COMPARISON OF THREE INTRAOPERATIVE WARMING DEVICES

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INTRODUCTION

Thermal homeostasis is important for the overall well-being of people and animals. Hypothermia is common during and after surgeries. Anesthesia-induced hypothermia may alter physiological mechanisms of thermoregulation and may lead to debilitations. These consequences include prolonged duration of drug action, myocardial ischemia,[13,14,31] coagulopathies,[38,49,50,63] decreased resistance to surgical wound infections,[2-4,7,30,65] and prolonged recovery time.[31,32,52,62] General anesthesia tends to promote heat loss by delaying peripheral vasoconstriction and shivering, which are the normal autonomic responses to decreases in core body temperature. The combination of anesthesia, exposure to a relatively cold operating room environment, evaporation from surgical incisions, and conductive cooling produced by administration of relatively cool intravenous (IV) fluids can result in unintended perioperative hypothermia. Unless active warming measures are taken, the patient will lose body heat and endure hypothermic consequences. Therefore, proactive warming measures are needed to prevent excessive heat loss from the patient to the environment.

There are many intraoperative warming devices available today. The goal of any warming device is to prevent intraoperative hypothermia or treat preexisting hypothermia. Circulating water blankets [Figure 1] have been used for years. A circulating water blanket consists of a power unit incorporating an electric heater and a water reserve to generate warm water, which is delivered downstream to a plastic blanket and returned to the reserve unit for re-warming. The circulating water temperature can be controlled by a thermostat set at various temperatures, which range from 30°C to 42°C. The Bair Hugger® [Figure 2] using forced air is another commonly used device to control intraoperative temperature loss. It consists of a power unit incorporating an electric heater and fan to generate warm air flow, which is delivered downstream to a quilt-like blanket.[6,30] The forced air warming unit can be set at "low" (~33°C), "medium" (~38°C), or "high" (~43°C) temperature setting. The efficacy of the forced-air warming has been proven for a wide variety of surgical procedures.[27,29,35,39,46,47,60] Studies have also compared forced-air to other commonly used intraoperative warming methods such as fluid warmers, circulating water blankets, airway humidifiers, heat lamps, and have found it to be far superior.[29]

Recently, another warming device (Thermal-V® surgery unit) [Figure 3] using an "even heat" distribution system has become available. This warming unit consists of two stainless steel panels that are used flat or folded into a "V-shape" conforming with existing surgery tables. The heat conductibility of the heavy-gauge stainless steel allows consistent temperature from top to bottom and throughout the length of each panel. Each panel is independently regulated and temperature can be programmed from a low range of 21.1°C up to the high range of 41.3°C. To the authors' knowledge, there are no previous studies which have evaluated and compared the Thermal-V® surgery unit with other conventional ways of actively warming patients undergoing surgery.

The objective of this study was to compare and evaluate the efficacy of three active warming devices (circulating water, Bair Hugger®, and Thermal-V®) that may be used alone or in combination to minimize intraoperative hypothermia when applied to patients undergoing prolonged surgeries. The combination of the circulating water and the forced-air unit was used as the "positive control". Warming protocols evaluated were as follows: 1) positive controls - the Bair Hugger® forced-air warmer with an adult size cover set on "high" (~43^{o}C) positioned above the patient combined with a 38 x 56cm circulating water blanket set to ~42^{o}C positioned below the patient, 2) the Bair Hugger® forced air warmer with an adult size cover set on "high" (~43^{o}C) positioned below the patient, and 3) the Thermal-V® warming panels set to ~41^{o}C positioned below the patient. Patients were positioned directly on the warming devices. Our hypothesis was that the Thermal-V® surgery warming unit would be comparable or better than the forced-air alone and the combined forced-air and circulating water units in preventing intraoperative hypothermia.

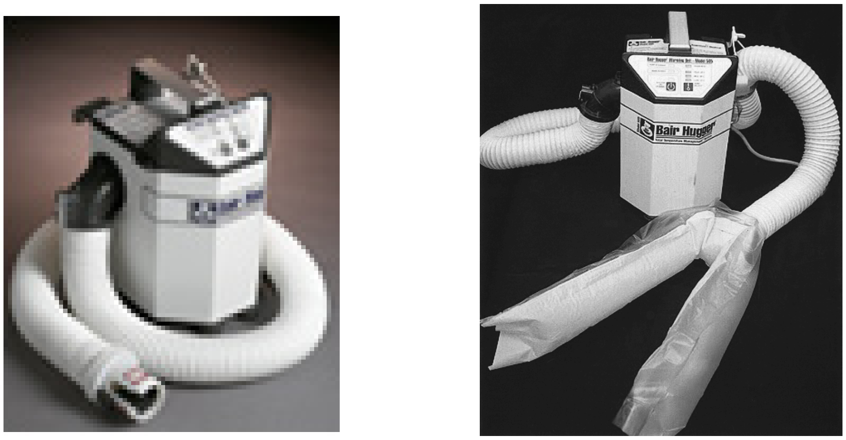

Figure 1. – Forced air warming unit (Bair Hugger)

Figure 2. – Circulating water blanket (T/pump)

Figure 3. – Conductive heating unit (Thermal-V)

CHAPTER II

LITERATURE REVIEW

Introduction

The mammalian body can roughly be described as having a core thermal compartment and a peripheral compartment. The thermal core of mammals is defined as those inner tissues of the body whose temperatures are not changed in their relationship to each other by circulatory adjustments or changes in heat dissipation to the environment.[18] The thermal core consists of the brain and the organs of the chest and abdomen. They comprise of only 6-10% of the total body mass, and yet account for approximately 75% of total metabolic heat production.[18] Peripheral compartment tissues include skin, mucosal surfaces, and underlying tissues. Peripheral temperatures may deviate from core temperature. Peripheral tissues make up over 90% of the total body mass, but generate less than 35% of the resting metabolic heat production.[19]

Normal core body temperature for the dog ranges from 37.8 to 39.3^{o}C (100.2 to 102.8^{o}F).[34] Hypothermia is defined as a subnormal body temperature (<37.8^{o}C) and can occur as a primary or secondary condition. Primary hypothermia results in the presence of normal heat production and exposure to a cold environment. Secondary hypothermia results from an underlying disease, injury, or drug-induced alterations of heat production and thermoregulation.[42] Primary hypothermia is further classified as mild (32°C to 37°C/ 90°F to 99°F), moderate (28°C to 32°C/ 82°F to 90°F), severe (20°C to28°C/ 68°F to 82°F), and profound (less than 20°C/68°F).[67] Temperatures associated with secondary hypothermia are reported to be higher and are classified as mild (36.7°C to 37.7°C/ 98°F to 99.9°F), moderate (35.5°C to 36.7°C/ 96°F to 98°F), severe (33°C to 35.5°C/ 92°F to 96°F), and critical (less than 33°C/92°F).[42]

Thermoregulation is a complex, highly integrated interaction between central and peripheral sensory input, central processing in the hypothalamus, and appropriate physiological responses to maintain thermal steady state.[43] Heat and cold thermal receptors are widely distributed throughout the body. Hypothermia occurs from increased heat loss, decreased heat production, or a combination of both. Body heat is lost through four basic mechanisms: radiation, convection, conduction, and evaporation. Radiation and convection are the two most important mechanisms of heat loss during surgery. Complications of hypothermia include bleeding due to an impaired coagulation cascade,[38,49,50,52,63] delayed anesthetic recovery,[31,32,52,58] myocardial ischemia,[13,14,31] shivering,[31] and decreased resistance to surgical wound infections.[2-4,30,65]

Hypothermia is a common and potentially serious complication of surgery and anesthesia. Operating room temperature is a critical factor influencing heat loss. It determines the rate at which metabolic heat is lost by radiation and convection from the skin and by evaporation from within surgical incisions. Since most metabolic heat is lost through the skin, cutaneous heat loss must be reduced to prevent a decrease in body temperature during surgery.[53,57] Prevention of cutaneous heat loss can be achieved through cutaneous warming. Various passive insulators and active warming systems are available for use intraoperatively.

Thermoregulation

Most mammals maintain relatively constant internal temperatures despite changes in ambient conditions and fluctuations in internal heat production. Heat balance, the ability to match heat loss and heat gain, is achieved by the appropriate activation of specific thermoregulatory effector mechanisms. In mammals, body temperature regulation is controlled by the central nervous system and specifically by the thermoregulatory center located in the pre-optic region of the anterior hypothalamus.[18] Temperature regulation is a negative feedback control system. This system consists of receptors that sense the existing central temperature, effector mechanisms that permit adjustment in temperature, and integrative structures that determine whether the existing central temperature is too high or too low.[34] Once these signals are interpreted, the appropriate physiological responses are activated. The thermoregulatory center establishes a “set point” core body temperature around which there are subtle fluctuations in body temperature. The thermoregulatory center in the hypothalamus interprets changes in body temperature through both peripheral and central thermal inputs. Peripheral thermal inputs are from the deep abdominal and thoracic tissues and the skin surfaces. Central thermal inputs are from the extrahypothalamic portions of the brain and the spinal cord.[53] The thermoregulatory center moderates both behavioral and physiological mechanisms to return the body to its established set point temperature.

Responses to thermal challenges fall into two categories: behavioral and autonomic. Behavioral responses involve postural changes and conscious sensing of the internal and external environmental conditions. An animal that possesses the ability to move has the ability to respond to adverse environmental conditions by selecting or creating an optimal environment. This makes it possible for them to remain within their thermoneutral zone. Thermoneutral zone is defined as the environmental temperature range in which the resting metabolic rate of an animal is low and independent of environmental temperatures.[18] Behavioral thermoregulatory responses include seeking shade during the heat of the day, curling up or nestling during excessive cold, changing posture and orientation to the sun, shuttling between the sun and shade or between still and moving air, and huddling in a group for warmth.

Autonomic thermoregulatory responses include changes in vasomotor tone, evaporative cooling (e.g. sweating and panting), and increased metabolic heat production.[58] Vasomotor tone determines blood flow through the subcutaneous heat exchange-vasculature structures (ie. footpads, tip of nose, and tongue of dogs) and thus, the transport of heat from the thermal core to the skin surface. Vasoconstriction reduces heat transfer and vasodilation increases heat transfer. Thermoregulatory vasoconstriction can decrease cutaneous heat loss by approximately 25%.[58] When the thermal core is within an acceptable temperature range, vasomotor tone is responsive to changes in ambient temperature. However, when temperatures deviate from the "set point" levels, appropriate vasomotor responses based on the core temperature will prevail regardless of ambient conditions.[18] Increased metabolic heat production includes increased voluntary activity, shivering, and non-shivering thermogenesis via increased production and secretion of thyroxine, norepinephrine, and epinephrine.[18,37]

The thermoregulatory system can be compromised by severe metabolic diseases, trauma, and/or anesthetic agents. Severe metabolic diseases can cause cachexia and decrease metabolic rate, which can impair the ability of the thermoregulatory center to regulate heat production.[42] Damage to the hypothalamus through direct injury significantly impairs thermoregulatory responses. Behavioral thermoregulatory responses become irrelevant during general anesthesia because patients are unconscious and frequently paralyzed. Although peripheral vasoconstriction during general anesthesia is an appropriate response to minimize heat loss from the thermal core, it also impedes the transfer of heat from the skin surface to the body core.

Heat Loss

Heat is produced internally in mammals as a by-product of cellular metabolism and as a result of muscular work, shivering, and chemical thermogenesis.[18] Increased metabolism to produce heat increases the consumption of oxygen, adenosine triphosphate, and glucose.[43] Heat is lost to the environment across the body surfaces. Cutaneous heat is lost from a patient to the environment through radiation, convection, conduction, and evaporation. These are the same fundamental mechanisms that modulate heat transfer between any two substances. Of these mechanisms, radiation and convection account for approximately 80% of the total heat loss in a patient.[43]

Radiation is the major type of heat loss in most surgical patients, accounting for roughly 60% of the total loss.[37,53,54] All surfaces with a temperature above absolute zero radiate heat. Similarly, all surfaces absorb radiant heat from surrounding surfaces. Radiant heat is exchanged between the body and objects in the environment that are not in contact with the skin, and is independent of the intervening air temperature. If the temperature of the surrounding tables, walls, and nearby objects is less than that of the patient, more heat is radiated from the body than is received from the objects. Radiant heat loss occurs primarily from the head and non-insulated areas of the body.[37]

Convective loss is the second most important mechanism by which heat is transferred from patients to the environment. It occurs with the movement of fluid or gas, especially in conditions of increased air currents. Air currents carry more heat away from the body by rapidly removing the warm, insulating layer of air that initially is in direct contact with the skin.[37] It influences both external heat transfer between the body and the surrounding environment and internal heat transfer between various tissues and regions of the body.[54] Natural convection occurs when a warm object is placed in a still body of cool fluid or gas. The cooler medium in direct contact with the warm object takes up heat from the object, becomes more buoyant, and rises. The upward streaming of the warmed fluids carries heat away from the object. Although, heat loss increases substantially in operating rooms equipped to provide laminar flow, actual augmentation for heat transfer has not been quantified and may be less than expected. The major factors that influence forced convection distribution of heat are peripheral blood flow, countercurrent heat exchange between adjacent arteries and veins, and the core-to-peripheral temperature gradient.[54] Forced convection heat transfer is associated with the movement of a fluid. Blood flow through metabolically active tissues increases heat transfer between the active cells and the cooler tissues and fluids surrounding them. Similarly, blood flow through the subcutaneous area delivers heat to the skin.[18]

Conduction is the direct transfer of heat from one surface to an adjacent surface. The conductive component is a slow radial flow of heat from relatively warm tissues at the central axis to cooler tissues near the skin. Conductive flow is largely determined by the diffusion coefficient, which is a function of tissue characteristics.[54] Heat transfer is proportional to the difference in the surface temperature and any insulation between them. Fat insulates nearly three times as well as muscle and provides substantial insulation. Conductive losses should be negligible during surgery because patients are usually in direct contact with a cloth padding of some kind, which are excellent thermal insulators.

Evaporation is the conversion of a material from a liquid state to a gaseous state.[18] It occurs when moisture (eg., surgical preparation solution) that is in contact with the skin or respiratory tract dissipates into the air, pulling heat with it. Evaporative losses increase once the skin and hair coat become wet during surgical preparation.[64] In people, sweating increases cutaneous evaporative losses enormously, but is rare during anesthesia. In the absence of sweating, evaporative loss from the skin surface is limited to less than 10% of total losses.[54] Only small amounts of heat are lost from the respiratory system. However, evaporative loss from within surgical incisions can contribute substantially to total heat loss.[56] Roe demonstrated in rabbits that approximately 50% of total heat loss results from evaporation with large abdominal incisions.[48]

During anesthesia, additional conductive heat is lost by administration of cold or room temperature intravenous fluids. A unit of refrigerated blood or 1 liter of crystalloid solution administered at room temperature decreases mean body temperature approximately 0.25°C.[52] Heat loss due to cold intravenous fluids becomes significant when large amounts are administered. In general, fluids should be warmed to 40°C to 45°C if more than two liters/hour are to be administered.[37,52]

Hypothermia

Hypothermia (temperature <37.7°C) during general anesthesia develops with a characteristic pattern. Phase I, or redistribution hypothermia, is a rapid decrease in core temperature. Core temperature usually decreases 0.5°C to 1.5°C during the first hour after induction of general anesthesia.[44,52-54,58] Anesthetic-induced vasodilation slightly increases cutaneous heat loss, but is not the major cause of hypothermia immediately following induction of anesthesia. Hypothermia results in part from a 20-30% drop in metabolic rate that accompanies induction of anesthesia; however, this reduction is not sufficient to completely explain the observed hypothermia.[53] One factor is that general anesthetics are direct vasodilators and impair the central thermoregulatory control, thus inhibiting normal tonic thermoregulatory peripheral vasoconstriction of the arteriovenous shunts and capillaries located in the distal extremities.[58] Anesthetic induced vasodilation is the primary cause of hypothermia during the initial phases of anesthesia. Another reason for the dramatic drop in core temperature is due to altered distribution of heat within the body. Heat is usually not evenly distributed within the body. Core temperature represents only about half the body mass (mostly the trunk and head); the remaining mass is typically 2-4°C cooler than the core.[53] The significant core-to-peripheral tissue temperature gradient is normally maintained by normal tonic thermoregulatory vasoconstriction.[52-54] Tonic thermoregulatory vasoconstriction normally maintains a portion of heat in the core compartment, producing a normal 2-4°C core-to-peripheral temperature gradient. Induction of general anesthesia allows the redistribution of heat from the core thermal compartment to flow down the temperature gradient into peripheral tissues.[53,55]

Phase II of hypothermia is a slow, linear reduction in core temperature, which lasts for 2 to 4 hours.[53] It results from cutaneous and respiratory heat losses exceeding metabolic heat production. Roughly 90% of metabolic heat is lost through the skin surface and less than 10% of metabolic heat is lost via the respiratory system.[51] Finally, patients enter a plateau phase (phase III) after 3 to 4 hours of anesthesia.[53] Core temperature generally remains constant for the duration of the surgery. Core temperature plateau represents a thermal steady state (heat production equaling heat loss) in patients remaining warm. There is not a set plateau temperature for these patients. In others, the plateau phase is associated with peripheral thermoregulatory vasoconstriction triggered by core temperature of 33°C to 35°C.[53] Thermoregulatory vasoconstriction during anesthesia significantly decreases cutaneous heat loss (~25%)[58] by restricting the distribution of metabolic heat to the core compartment. This mechanism can maintain core temperature, but is not sufficient to produce a thermal steady state. Peripheral tissue temperature continues to decrease because it is no longer being supplied with sufficient heat from the core. Due to this continued decrease in temperature, a core temperature plateau resulting from thermoregulatory vasoconstriction is thus not a thermal steady state.[53]

The extent to which induction of general anesthesia induces redistribution hypothermia (phase I), in individual patients depends on a number of factors. The most important being the patient's initial body temperature. If a patient's temperature is lower than normal, the redistribution of heat will make them more hypothermic. Body morphology is another important factor. Obese patients redistribute less heat than those of normal weight. The major thermoregulatory problem in obese patients is dissipation of metabolic heat and they spend much of their time in vasodilation. This results in having a higher than normal temperature, which reduces the core-to-peripheral flow of heat after induction of anesthesia.[54] Conversely, very thin patients redistribute more. Other factors that increase systemic heat imbalances and thus induce hypothermia include a cool environment of the operating room and large surgical incisions.[48]

Complications of Hypothermia

The most significant adverse effect of intraoperative hypothermia includes blood loss due to an impaired coagulation cascade.[38,49,50,52,63] The general mechanisms that contribute to temperature-related coagulation disorders include impaired platelet function, reduced intrinsic and extrinsic pathways of coagulation, and increased fibrinolysis.[50,52] In-vitro and in-vivo studies suggest that perioperative hypothermia can aggravate surgical bleeding by impairing platelet function[38,63] and directly decreasing the enzymatic coagulation reactions.[49] Michelson, et al, demonstrated that hypothermia inhibits platelet activation due to the lack of thromboxane B_2 (the stable metabolite of thromboxane A_2) generation in humans both in vitro and in vivo. Platelet activation was also inhibited, as demonstrated by up regulation of platelet surface protein GMP-140 and down regulation of platelet surface glycoprotein Ib-IX complex (the von Willebrand factor receptor).[38] Furthermore, hypothermia prolongs both prothrombin (PT) and partial thromboplastin (PTT) times by directly inhibiting the series of enzyme reactions.[49,63] Both Michelson and Valeri studies demonstrated that re-warming hypothermic blood completely reversed the platelet activation defect.[38,63] A recent study in patients undergoing total hip arthroplasty showed consistent results, indicating that hypothermia significantly increased bleeding which required blood transfusions.[50] The maintenance of intraoperative normothermia reduces overall blood loss and may reduce the need for transfusions of platelets and other blood components.

Many of the most serious consequences of intraoperative hypothermia are manifested in the postoperative period.[31,52,58] These include delayed anesthetic recovery,[31,32,52,58] myocardial ischemia,[13,14,31] shivering with resultant discomfort,[31] and decreased resistance to surgical wound infections.[2-4,30,65] Wound infections are among the more serious complications of anesthesia and surgery causing increased morbidity. Perioperative hypothermia is considered a risk factor for wound infection in human medicine. Hypothermia can contribute to wound infection in two ways: 1) directly impairing immune function, including T-cell-mediated antibody production[3] and non-specific oxidative bacterial killing by neutrophils[3,4,30,65] 2) triggering thermoregulatory vasoconstriction and subsequent decreased oxygen delivery (tissue hypoxia).[30,51,52] Furthermore, wound healing is delayed due to a reduced production of specific proinflammatory cytokines responsible for angiogenesis and fibroblast production.[3] A clinical trial in humans undergoing colorectal surgery showed that more patients (19%) in the hypothermic group developed wound infections, delayed wound healing, and prolonged the duration of hospitalization by several days.[30]

In contrast to these findings, more recent human[40] and animal[2,7] studies have demonstrated that intraoperative hypothermia does not increase the risk for wound infections. Beal, et al, found that the duration of anesthesia rather than hypothermia significantly increased the infection risk (4.8%) of clean wounds in dogs.[2] They found that for each minute of additional anesthesia time, there was a 0.5% increased risk of infection. Therefore, an animal is at a 30% greater risk of postoperative wound infection for each additional hour of anesthesia.[2] These results are consistent with Brown, et al's, findings that the longer duration of anesthesia (surgery and shaving of the skin before induction of anesthesia) poses a risk for postoperative wound infection in dogs and cats.[7]

It has been hypothesized that adrenergic vasoconstriction and metabolic responses to hypothermia can upset the balance between myocardial oxygen supply and demand, leading to myocardial ischemia or infarction.[13,14] Metabolic changes associated with re-warming during the postoperative period places additional demands on the cardiovascular system. Frank, et al, results showed a significantly greater incidence of postoperative myocardial ischemia, angina, and hypoxemia (PaO_2 of less than 80 mmHg) in hypothermic patients.[13] The higher incidence of ischemia was thought to be due to hypothermic patients having a greater total body oxygen consumption or an increased pulmonary shunting during the early postoperative period. This study demonstrated an association between hypothermia and myocardial ischemia postoperatively. In another study, Frank, et al, demonstrated a higher incidence of ventricular tachycardia and ECG changes occurring in hypothermic patients postoperatively, despite similar incidence in hypothermic and normothermic groups intraoperatively .[14] Due to this disparity between intraoperative and postoperative findings, it was concluded that anesthetics may protect patients from adverse effects of cold stress intraoperatively. The adverse effects of hypothermia are likely to be manifested in the postoperative period when the adrenergic and metabolic responses are reactivated as the patient recovers from anesthesia.[14]

Postoperative shivering occurs frequently. Brain anesthetic concentrations usually decrease rapidly during the initial postoperative period, allowing re-emergence of thermoregulatory responses including vasoconstriction and shivering.[31] Shivering is an involuntary, oscillatory muscular activity that augments metabolic heat production. Vigorous shivering can increase metabolic heat production up to 600% above basal level.[66] The origin of postoperative shivering is unclear and various mechanisms have been proposed. The conventional explanation for postanesthetic tremor is that anesthesia-induced thermoregulatory inhibition abruptly dissipates, thus increasing the shivering threshold toward normal.[66] Difficulties with this proposed explanation include the observations that tremors frequently are not observed in markedly hypothermic patients and that tremors occur commonly in normothermic patients, suggesting that other mechanisms besides heat loss and subsequent decreased in core temperature may contribute to the development of shivering. These include uninhibited spinal reflexes, postoperative pain, decreased sympathetic activity, and adrenal suppression.[66] The incidence of postoperative shivering is reported to be approximately 40% in humans, but that percentage has decreased in recent years.[52] This may be due to patients being kept normothermic perioperatively and/or opioids being administered more frequently and in larger doses than in the past. Post operative shivering can aggravate postoperative pain simply because vigorous muscular activity will cause stretching of the surgical incisions. People often describe shivering as the most unpleasant memory of their postoperative experience and is likely to be uncomfortable for animals as well. Despite the alternative etiologies, normal thermoregulatory shivering in response to core and skin hypothermia remains the most common cause of postoperative shivering.[66]

The enzymes that moderate organ function and metabolize most drugs are highly temperature-sensitive. Hypothermia alters the pharmacodynamics of various drugs, especially volatile anesthetics.[51] Increased solubility of volatile anesthetics and reduced metabolism of intravenous drugs suggest that hypothermia might prolong recovery from general anesthesia.[32,62] Prospective studies have demonstrated that hypothermia significantly delayed recovery by several hours in human patients undergoing minor procedures[62] and major abdominal surgery,[31,32] even when core normothermia was not a discharge criteria.[32] Intraoperative core temperatures in hypothermic patients usually increase relatively slowly, requiring several hours to return to normal values.

Temperature Monitoring

Accurate recording and monitoring of changes in core temperature is an important component of the routine care of animals undergoing surgery. While temperature is considered the most basic of observations, conflicting opinions exist about the most accurate measure of core temperature. Many sites are routinely used to measure an approximation of core body temperature. These sites include rectum, oral cavity, bladder, axillary, nasopharynx, esophagus, and tympanum. While temperature in the hypothalamus is believed to be the most accurate measure of core temperature, it is not easily accessible. Blood temperature in the pulmonary artery (PA) is also considered to be an equally accurate core temperature measurement and is generally referred to as the "gold standard" because of its accessibility.[36]

The rectal site is widely assumed to be the best reflection of core temperature.[20,61] Despite this assumption, it has been suggested that rectal recordings may not be an accurate reflection of true body temperature because it lags behind core temperature during rapid changes in body heat.[19,36] Recordings may also be influenced by rectum's excellent insulation properties and/or the presence of feces. Due to the tympanic membrane sharing its blood supply with the same vasculature as the hypothalamus via the internal carotid artery, it was also considered to be an accurate and rapidly responsive estimate of core body temperatures.[17, 36] However, it is now recognized that thermoregulatory responses are determined by an integrated thermal input from all body tissues.[18] Therefore, tympanic membrane temperatures are no more accurate than other estimates of total body heat content, such as rectal and esophageal temperatures.[5,20, 22,28, 36, 61] Machon, et al, demonstrated that rectal and esophageal temperatures were an accurate reflection of each other and did not differ at any time during their study comparing temperature measurement sites in anesthetized cats, but tympanic membrane temperatures always read significantly lower.[35] The lower inconsistent results may be due to the wide angle view of the probe tip, the limited depth of insertion, misdirection of the probe, and the difference in ear canal anatomy in animals compared to humans.[20, 22,28] The external ear canal is longer in dogs than in humans. The tip of the probe would not be close to the tympanic membrane in dogs as it would be in people.

Indirect, non-invasive thermography available includes mercury-glass thermometers, digital oral and rectal thermometers, and infrared tympanic thermistor probes. The slow and cumbersome mercury-in-glass thermometers have been replaced with electronic and infrared tympanic membrane thermometers. More direct thermography includes bladder, nasopharyngeal, rectal and esophageal thermistor probes, and pulmonary artery catheter placement for continuous monitoring.[36] Temperature probes incorporated into esophageal stethoscopes are also available but must be positioned at the point of maximal heart sounds, or distally, to provide accurate readings.[53]

The objective of temperature monitoring and perioperative thermal management is to detect thermal disturbances and maintain appropriate body temperature during anesthesia. Due to core temperatures decreasing 0.5°C to 1.5°C in the first 30 minutes after induction of anesthesia[44,52-54,58], core body temperature should be measured in most patients given general anesthesia for longer than 30 minutes and in all patients whose surgery lasts longer than one hour.[53]

Warming Devices

The initial redistribution hypothermia is difficult to treat for two reasons: (1) the internal core-to-peripheral flow of heat is large and (2) heat applied to the skin surface takes longer to reach the core. Transfer of applied heat is especially slow when patients are vasoconstricted.[52] Consequently, even the most effective clinical warmers may not prevent hypothermia during the first hour of anesthesia. Normally, about 90% of metabolic heat is lost through the skin surface. Therefore, any effective warming system must modulate cutaneous heat loss. Available systems to combat cutaneous heat loss can be categorized as passive insulation or active cutaneous heating.

The simplest method of decreasing cutaneous heat loss is to apply passive insulation to the skin surface, between the patient and metal operating table and over the patient. Passive insulators include cotton blankets, surgical drapes, plastic sheeting, space blankets, and bubble wrap. A single layer of each reduces heat loss approximately 30%.[56] Passive insulators provide relatively little insulation, instead, it is the layer of still air between the cotton blanket and the skin that "insulates" and retains most of the heat.[51] Blankets prevent air movement and keep the insulating layer in place. Therefore, covering the patient with additional layers of insulation further reduces heat loss only slightly. Cutaneous heat loss is roughly proportional to surface area throughout the body. The efficacy of applied insulation is thus also directly proportional to the covered surface area.[51] Passive insulation alone is rarely sufficient to maintain normothermia in patients undergoing large operations. At best, passive insulation can reduce cutaneous heat loss to nearly zero. Doing so will increase mean body temperature roughly 1^{o}C/hour in postoperative patients, depending on the metabolic rate and size of patient.[51,57]

Active cutaneous warming is often required to compensate for the relatively cool operating room environment and the heat loss associated with major surgery. Active warming systems maintain normothermia better than passive insulation.[9,11,12,15,16,21, 24-27,29,31,33-35,39,46,52-54,57,60,64] Active cutaneous warming systems include circulating water blankets, forced air, radiant heating, and negative-pressure warming. For intraoperative use, circulating water and forced air are the two major systems available.

Circulating water blankets are a classic active intraoperative warming system and have been used for decades with success. Studies evaluating the efficacy of circulating water blankets used in cats,[11,21,44,64] dogs,[8,11,44,64] and humans[57] have shown that hypothermia can be limited by decreasing cutaneous heat loss. Unfortunately, their efficacy is limited by a number of factors directly related to their position below patients. The dorsum of animals is a relatively small fraction of the total surface area. Consequently, the majority of metabolic heat is lost from the ventral surface of the body.[51] Even effective heat transfer through the back cannot compensate for the typically large ventral losses, especially in celiotomies. Furthermore, the blood flow is restricted through capillaries that are compressed by the patient's own weight. The circulating water blanket has been shown to be more effective and safer when positioned over the patient rather than under it.[51,57] This could be due to circulating heating blankets being in contact with only a small percentage of the body surface. Increasing the contact surface area by wrapping the blanket around the animal may help decrease heat loss[23], but could interfere with the surgical field.

The forced-air warming systems consist of an electrically powered heater-blower unit and a patient cover. Most covers consist of some combination of fabric, plastic, or paper. Most are disposable and designed for single patient use. The blowers are available in various sizes and configurations. Commercial blankets are available in three types that cover, surround, or are placed under the patient.[45] The choice of blanket depends on the size of the patient and type of surgery performed. The forced-air patient warming device injects warm air into a disposable paper quilt-like blanket. The warm air inflates the blanket and then exits toward the patient through small slits, thus providing a shell of warm air around the patient. Studies documenting the success of using a forced-air warming system to minimize heat loss in anesthetized humans were first published in 1989.[10,60] Forced-air warming has been evaluated in numerous other studies since and have consistently shown it to maintain normothermia during long operations.[9,12,15,16,25,27,29,31,33,35,39,47,56,60] Advantages of forced air warming include an adjustable thermostat, an unobstructed surgical field, and minimal risk of thermal injury.

Other ways of limiting the loss of heat includes resistive heating and radiant warmers. Resistive heating (electric blanket) is as effective as forced air, but is much less expensive because it does not require a disposable blanket. Radiant warmers use special incandescent bulbs or heated surfaces to generate infrared radiation. The advantage of radiant heating is that it does not require contact between the warmer and patient because the heat energy is carried by photons and does not depend on the intervening air.[51] Radiant heating is ideal for neonatal intensive care units, where it is important that patients remain visible.[51] The major disadvantage of this warming system is that convective losses continue and energy transfer decreases rapidly as the distance between the warmer and patient increases. Due to this, the heating device must be positioned immediately parallel and adjacent to the skin surface. The concern for thermal injury is high with this type of heating. The most serious complication of radiant warmers is extreme hyperthermia and may result in death or permanent neurological damage. Insensible water loss markedly increases when infants are placed in the warm, dry, open environment under radiant warmers.[69] First degree burns have also been attributed to radiant warmers. Emissions from some radiant warmers at their maximum intensity are of the same order of magnitude as the maximum level recommended for occupational exposure to infrared radiation.[69]

A recently developed intraoperative warming unit (Thermal-V®) uses an even heat distribution system. This unit is made up of two heavy-gauge satin finish type stainless steel (top) and ABS plastic (bottom) panels securely sealed so fluids can not penetrate. Complete sealing makes this unit easy to wash. The panels can lay flat or fold to configure with existing surgery tables up to a 90 degree angle and can be used together (side by side) or independently. The heat conductibility of the heavy-gauge stainless steel panels allow for consistent temperature from top to bottom and throughout the length of each panel. The temperature on each panel is independently regulated and can be digitally programmed up to 106°F without causing thermal burns. Manufacturer recommendations suggest placement of patient directly onto panel without a cotton blanket or towel.

Conclusions

Body temperature is normally controlled by a negative feedback system in the hypothalamus, which integrates thermal information from most tissues. Approximately 80% of this thermal information is derived from core body temperature, which can be approximated with an esophageal, nasopharyngeal, or rectal continuous thermometer probes, infrared tympanic membrane probes, or digital rectal thermometers.[53] The hypothalamus coordinates increases in heat production, increases in environmental heat loss, and decreases in heat loss as needed to maintain normothermia. Hypothermia is common during surgery and anesthesia due to heat loss from the core compartment, especially in abdominal surgeries. Hypothermia initially results from an internal redistribution of body heat from the core to peripheral tissues. Core temperature then decreases linearly at a rate determined by the difference between heat loss and production. When patients become sufficiently hypothermic, they again trigger thermoregulatory vasoconstriction, which restricts core-to-peripheral flow of heat. Vasoconstriction is very effective in minimizing further core hypothermia.

Postoperative return to normothermia occurs when brain anesthetic concentration decreases sufficiently to again trigger normal thermoregulatory defenses. However, residual anesthesia and opioids given for treatment of postoperative pain decreases the effectiveness of these responses. Consequently, return to normothermia often needs 2 to 5 hours, depending on the degree of hypothermia.[52] Delayed return to core normothermia appears to result largely from postoperative thermoregulatory impairment.

A reasonable strategy for detecting and preventing thermal disturbances is to monitor core temperature in patients subjected to general anesthesia lasting longer than 30 minutes.[53] Preventing hypothermia will shorten the period of recovery from anesthesia, reduce stress, and therefore contribute to a successful outcome to surgery. When safety protocols are adhered to, active warming devices prevent loss of heat from the patient to the environment or can actively transfer heat into patients, and all have shown to be superior to no warming treatment at all. Among the clinically available active systems, forced-air heating has been demonstrated to be the most effective and can usually maintain normothermia even during the longest operations.

CHAPTER III

METHODOLOGY

Materials and Methods

The study population consisted of a total of 238 dogs that underwent surgical procedures between 2005 and 2008. The population was made up of client owned dogs and dogs from the local animal shelter. This study was approved by the Oklahoma State University's Institutional Animal Care and Use Committee (IACUC). The dogs were randomly categorized into two major groups (group A and B) each containing 119 patients. Group A (n=119) was the group in which patients were scheduled for a celiotomy procedure (ie. exploratory laparotomy, ovariohysterectomy). Group B (n=119) was the group in which patients were scheduled for a non-celiotomy procedure (ie. skin mass excision, ophthalmic procedure, orthopedic procedure, orchidectomy). For each group, patients had to be undergoing a procedure lasting no less than one hour of surgery time (incision to closure). Dogs in each major group (A and B) were randomly assigned to one of three sub-groups. Dogs in Group 1 (n=39) were placed on a circulating warm water blanket (T/pump®) with the forced-air warming unit (Bair Hugger®) placed over the animal in such a way that the operative field was not disturbed. Group 1 was the "positive control" group. Due to no warming being unethical, there was no negative control group. Dogs in Group 2 (n=40) were placed on a forced-air warming unit without the circulating warm water blanket. Dogs in Group 3 (n=40) were placed on two warming panels (Thermal-V®) without a circulating warm water blanket.

Data collection for all patients included gender, weight, body condition score, ASA physical status, and type of surgery (celiotomy or non-celiotomy). Gender and weight were gathered from the medical records and physical exams. The body condition score and physical status were determined by a single observer (MAF). The Purina body condition scoring system[70] was used and scoring ranged from one to nine, one being emaciated and nine being grossly obese. Physical status of each patient was identified using the ASA classification system[12,44]: Class I – normal patient with no organic disease, Class II – patient with mild systemic disease, Class III – patient with severe systemic disease that limits activity but is not incapacitating, Class IV – patient with incapacitating systemic disease that is a constant threat to life, and Class V – moribund patient not expected to live 24 hours with or without surgery. The type of surgery was recorded at the time of temperature evaluation.

Information collected also included duration of surgery (defined as the time from initial skin incision to placement of the last skin suture/staple), preoperative body temperature (defined as the temperature of the animal before induction), postoperative body temperature (defined as the temperature of the animal at the time of extubation), low body temperature (defined as the nadir temperature during the intraoperative period), and high body temperature (defined as the zenith temperature during the intraoperative period). Normal core body temperature for the dog ranges from 37.8 to 39.3°C (100.2 to 102.8°F)[34] and mild hypothermia is defined as a temperature of less than 37.8°C (~100°F). For all dogs, core body temperature using an esophageal and rectal thermography was continuously monitored and recorded intermittently. Temperature was monitored with a digital rectal thermometer during recovery in all patients. Patient parameters (non-invasive blood pressure, heart rate, respiratory rate, end-tidal carbon dioxide levels, and electrocardiogram) were all monitored intraoperatively.

We compared and evaluated the efficacy of three active warming devices that may be used alone or in combination to minimize intraoperative hypothermia when applied to patients undergoing prolonged surgeries lasting over one hour. The warming protocols evaluated were 1) the forced-air warmer (Bair Hugger® Model 505, Arizant Healthcare Inc., Eden Prairie, Minnesota) with an adult sized cover set on "high" (~43° C) positioned above the patient and a 38 cm x 56 cm circulating water blanket (T/pump® Model TP500, Gaymar Industries, Inc., Orchard Park, New York) set to ~42°C positioned below the patient (positive control warming device); 2) the Bair Hugger® forced air warmer with an adult sized cover set on "high" (~43°C) and positioned below the patient; and 3) two 18"W x 48"L warming panels (Thermal-V®, Temp Stabilizers, Inc., Owasso, Oklahoma) set to ~41°C and positioned in a V-configuration below the patient. Patients were all positioned directly onto warming devices. All heating units were given time to cycle through a warm up process of 10 minutes prior to placement of the patient. All heating units were positioned under the patient. Warming began immediately after the patient was moved to the operating table and was continued until the end of the procedure.

As part of the pre-operative physical exam, the body temperatures of each patient were recorded before induction using a digital rectal thermometer. Then it was measured at the time of induction when an esophageal temperature thermistor (Passport, Datascope Corporation, Paramus, New Jersey) could be inserted, and again immediately after the patient was prepped for aseptic surgery in the operating room. The readout of the esophageal temperature thermistor probes were continuously monitored visually and the temperature was recorded every 15 minutes for the first hour, then at 30 minute intervals intraoperatively until the end of the procedure. This was done for each warming device to determine mean temperature and the magnitude of increase from time of induction to extubation. Temperatures were also recorded manually post-operatively during recovery using a commercially available digital rectal thermometer.

The ambient operating room temperature was monitored continuously and recorded at the beginning and end of each procedure using a commercial room thermometer (Acu-Rite®, Chaney Instrument Company, Lake Geneva, WI). The commercial thermometers were all calibrated and tested to ensure accuracy. This was done prior to placement of the thermometer in each operating room and once a month after placement.

All patients underwent general inhalation anesthesia for their procedures. Standard pre-medication and induction techniques were used at the discretion of the attending anesthesiologist. Although the anesthetic protocols were different for each patient, the most common premedication combination used was glycopyrolate and hydromorphone. The majority of the patients were induced with propofol and isoflurane was the gas inhalant used in each procedure. Anesthetic depth varied between patients, but they were all maintained with isoflurane. All patients' heart rate, respiratory rate, and blood pressure were monitored intraoperatively using standard monitors (Passport, Datascope Corporation, Paramus, New Jersey).

All statistical analyses were conducted using PC SAS Version 9 (SAS Institute, Cary, NC). The experiment was designed as a 2 x 3 factorial arrangement in a completely randomized design with repeated measures. One factor was surgery type (2 levels) and the other factor was treatment (3 levels). Analysis of variance techniques was used to evaluate the effects of the factors in question. Extraneous factors such as age, gender, weight, body condition score, and ASA physical status were included as covariants in the model. The simple effects of treatment for each surgery type and time point was assessed with a SLICE option in an LSMEANS statement in PROC MIXED (SAS Institute, Cary, NC). Statistical significance was determined at the 0.05 level.

CHAPTER IV

FINDINGS

A total of 238 dogs were entered into the study population over a period of 20 months. The total number of dogs in the celiotomy (open abdomen) group and the non-celiotomy (closed abdomen) group was 119 and 119, respectively. Each subgroup's totals for the corresponding treatments A and B were as follows: circulating water/forced air (n=39); forced air (n=40), and Thermal-V (n=40). The mean weight of the overall study population was 23.3 kg (+/- 14.7 kg). On a scale from 1-9, the mean body condition score of the overall study population was 4.8 (+/- 1.1). The mean ASA status for the overall population was 1.6 (+/- 0.6). The majority of the dogs were ASA 1 and 2. The mean duration of the surgical procedures was 100.2 minutes (+/- 36.8 minutes). Among the parameters measured, mean patient weight, body condition score, ASA status, and duration of surgical procedures did not have any significant effect on the results from the three groups - control (circulating water/forced air), forced air, and Thermal-V.

The mean ambient temperature for the operating rooms at the beginning of each procedure was 69.8°F (+/- 2.2°F) and 71.0°F (+/- 2.4°F) at the end of procedure. The mean pre-operative temperature for the overall study population was 101.4°F (+/- 1.03°F). The mean temperature at time of induction was 100.5°F (+/- 1.24°F). The mean temperature at time of sterile prepping in the OR was 99.1°F (+/- 1.88°F). Ambient operating room temperature, pre-operative temperature, temperature at time of induction, and temperature at time of sterile preparation did not have any significant effect on the results from each treatment group.

The mean temperature of patients in the control group at time of skin incision (0 minutes) was 98.2°F (+/- 0.25°F) for the non-celiotomy and 97.8°F (+/- 0.33°F) for the celiotomy. The mean temperature of patients in the forced air group at time of skin incision (0 minutes) was 98.3°F (+/- 0.29°F) for the non-celiotomy and 97.5°F (+/- 0.30°F) for the celiotomy. The mean temperature of patients in the Thermal-V group at time of skin incision (0 minutes) was 98.7°F (+/- 0.25°F) for the non-celiotomy and 98.3°F (+/- 0.30°F) for the celiotomy. There were no significant differences in temperatures from each type warming unit. There was a significant difference in temperature noted for the type of surgery in the forced-air group. Temperatures were significantly lower in the celiotomy group.

The mean temperature of patients in the control group at 15 minutes after skin incision was 98.1°F (+/- 0.23°F) for the non-celiotomy and 97.5°F (+/- 0.31°F) for the celiotomy. The mean temperature of patients in the forced air group at 15 minutes after skin incision was 98.1°F (+/- 0.27°F) for the non-celiotomy and 97.3°F (+/- 0.27°F) for the celiotomy. The mean temperature of patients in the Thermal-V group at 15 minutes after skin incision was 98.4°F (+/- 0.25°F) for the non-celiotomy and 98.0°F (+/- 0.28°F) for the celiotomy. There were no significant differences between the temperatures from each warming unit. There was a significant difference in temperature noted for the type of surgery in the forced-air group. Temperatures were significantly lower in the celiotomy group.

The mean temperature of patients in the control group at 30 minutes after skin incision was 98.1°F (+/- 0.23°F) for the non-celiotomy and 97.2°F (+/- 0.30°F) for the celiotomy. The mean temperature of patients in the forced air group at 30 minutes after skin incision was 98.2°F (+/- 0.24°F) for the non-celiotomy and 97.2°F (+/- 0.25°F) for the celiotomy. The mean temperature of patients in the Thermal-V group at 30 minutes after skin incision was 98.3°F (+/- 0.23°F) for the non-celiotomy and 97.8°F (+/- 0.26°F) for the celiotomy. There were no significant differences between temperatures from each warming unit. There was a significant difference in temperature noted for the type of surgery in the control and forced-air groups. Temperatures were lower in the celiotomy groups for each warming unit.

The mean temperature of patients in the control group at 45 minutes after skin incision was 98.2°F (+/- 0.24°F) for the non-celiotomy and 97.0°F (+/- 0.29°F) for the celiotomy. The mean temperature of patients in the forced air group at 45 minutes after skin incision was 98.2°F (+/- 0.24°F) for the non-celiotomy and 97.2°F (+/- 0.23°F) for the celiotomy. The mean temperature of patients in the Thermal-V group at 45 minutes after skin incision was 98.1°F (+/- 0.21°F) for the non-celiotomy and 97.6°F (+/- 0.26°F) for the celiotomy. There were no significant differences between temperatures from each warming unit. There was a significant difference in temperature noted for the type of surgery in the control and forced-air groups. Temperatures were lower in the celiotomy groups for each warming unit.

The mean temperature of patients in the control group at 60 minutes after skin incision was 98.2°F (+/- 0.25°F) for the non-celiotomy and 96.6°F (+/- 0.30°F) for the celiotomy. The mean temperature of patients in the forced air group at 60 minutes after skin incision was 98.3°F (+/- 0.24°F) for the non-celiotomy and 97.2°F (+/- 0.23°F) for the celiotomy. The mean temperature of patients in the Thermal-V group at 60 minutes after skin incision was 98.0°F (+/- 0.22°F) for the non-celiotomy and 97.5°F (+/- 0.26°F) for the celiotomy. There were no significant differences between temperatures from each warming unit. There was a significant difference in temperature noted for the type of surgery in the control and forced-air groups. Temperatures were lower in the celiotomy groups for each warming unit.

The mean temperature of patients in the control group at 90 minutes after skin incision was 98.5°F (+/- 0.33°F) for the non-celiotomy and 96.2°F (+/- 0.43°F) for the celiotomy. The mean temperature of patients in the forced air group at 90 minutes after skin incision was 98.2°F (+/- 0.27°F) for the non-celiotomy and 97.1°F (+/- 0.26°F) for the celiotomy. The mean temperature of patients in the Thermal-V group at 90 minutes after skin incision was 97.7°F (+/- 0.20°F) for the non-celiotomy and 97.3°F (+/- 0.36°F) for the celiotomy. There were no significant differences between temperatures from each warming unit. There was a significant difference in temperature noted for the type of surgery in the control and forced-air groups. Temperatures were lower in the celiotomy groups for each warming unit.

The mean temperature of patients in the control group at 120 minutes after skin incision was 98.4°F (+/- 0.41°F) for the non-celiotomy and 96.2°F (+/- 0.59°F) for the celiotomy. The mean temperature of patients in the forced air group at 120 minutes after skin incision was 98.5°F (+/- 0.43°F) for the non-celiotomy and 97.0°F (+/- 0.45°F) for the celiotomy. The mean temperature of patients in the Thermal-V group at 120 minutes after skin incision was 97.5°F (+/- 0.24°F) for the non-celiotomy and 96.8°F (+/- 0.59°F) for the celiotomy. There were no significant differences between temperatures from each warming unit. There was a significant difference in temperature noted for the type of surgery in the control and forced-air groups. Temperatures were lower in the celiotomy groups for each warming unit.

The mean temperature of patients in the control group at 150 minutes after skin incision was 98.9°F (+/- 0.72°F) for the non-celiotomy and 97.9°F (+/- 1.03°F) for the celiotomy. The mean temperature of patients in the forced air group at 150 minutes after skin incision was 98.9°F (+/- 0.66°F) for the non-celiotomy and 97.1°F (+/- 0.26°F) for the celiotomy. The mean temperature of patients in the Thermal-V group at 150 minutes after skin incision was 97.5°F (+/- 0.28°F) for the non-celiotomy and 97.7°F (+/- 0.89°F) for the celiotomy. There were no significant differences between temperatures from each warming unit and surgery type.

The mean temperature of patients in the control group at 180 minutes after skin incision was 99.4°F (+/- 1.13°F) for the non-celiotomy. There were no surgeries recorded that lasted to 180 minutes for the celiotomy control group. The mean temperature of patients in the forced air group at 180 minutes after skin incision was 97.7°F (+/- 0.41°F) for the non-celiotomy and 97.2°F (+/- 0.21°F) for the celiotomy. The mean temperature of patients in the Thermal-V group at 180 minutes after skin incision was 97.8°F (+/- 0.19°F) for the non-celiotomy and 95.4°F (+/- 0.70°F) for the celiotomy. There were no significant differences between temperatures from each warming unit. There was a significant difference in temperature noted for the type of surgery in the Thermal-V group. Temperatures were lower in the celiotomy group.

The results are summarized in the following graphs [Figures 4, 5, 6].

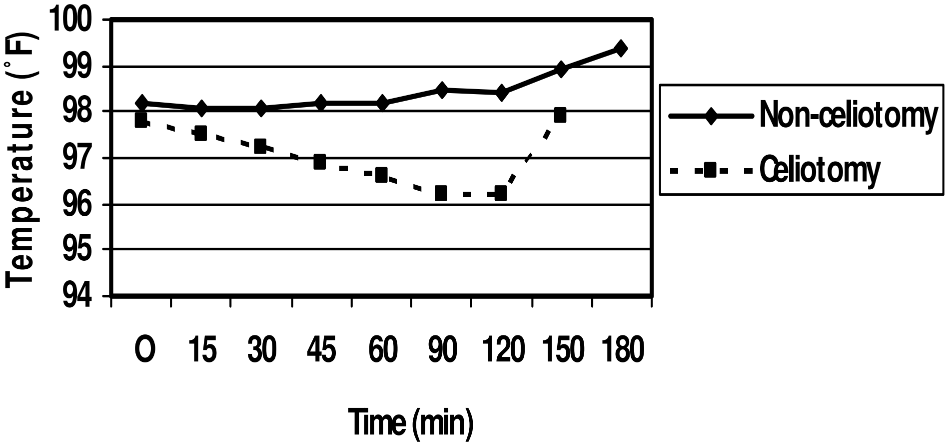

Figure 4. – Core temperatures of patients undergoing celiotomy and non-celiotomy procedures while maintained on the Bair Hugger and T/pump (control group).

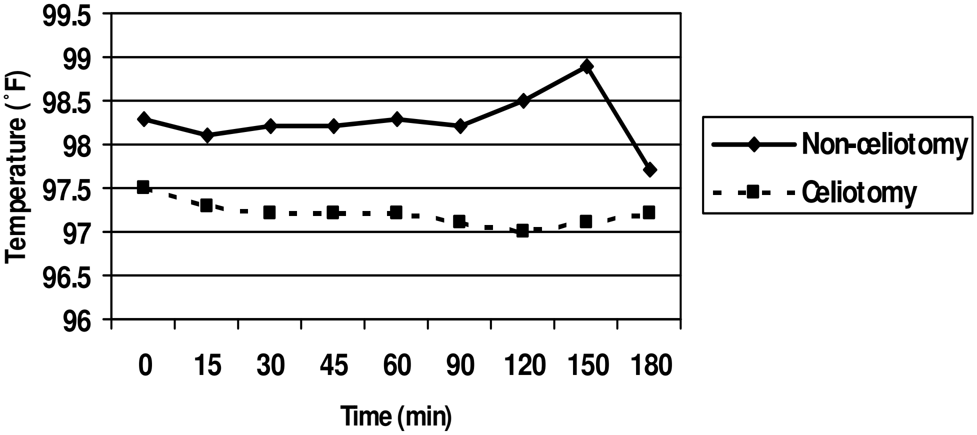

Figure 5. – Core temperatures of patients undergoing celiotomy and non-celiotomy procedures while maintained on the Bair Hugger. Temperature was well maintained throughout the procedures.

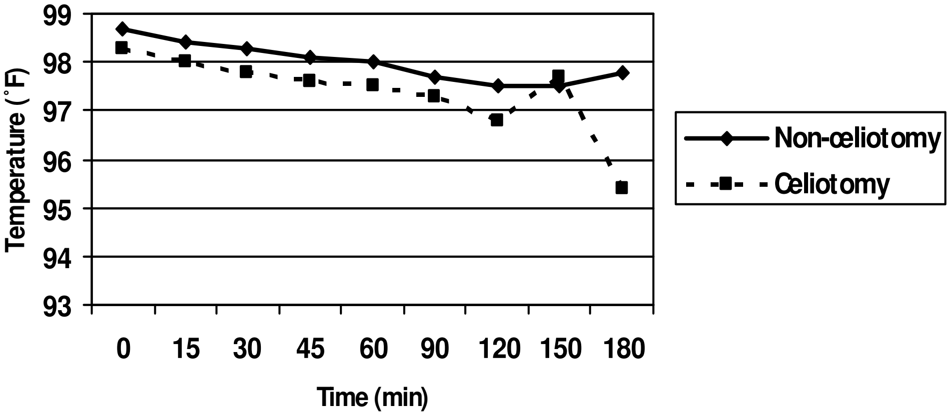

Figure 6. – Core temperatures of patients undergoing celiotomy and non-celiotomy while maintained on the Thermal-V. Temperatures were well maintained throughout the procedures until after 150 minutes (celiotomy).

The mean temperature at the end of procedure (time when the last suture or staple was placed) was 97.6^{o}F (+/- 1.89^{o}F). The mean rectal temperature during recovery was 97.9^{o}F (+/- 1.78^{o}F). Temperatures at the end of procedure and during recovery did not have any significant effect on the results of each warming device.

CHAPTER V

DISCUSSION

With the increased awareness of possible adverse effects with inadvertent hypothermia, there has been a widespread adoption to using forced air warming. Although there have been many studies that proved the effectiveness of forced air warming over other methods of patient warming,[9,12,15,16,25,27,29,31,33,35,39,47,56,60] this is the first study that compared the Thermal-V surgical warming panels to the Bair Hugger® alone or in combination with the T/pump® circulating water blanket. This study showed that, in patients undergoing prolonged celiotomy or non-celiotomy surgery, the Thermal-V® warming unit is as clinically effective as the Bair Hugger® in minimizing the degree of anesthetic-induced hypothermia.

Changes in body temperature associated with the development of hypothermia followed a typical pattern comprised of three distinct phases. A rapid decrease in core body temperature occurred following the induction of general anesthesia. There was a 1°F significant drop in temperature that occurred from time of induction (mean 100.5°F +/- 1.24°F) to sterile preparation in the operating room (mean 99.1°F +/- 1.88°F). The most dramatic decreases in the mean body temperatures of anesthetized cats and dogs are reported to occur in the initial 20 minutes after anesthetic induction.[64] However, the first phase of anesthetic-induced hypothermia in human adults is reported to last approximately 45 minutes.[53] This time frame correlates with the findings of the present study. By 30-45 minutes after induction of the present study, all dogs in all three groups experienced a decreased in body temperature of 1°F. The initial rapid decline in core body temperature observed in all of the dogs in this study was primarily because of a redistribution of heat from the warm central compartment to cooler peripheral tissues. These results are comparable to other studies in that the significant portion of hypothermia does develop in the early anesthetic period.[8,31,33,44,47,56,58,64] In the second phase, heat loss to the environment proceeds in an almost linear manner until a balance is finally reached between metabolic heat production and environmental heat loss. Achievement of thermal steady states (where heat production equals heat loss) marks the final phase of anesthetic-induced hypothermia.

Although the three warming models reduced significant hypothermia that can develop in anesthetized dogs without any active heating, the warming systems were unable to prevent the initial redistribution of body heat and resultant decrease in core body temperature. Redistribution hypothermia (phase I) is difficult to treat except through prevention by active cutaneous warming before anesthesia, thus reducing the core-to-periphery temperature gradient. Pre-inductive skin warming has been shown to be effective in human patients.[59] It would be less feasible with veterinary patients because it would require them to lie still with an active warming system covering their body for 30 minutes or more.[59] Although forced air warming, circulating water blanket, and Thermal-V conductive heating can do little to prevent the first phase of anesthetic induced hypothermia, the results suggest that active warming during this phase is important in minimizing on-going heat loss. Failure to provide active heating during this period results in a loss of total body heat content which is not easily replenished and can have detrimental consequences.

In this study, there were no statistically significant differences in temperatures between the types of warming devices used. However, there were temperature differences noted between the types of surgical procedure, celiotomy verses non-celiotomy, for each device [Figures 7 and 8]. This difference could be due to the enhanced loss of heat through evaporation in the celiotomy procedures. Procedures requiring entry into the body cavity increases the likelihood of heat loss. Heat loss from radiation, convection, and evaporation is increased during a celiotomy, because greater surface area is exposed when the abdominal cavity is opened.[41,48] Comparing the length of an incision for an exploratory laparotomy verses an ovariohysterectomy and how much it affects heat loss and hypothermia were not evaluated in this study. Exploratory laparotomy incisions are larger and would most likely, lose more heat leading to hypothermia. Further studies comparing of size of incision to the amount of heat loss and hypothermia is warranted. During celiotomy, the abdomen may or not require lavage. Warmed solution for lavage is recommended and is thought to help increase or maintain body temperature by convection of heat from the lavage solution to the animal. In a study of dogs undergoing celiotomies, Nawrocki showed that lavaging with saline solution warmed to 110+/-4°F (43+/-°C) could significantly increase core body temperature.[41] The increase in body temperature occurred 2 to 6 minutes after initiation of lavage and continued to increase throughout the 15-minute lavage period.[41]

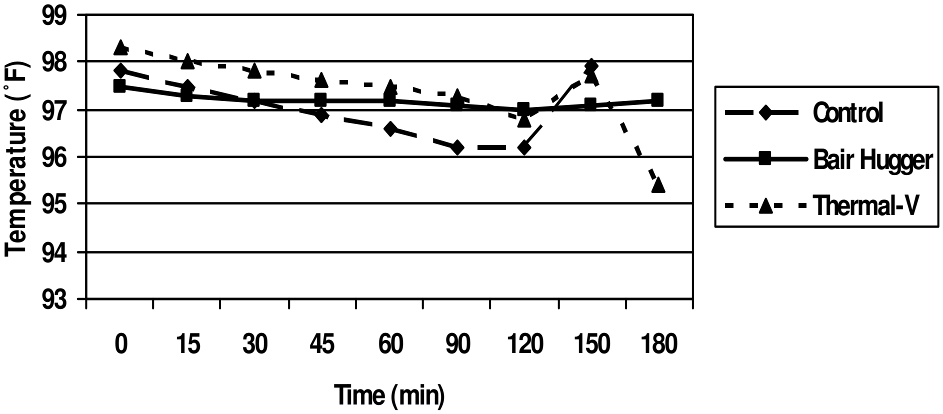

Figure 7. – Core temperature in patients undergoing celiotomy lasting up to 180 minutes. Control group did not have any patients in surgery longer than 180 minutes. Temperature in the Thermal-V group decreased significantly after 150 minutes of surgery, while the other devices maintained or increased.

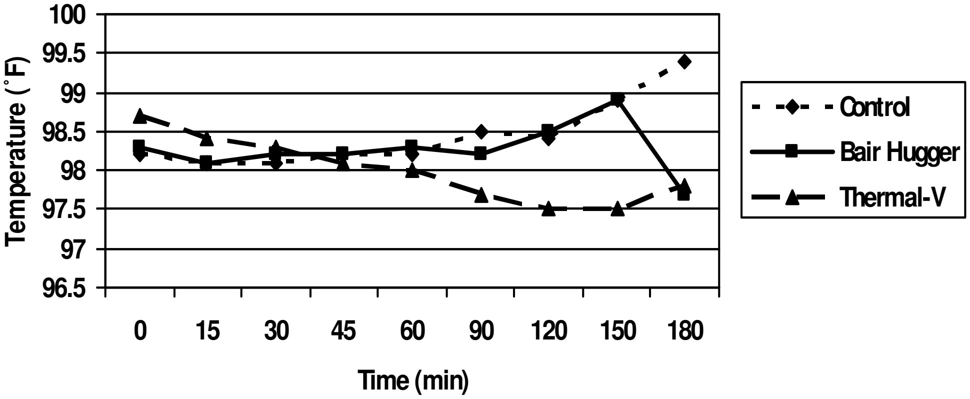

Figure 8. - Core temperature in patients undergoing non-celiotomy lasting up to 180 minutes. Temperatures were higher compared to the celiotomy group.

Environmental temperatures remains an important factor in determining heat balance in anesthetized patients.[5,53] Raising room temperature can reduce the thermal gradient between patients and their environment, thus minimizing heat loss. Human adults require ambient temperatures of at least 22°C to maintain normal body temperatures during general anesthesia.[35] Anesthetized infants and neonates require much higher room temperatures as high as 26°C to prevent significant hypothermia.[5] Optimal environmental temperatures for maintaining normothermia in anesthetized small animals have not been established. In this study, the temperatures did not vary significantly between each operating room at the beginning (mean 21°C) and end of each procedure (mean 21.7°C). Due to maintaining consistent temperatures from room to room, the operating room temperature did not have any significant effect on the outcome. If the room temperature was higher, the warming devices may have been more effective in minimizing hypothermia in the anesthetized dogs.

The main safety concern with any warming method is burn prevention. The probability of burns depends on temperature and length of warming, and is inversely related to perfusion of the warmed area. Perfusion may be compromised either intrinsically (thermoregulatory or other control mechanisms and vascular insufficiency) or extrinsically (external pressure exerted by the warming device).[16] Perfusion is likely to be compromised by external pressure with any of the warming methods. Any external pressure would be due to the animals' own weight. Even after prolonged application of forced air warming, circulating blanket, and the conductive heating panels of the Thermal-V® at the high temperature settings, none of the patients in this study sustained any immediate postoperative burn injuries or other adverse events. Previous attempts by other companies to make a heated metal top table have resulted in burns. The high limit on the Thermal-V setting was 106°F, but was not achieved in this study. There were no procedures that extended beyond 180 minutes. It is not known is a long procedure (>180 minutes) using the maximum temperature setting would cause thermal burns. Although there was not a follow-up on whether any of the patients experienced thermal burns in this study, there were no complaints from the owners postoperatively. There have been few reported cases of burns due to the use of forced air warming in the literature[1,13,32], most of these cases can be attributed to improper use of the equipment. All units tested in this study seem to provide a safe level of warming, if properly used.

CHAPTER VI

CONCLUSION

Unintentional hypothermia commonly occurs in anesthetized veterinary patients. Factors other than the choice of anesthetic drugs, such as length of surgery, surface area of surgical preparation, operative site, depth of anesthesia, physical status of patient before and during anesthesia, and environmental and contact surface temperature all contribute to the development of hypothermia.[21] Mild intraoperative hypothermia can produce potentially serious complications of surgery including blood loss due to an impaired coagulation cascade.[38,49,50,52,63] Anesthetic depth is also an important determinant of temperature regulation in an anesthetized patient. Deep levels of anesthesia contribute to ongoing decreases in body temperature by depressing heat production and promoting heat loss. Anesthetic agents can interfere with thermoregulatory processes by blocking input, altering thermoregulatory thresholds, or by preventing normal efferent responses to changes in body temperature. The most serious consequences of intraoperative hypothermia are manifested in the postoperative period. These include delayed anesthetic recovery,[31,32,52,58] myocardial ischemia,[13,14,31] shivering with resultant discomfort,[31] and decreased resistance to surgical wound infections.[2-4,30,65] Impairment of immune function, decreased cutaneous blood flow, and reduced tissue oxygen availability can all contribute to an increased risk of wound infection. In addition, the pain and discomfort associated with hypothermia and shivering in the postoperative period is a frequent complaint of human patients.[52,66] Mild to moderate hypothermia may not influence outcome in healthy dogs and cats, but should be considered increasingly important in older or more debilitated patients.

Successful management of hypothermia in surgical patients requires an accurate means of recording and monitoring changes in core temperatures. Direct means of measuring core temperature, including the implantation of thermistors in a central vein, are limited by their invasiveness and the necessity of maintaining a sterile field.[24] Therefore, rectal, esophageal, and tympanic thermography are often used indirectly to determine core body temperature in animals and humans undergoing abdominal surgery.[2,20,36,54,61] Esophageal and rectal temperature measurements vary slightly from measurements taken via thermistors implanted in a central vein. The difference has been attributed to factors such as the metabolic process within the stomach and colon, inconsistent placement of the temperature probes, the sensitivity of the equipment used, and the presence of fecal material within the rectum that may insulate the probe from the surrounding tissues.[20,36,61]

The importance of maintaining a patient's core body temperature during anesthesia to reduce the incidence of postoperative complications has been well documented. Methods for treating or preventing hypothermia include passive external warming, active external warming, and active internal warming. Increases in core temperature of 0.4-2^{o}C per hour have been reported for external passive and active warming.[18] Active internal core warming techniques are the most invasive and most effective for rapidly raising body core temperatures because such techniques provide direct access to the circulating blood. Extracorporeal warming of blood by cardiopulmonary bypass or hemodialysis is the most effective of the invasive warming techniques. Increases in core temperature of up to 10°C per hour have been reported.[18]

The comparative advantages of these warming devices can be addressed with regard to practicality of use and overall cost. This study proved that the Thermal-V® warming unit can be an effective way to prevent excessive heat loss in anesthetized patients. Of the many other intraoperative warming devices which are available, forced air warming unit have been shown to be the most practical and effective to date. While forced air devices are effective in preventing mild hypothermia during general anesthesia, there are some inherent problems with this warming method. There is a significant cost associated with the single patient use blankets.[12,68] Blankets cost approximately $15 each ($150 for a box of 10) and have to be replaced after each use. The forced air blower unit alone costs approximately $3000. Given some of the drawbacks with forced air warming systems, such as expenses of the single use blanket, this new conductive heating device offers an alternative method of active warming with advantages in terms of cost and possible application to a wide variety of surgical procedures. The Thermal-V® unit costs around $1800 with no ongoing costs. Without the need for a blanket, the Thermal-V® warming unit can have lower operating costs. It appears that the conductive heating of the Thermal-V® can be an effective way to prevent excessive heat loss in anesthetized patients. The reduced running cost compared to forced air warmers makes this device an attractive alternative for active warming in the operating room.

To further determine if the Thermal-V warming unit is as effective at lower temperature settings, additional studies of comparing active peripheral warming devices to the Thermal-V at lower temperature settings and using a larger number of patients is warranted. Comparing the warming devices for specific procedures (ie. thoracotomy, celiotomy, and orthopedic) with the device set at various set temperatures could be evaluated. Evaluating whether shorter length of hair coat contributed to heat loss and hypothermia is something that could also be evaluated.

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VITA

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Scope and Method of Study: Thermal homeostasis is important for the overall well-being of people and animals. Hypothermia is common during and after surgeries. The combination of anesthesia, exposure to a relatively cold operating room environment, evaporation from surgical incisions, and conductive cooling produced by administration of relatively cool intravenous fluids can result in unintended perioperative hypothermia. Anesthesia-induced hypothermia may alter physiological mechanisms of thermoregulation and may lead to prolonged duration of drug action, myocardial ischemia, coagulopathies, decreased resistance to surgical wound infections, and prolonged recovery time. Unless active warming measures are taken, the patient will lose body heat and endure hypothermic consequences. Therefore, proactive warming measures are needed to prevent excessive heat loss from the patient to the environment. The goal of any warming device is to prevent intraoperative hypothermia or treat preexisting hypothermia. The efficacy of three active warming devices (T/pump circulating water, Bair Hugger, and Thermal-V) that may be used alone or in combination to minimize intraoperative hypothermia when applied to patients undergoing prolonged surgeries was evaluated. Our hypothesis was that the Thermal-V warming unit would be comparable or better than the other units.

Findings and Conclusions: There were no statistically significant differences between patient temperatures for each warming device in surgeries that lasted 180 minutes. The combined circulating water blanket and force air warming system and forced air warming device used alone were significantly better in preventing excessive heat loss in patients undergoing celiotomies. Thermal-V unit was able to prevent excessive heat loss in patients undergoing surgeries up to 150 minutes. Mean patient weight, body condition score, ASA (American Society of Anesthesiologists) status, and duration of surgical procedures did not have any effect on the outcome. Ambient operating room temperature, pre-operative temperature, temperature at time of induction, and temperature at time of sterile preparation did not have any effect on the results either. Given some of the drawbacks with other warming systems, the Thermal-V offers an alternative method of active warming with advantages in terms of cost.

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