogs were kept on a blanket and no additional warming was provided. Room temperature range throughout all anesthesia and the recovery periods was 16.5 to 20.9°C, with no statistical differences between animals and treatments. In the NTC and the CBTR group, the standard deviation of room temperature throughout the whole study period was 1.08°C and 1.30°C, respectively.

Monitored variables

From induction of GA until the regaining of sternal recumbency, several variables were monitored and recorded every 10 minutes, by a single anesthetist in all treatments. These included heart rate (HR), using an esophageal stethoscope during GA, and femoral pulse palpation during recovery, respiratory rate (RR), based on observation of the breathing system reservoir bag during GA, and chest movements during recovery, mean arterial pressure (MAP, Dynamap 8100, Critikon, Tampa, FL, USA, measured on the metacarpus of the left front limb), arterial hemoglobin oxygen saturation (OS, Nellcor, Boulder, CO, USA,) measured with the probe on the tongue), anesthetic depth (AD), capillary refill time, rectal (RT) and skin temperature (using the CBTR system thermistors) and room temperature (using a standard alcohol air thermometer). During recovery, RT was record-

ed using a digital medical thermometer (Domotherm TH1, Uebe Medical, Wertheim, Germany). The AD was assessed using a subjective cumulative scoring system that combined the palpebral reflex and tongue and jaw tone. Each of these was assigned a score from 0 to 2 (0, absent reflex/tone; 1, mild reflex/tone; 2, strong reflex/tone). Thus, the minimum and maximum possible AD scores were 0 and 6, respectively. The desired anesthetic depth was a surgical plane of anesthesia, in which both, the palpebral reflex and jaw tone were maintained, but were weak. During recovery, monitoring for shivering was done and its time of occurrence, intensity and duration were recorded. Shivering was subjectively assessed using a scale from 0 to 2 (0, no shivering; 1, mild shivering; 2, intense shivering). From induction of GA to gain of sternal recumbency, dogs were constantly connected to an ECG-monitor (Bioscope M100, Fukuda, Tokyo, Japan), set to record any event of arrhythmia on a paper strip.

Laboratory tests

Blood samples for complete blood count were collected in potassium-EDTA tubes prior to intubation (time 0) and at 150 minutes from intubation, and analyzed within 15 minutes from collection using an automatic impedance particle hematology analyzer calibrated for canine blood (VET-ABX, MINOS-ST, Montpellier, France). Differential leukocyte counts were performed manually on modified Wright's-stained blood smears (Hema-Tek 2000 Slide Stainer, model 4488B, Bayer Corporation, Elkhart, IL, USA, Stain: Hematek stain pack; Modified Wright's Stain). These blood samples were later centrifuged and total plasma protein was measured using a calibrated standard medical refractometer (Atago Co Ltd, Tokyo, Japan). Blood samples for serum biochemistry and cortisol concentration were collected in plain tubes at times 0, 60 and 120 minutes and at termination of GA (at 150 minutes). Samples were allowed to clot at room temperature, centrifuged and sera were separated and analyzed within 4 hours from collection (Selective Chemistry Analyzer and ion-selective electrode electrolyte analyzer, Kone Corporation, Espoo, Finland, at 37˚C). Sera for cortisol concentration determination were frozen at -20˚C pending analysis which was performed within 24 hours from collection in a single run using (Coat-A-Count, Diagnostic Products Corporation, USA). Samples for PT and aPTT were collected in 3.2% potassium-citrate tubes at times 0, 90 and 150 minutes. Plasma was separated immediately and analyzed within 30 minutes from collection using a manual coagulometric analyzer calibrated for canine blood (KC 1A Micro, Amelung GmbH, Lemgo, Germany). Arterial blood samples for blood gas analyses (ABG) were collected at times 0, 60, 120 and 150 minutes in sealed heparinized syringes and analyzed (Nova blood gas analyzer, Nova Biomedical, Waltham, MA) within 10 minutes from collection. Blood samples prior to GA were obtained from cephalic vein, while during, and after GA, blood samples were obtained from an arterial line, placed in the metatarsal artery.

STATISTICAL ANALYSIS

For all data, mean, standard deviation (SD), median and range were calculated. The distribution pattern (normal or non-normal) of data for each measured variables was assessed using Shapiro-Wilk's test. The two treatments were compared for all measures using Student's *t*- or Mann-Whitney *U*- tests, for normally and non-normally distributed data, respectively. $P \leq 0.05$ was considered statistically significant.

RESULTS

After 150 minutes of anesthesia, mean rectal temperature of the NTC group decreased by 6.25 ± 1.0˚C (16.42 ± 2.44%) from the mean initial temperature while in the CBTR group, the rectal temperature decreased by 0.57 ±1.46˚C (0.83 ± 2.17%) from mean initial rectal temperature. Rectal temperature was significantly *(*$P<0.001$) higher in CBTR compare to NTC groups 150 minutes post initiation of the anesthesia mean (37.3 ± 0.7˚C versus 31.8 ± 0.6˚C, respectively) (Table 1).

In the CBTR group, hypothermia (<37˚C) was prevented in 5/6 dogs throughout GA (Table 1) and during recovery. In one of these dogs (#5), the pre-GA rectal temperature was 39.0˚C and was higher than system's set-point temperature (37.8˚C). In response, the CBTR system cooled down the dog to the pre-programmed set-point. At termination of GA (i.e., at 150 minutes), his rectal temperature was 37.3˚C. In the remaining dog of the CBTR group (the first tested with the CBTR system), the rectal temperature at termination of GA was 36.0˚C. No burns or other signs of skin irritations were observed in any dog during or after use of the CBTR heating system.

Mean HR was significantly lower in the NTC group compared to the CBTR group (101.8 ± 16.7 versus 113.8 ±

Table 1: Rectal temperature of six beagle dogs using no thermal care and a computerized body temperature regulation system at 10 and after 150 minutes of general halothane anesthesia

Dog number	No thermal care				Computerized body temperature regulation			
	T_{10}[1] (°C)	T_{150}[2] (°C)	$\Delta_{10\text{-}150}$[3] (°C)	$\Delta\%_{10\text{-}150}$[4]	T_{10}[1] (°C)	T_{150}[2] (°C)	$\Delta_{10\text{-}150}$[3] (°C)	$\Delta\%_{10\text{-}150}$[4]
1	37.7	31.8	5.9	15.65	36.6	36.0	0.6	1.64
2	37.9	32.8	5.9	13.76	38.0	37.8	0.2	0.53
3	38.2	31.2	7.0	18.32	38.0	37.6	0.4	1.05
4	38.6	31.1	7.5	19.43	38.7	37.5	1.2	3.10
5	38.4	31.6	6.8	17.71	39.0	37.3	1.7	4.36
6	37.3	32.1	5.2	13.94	36.9	37.6	0.7	2.17
Mean±SD[5]	38.0±0.5	31.8±0.6*	6.4±0.9*	16.42±2.44*	37.9±1.0	37.3±0.7*	0.57±0.8*	1.46±2.2*

1) rectal temperature at 10 minutes of anesthesia; 2) rectal temperature at 150 min of anesthesia; 3) difference between the rectal temperatures at 10 and 150 min of anesthesia; 4) percent difference in rectal temperatures at 10 and 150 min of anesthesia; 5) standard deviation.
*) significant difference between dog groups (P<0.0001).

Table 2: Heart and respiratory rates, mean arterial blood pressure, anesthetic depth, capillary refill time and oxygen saturation of six beagle dogs at 10 and 150 minutes of general halothane anesthesia using a computerized body temperature regulation system and no thermal care

Group / Parameter	NTC[1] $\Delta_{10\text{-}150}$[3] Mean±SD[5]	CBTR[2] $\Delta_{10\text{-}150}$[3] Mean±SD[5]	P value	NTC[1] $\Delta\%_{10\text{-}150}$[4] Mean±SD[5] (%)	CBTR[2] $\Delta\%_{10\text{-}150}$[4] Mean±SD[5] (%)	P value
Heart rate (bpm)	91±41	33±30	0.023	47.3±14.4	19.6±13.7	0.006
Respiratory rate (bpm)	2.0±3.3	0.3±5.2	0.434	8.3±13.9	1.3±24.3	0.319
Mean arterial blood pressure (mmHg)	1.5±16.5	24.7±19.9	0.034	23.5±24.7	31.1±25.3	0.033
Anesthetic depth[6]	2.33±1.21	2.2±2.0	0.277	88.3±20.4	75.0±41.8	0.141
Capillary refill time (sec)	0.0±0.4	0.3±0.4	0.203	2.8±31.0	12.5±20.9	0.247
O_2 Saturation (%)	0.17±1.83	0.83±1.83	0.611	0.2±1.9	0.9±1.9	0.609

1) No thermal care group; 2) computerized body temperature regulation group; 3) absolute difference between values at 10 and 150 min of anesthesia; 4) percent difference between values at 10 and 150 min of anesthesia; 5) standard deviation; 6) the AD was assessed using a subjective cumulative scoring system that combined the palpebral reflex and tongue and jaw tone. Each of these was assigned a score from 0 to 2 (0 – absent reflex/tone; 1 – mild reflex/tone; 2 – strong reflex/tone).

12.8 beats per minute, respectively; P=0.016). Mean MAP was significantly lower in the NTC group compared to the CBTR group (84.33 ± 15.24 versus 99.99 ± 19.93 mmHg, respectively; P=0.038) (Table 2). No cardiac arrhythmias were observed during the study.

The mean decrease of the WBC at the end point of GA was significantly (P=0.005) higher in the NTC group compared to the CBTR group 61.34 ± 0.47% versus 40.13 ± 7.25%, respectively). There were no other significant group differences in hematological analytes. At termination of GA, serum potassium concentration was significantly lower (P=0.022) in the NTC group compared to the CBTR group (mean decrease of 16.01 ± 9.11% versus 2.37 ± 9.87%), respectively compared to its pre-anesthetic values. In the NTC group, 4/6 dogs developed hypokalemia (potassium <3.5 mmol/L) while in the CBTR group, serum potassium concentration remained within reference interval in all dogs. There were no other group differences during GA in other serum biochemistry analytes, arterial blood gases, serum cortisol and coagulation tests.

The times to extubation were 51.00 ± 22.06 minutes versus 9.83 ± 3.49 minutes in the NTC and CBTR groups, respectively (P=0.005) (Table 3). The time to sternal recumbency was significantly (P=0.004) longer in NTC group

Table 3: Times to extubation and to gain of sternal recumbency in six beagle dogs anesthetized for 150 minutes using no thermal care and a computerized body temperature regulation system

Parameter	Time to extubation (min)		Time to sternal recumbency (min)	
Group / Dog number	No thermal care	Computerized body thermoregulation system	No thermal care	Computerized body thermoregulation system
1	30	7	45	30
2	25	13	40	20
3	60	10	80	19
4	70	7	80	20
5	80	15	75	20
6	45	7	75	15
Mean±SD[1]	51.7±22.1*	9.8±3.5	66.7±18.9**	17.1±5.5

1) standard deviation; *) significantly higher compared to the computerized body thermoregulation group (P=0.005);
**) significantly higher compared to the computerized body thermoregulation group (P=0.004).

compared to the CBTR group (66.00 ± 18.89 versus 19.83 ± 5.49 minutes, respectively) (Table 3). There were no group differences in AD or shivering index.

DISCUSSION

The results present evidence that the CBTR system is a highly effective and safe modality to avoid GA-induced hypothermia in dogs. Studies of human patients using this system under GA and surgery have reported similar results (13-16). This is clearly demonstrated by the fact that the mean rectal temperature decrease at termination of GA in the NTC group was 12-fold higher compared to the CBTR group, and its percent decrease compared to the initial rectal temperature was 16-fold higher in this group. Using the accepted definition of hypothermia in dogs (2), all the NTC dogs showed mild to moderate hypothermia at termination of GA.

Development of hypothermia during GA occurs routinely and is reported in 60 to 90% of human patients, unless preventive measures are taken (17). In dogs, the first evidence of field anesthesia-related hypothermia was reported as early as the end of 18th century (18). The nature and development rate of hypothermia in anesthetized human patients have been investigated previously (2, 19). During GA, core body temperature initially decreases towards the temperature of the cooler body areas, such as the skin due to GA-induced peripheral vasodilatation. During the second phase, core body temperature decreases almost linearly, and during the third phase, after three to four hours of GA, the development rate of hypothermia slows considerably compared to its progression during the first two phases (20, 21). In previous studies, performed in anesthetized dogs during various surgical procedures, a sharp core body temperature decrease was observed during first hour of GA, followed by slower decrease afterwards (6, 20). The results of these previous studies were influenced by surgery-related procedures (i.e., hair clipping, scrubbing and cutaneous application of alcohol-containing solutions over the surgical area) that likely contributed to the development rate and extent of hypothermia in these dogs.

Warm water circulating blankets are considered safe and effective for prevention and treatment of hypothermia, and can be placed under or over the trunk, or be applied or wrapped over different places on the body (11). The efficacy of three warming protocols using water circulating blankets was previously assessed and compared. These included a single circulating warming blanket over the trunk, two circulating warming blankets over and under the trunk and a circulating warming blanket applied around the feet and legs only (11). After 2.5 hours of GA, dogs in the third treatment group had significantly higher core body temperatures (37.4˚C) than those in the first and second treatments (36.4 and 36.7˚C, respectively) (11). It was thus concluded that placement of heated water blankets around the extremi-

ties is superior to its placement over and under the trunk. The CBTR system, used in the present study has utilized the above described advantage of applying the water blanket over the extremities. Coverage of the entire trunk excluding the ventral abdomen by the vest provided an additional advantage. This approach likely had a major role in the system's present good performance.

Hypothermia in dogs is defined by a body temperature <37°C (2). In the present study, using this definition, hypothermia was completely prevented in 5/6 dogs, in the CBTR group, in which rectal temperature did not decrease <37°C throughout GA. In the remaining dog of this group, the first to be treated with CBTR, the CBTR system was not sufficiently preheated, and its operation was initiated immediately upon induction of GA. In the other dogs in this group, the CBTR system was appropriately preheated prior to its application to the dogs. It is likely that lack of preheating of the CBTR system was responsible for the fall in rectal temperature observed. The result in this dog exemplifies the importance of prevention of the initial phases of hypothermia.

Another interesting feature of the CBTR system can be observed in dog #5, that had an initial rectal temperature of 39.0°C, higher than the programmed system's set-point temperature. In case of this animal, since the measured rectal temperature was higher than the system's set-point temperature, the CBTR system initially cooled this dog in order to reach the set-point temperature. Only when rectal temperature had decreased below programmed set-point temperature system started to warm the water circulating.

The effects of hypothermia on the cardiovascular system are well recognized. These most commonly include decreased HR, cardiac output (22) and arterial blood pressure, while cardiac excitability increases (8). In our study, the HR and MBP were significantly higher in the CBTR group compared to the NTC group, and these findings also exemplify the positive effects and efficacy of the CBTR system in prevention of hypothermia-related deleterious effects on cardiovascular function.

In the NTC group, although hypothermia was present in all dogs, no cardiac arrhythmias were recorded in this group. Hypothermia is known to induce cardiac arrhythmia, and this has been described in several animal studies (22, 23), however, it is reported at temperatures below those recorded here. Interestingly, in the NTC group, there was a decrease in potassium concentration at termination of GA, and its concentrations at termination of GA were significantly lower compared to those of the CBTR group. Hypokalemia was present in four of six NTC dogs. In comparison, in the CBTR group, the decline in serum potassium was not statistically significant and potassium concentrations remained within the reference interval. Similar results were reported previously (11). A decrease in potassium concentration during hypothermia has been associated with increased hypothermia-induced cardiac excitability (25). Since no ABG analysis abnormalities were observed in any dog in the study, and no group differences were present in these analytes, acidosis cannot account for the decrease in potassium concentration in the NTC group.

Hematologically, the only statistically significant difference between the groups was in the WBC count. In both groups WBC decreased during anesthesia, however, the NTC group showed a greater decrease. Previous studies have associated hypothermia and decreased WBC with a higher incidence of secondary infections (2, 26). It has been shown that mild perioperative hypothermia can triple the incidence of secondary infections and prolongs the hospitalization by 20% (from 11.8 ± 4.1 to 13.5 ± 4.5 days) (27). Thus, it would seem the CBTR system has a beneficial effect in decreasing the severity of the hypothermia-induced decrease in WBC count, and therefore, might possibly prevent the above mentioned associated complications.

Coagulation functions decrease during GA-induced hypothermia, and both PT and aPTT are prolonged during hypothermia (26, 28, 29). Hypothermia also decreases the platelet count, and thrombocytopenia has been reported to occur when body temperatures fall to 20 to 25°C (26). However, our study showed no statistically significant differences in PT, aPTT and platelet count between the groups or within groups, before and after anesthesia. However, in all our dogs, body temperatures during and at termination of GA were well above 25°C, and thus thrombocytopenia was not to be expected (26). It should be noted that coagulation functions *in vivo* might be prolonged in face of hypothermia. *In vitro* testing of coagulation functions however is undertaken at 37°C and thus might incorrectly represent their *in vivo* performance, which may diminish the apparent influence of hypothermia on PT and aPTT.

The times to extubation and to sternal recumbency were both significantly longer in the NTC compared to the

CBTR group. Long recovery periods have been well documented in cases of hypothermia in humans (27, 30) as well as in animals (20, 31). During hypothermia, hepatic detoxification and conjugation rates decrease (29). The metabolism of anesthetic drugs slows and consequently their half life increase, so that when the body temperatures are <28°C, unconsciousness is maintained without any anesthetic agent (32). The present results show that the CBTR system shortens the post anesthetic recovery period. This should lower the risk of complications during the recovery period (e.g., aspiration and depression) and can save labor, required for intensive post-GA patient monitoring.

This study has several limitations. First, although no statistical differences in room temperature between treatment groups were present, variations in room temperature might have affected individual dogs' body temperature, thereby introducing variance. Dogs in the NTC group were more likely affected by such changes compared to the CBTR group. Second, the CBTR system was compared to NTC. Under modern conditions in veterinary medicine, other heating devices are currently in use, and it would have been interesting to compare the performance of the CBTR with such appliances. Third, halothane has been replaced in many veterinary settings with newer inhalant anesthetics, and it would have been more appropriate to use one of that latter instead of halothane. Fourth, although the order of the dogs in each set of anesthetic treatment was identical, this order was not randomized. Lastly, monitoring of the depth of anesthesia was done using subjective criteria. More sophisticated and precise monitors such as end-tidal gas analyzers were not used in this study. Their use would have ensured a similar anesthetic depth in all dogs, in both treatments.

In conclusion, notwithstanding the limitations listed above, the CBTR system proved to be safe and efficacious. An additional advantage of the system is that the fitted garment that can be configured to cover most surface areas of the dog, so as not to interfere with areas that must be exposed during the surgery. This allows performance of a wide range of surgical procedures, with minimal exposure of the dog to the cold environment.

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CONFLICT OF INTERESTS

None of the authors have any financial or other connections with M.T.R.E., Or-Akiva, Israel. The study was carried out at their request, however, no member of the company had any influence in the design of the study or in the interpretations of the results.

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