Inadvertent Perianesthetic Hypothermia in Small Animal Patients

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KEYWORDS
- Dog • Cat • Anesthesia • Hypothermia • Temperature
- Inadvertent perianesthetic hypothermia

KEY POINTS
- Inadvertent perianesthetic hypothermia is one of the most common complications associated with anesthesia.
- Hypothermia has been associated with many adverse events, including altered pharmacokinetics of anesthetic and analgesic drugs, dysfunction of organ systems, increased patient susceptibility to infection, reduced wound healing, altered coagulation, hypotension, and delayed recovery.
- Heat loss–minimizing techniques should be applied to dogs anesthetized for longer than 20 minutes.
- Heat loss techniques can be passive, active, or metabolic in nature.
- Passive techniques include insulatory materials, such as blankets, to minimize loss of existing body heat.

INTRODUCTION
Core temperature is defined as the temperature at which vital organs are maintained and is the temperature of deep structures of the body as compared with that of peripheral tissues. Core body temperature is maintained at a temperature that optimizes enzyme function and homeostasis and therefore, body temperature is considered a “vital sign.”1 Thermoregulation is the ability of an organism to keep its body temperature within certain boundaries, even when the surrounding temperature is very different. The ability to thermoregulate core body temperature can be disrupted by many conditions, including extreme changes in environment, illness and diseases,
and anesthetic and analgesic drugs. In the operating theater, secondary to environ-
mental and pharmaceutical influences, inadvertent perianesthetic hypothermia (IPH)
is likely and an understanding of the physiology and pathophysiology of thermoregu-
lation, effect of drugs, and options for temperature management can enhance patient
care.

**Physiology of Thermoregulation and the Response to Hypothermia**

Core body temperature is one of the most vigorously defended physiologic para-
meters of the mammalian body and results from a balance of heat production
and heat loss. The hypothalamus acts as the major thermoregulatory center or
“thermostat” and acts in concert with other minor centers in the skin, abdomen,
thorax, spinal cord, and other centers in the brain to define and maintain a set point
body temperature.\(^2\,^3\) Threshold temperatures for activation of heat-generating or
cooling physiologic and behavioral changes are set in the posterior hypothalamus.
The threshold temperatures for most mammals is a very narrow range of approxi-
mately 0.2°C above or below the set point body temperature and in healthy animals
thermoregulatory defenses are quite effective.\(^3\) Thermoregulation occurs through a
complex mechanism of afferent thermal sensing, central regulation, and efferent
responses to changes in environmental and body temperature.\(^4\) Afferent sensing
starts with thermally sensitive cells in virtually all tissues within the body. Cold
and warm sensitive cells are anatomically and physically distinct from each other.\(^4\)
Cold-signaling cells use myelinated A-delta nerve fibers to transmit their impulses
to the spinal cord, whereas warm-signaling cells use nonmyelinated C fibers.\(^3\)
Myelinated fibers propagate nerve impulses at a greater velocity than nonmyelin-
ated fibers and are better at sending localizing information, and thus cold temper-
atures may be more rapidly felt and localized to parts of the body. Interestingly,
information from pain-sensing neurons also use A-delta and C fibers for signal
propagation.\(^5\) Temperature-sensitive receptors for cold and warmth are physiolog-
ically distinct and reside in the skin, spinal cord, abdominal viscera, and around the
great veins in the upper abdomen and thorax.\(^6\) Within the skin, there is approxi-
mately 10 times the number of cold-sensitive receptors compared with warmth-
sensitive receptors, suggesting that peripheral detection of cold environmental
temperatures has greater physiologic importance.\(^6\) The firing or signaling rate of
these temperature-sensitive receptors increases as the surrounding tissue temper-
ate moves away from the established temperature set point. For example, as the
skin temperature drops, the cold-sensitive receptors increase the firing rate of
nerve impulses that are sent to the spinal cord.

On interfacing with the spinal cord, nerve impulses carrying temperature information
travel to higher centers mainly thought spinothalamic tracts in the anterior spinal cord.
Various other spinal tracts can convey thermal information to the brain and therefore
an organism can elicit some response to changes in temperature even if the spinothala-
mic tracts are damaged.\(^4\)

The preoptic area in the anterior hypothalamus also contains temperature-sensitive
neurons.\(^6\) Heat-sensitive and cold-sensitive neurons respond in much the same
manner as those found throughout the body, indicating that core brain temperature
is also well regulated. Temperature information from the preoptic area of the anterior
hypothalamus is combined with temperature information entering the higher centers
from the spinal cord and is directed to the posterior hypothalamus for integration
into whole-body temperature regulation. When this information indicates that the
body has fallen outside of the temperature set point, appropriate efferent responses
are activated to return body temperature to the normal range.
Efferent responses can be divided into body temperature–increasing and body temperature–decreasing activities. Temperature-increasing activities include vasoconstriction and activation of arteriovenous shunts, piloerection, shivering, and metabolic thermogenesis. Temperature-decreasing activities include vasodilation, sweating, panting, and decreased metabolic thermogenesis.

Changes in vascular tone and blood flow, particularly to the skin, are one of the most immediate responses to changes in body temperature. During hypothermia, peripheral cutaneous blood flow is decreased to reduce heat loss through the skin. Blood flow to the skin is functionally divided into 2 types: nutritional, supplied by capillaries; and thermoregulatory, mainly through arteriovenous shunts. These shunts are anatomically distinct from the capillary beds of the skin and do not compromise peripheral tissue metabolic needs. On recognition that body heat conservation is necessary, the arteriovenous shunts are activated to promote centralized blood flow and reduce heat loss through the skin.

Piloerection quite literally means hairs standing on end. For most mammals, including dogs, piloerection is a somewhat effective method of reducing heat loss. Piloerection occurs when musculi arrectores pilorum, the tiny muscles that elevate hair follicles above the skin, contract in response to sympathetic stimulation. This smooth muscle makes a connection from the fibrils to the underlying connective tissue and involuntary contraction occurs in response to catecholamine. The heat retention properties that are a result of piloerection are not related to the properties of the hair, but are because of layers of motionless air that are trapped next to the skin and form an outer layer of insulation. This mechanism allows animals to compensate for a moderately cooling environment without the need to increase metabolism. The effectiveness of piloerection is somewhat dependent on body size. Animals heavier than 5 kg are more likely to benefit from piloerection, whereas it is less effective in smaller animals because of a higher body surface-to-volume ratio.

Shivering is an involuntary action of the body whereby skeletal muscle rapidly contracts or twitches. The primary motor center for shivering is located in the posterior hypothalamus near the third ventricle. This area is excited by cold signals from the skin and spinal cord and responds by sending signals to the brain stem and spinal cord, which in turn activates motor neurons. Muscle tone increases and nonrhythmical contractions increase until shivering begins. Shivering can be a quite effective bodily mechanism for hypothermia, as it can increase heat production by fourfold to fivefold. However, heat generation by shivering comes at a tremendous metabolic cost. During shivering, metabolic oxygen consumption increases up to 700%, which may be of critical importance in very sick patients, particularly in a patient with myocardial disease.

In response to hypothermia, the body can manufacture heat as a by-product of metabolism. This can occur directly, as hypothermia can increase metabolism of various cells, including adipose tissue, and indirectly via epinephrine and norepinephrine activation of metabolic pathways. Hypothermia is stressful to the body and results in an increased release of stress-related biochemicals, such as epinephrine and norepinephrine. Part of the metabolic increase of heat production is through the ability of epinephrine and norepinephrine to uncouple oxidative phosphorylation and result in the release of energy in the form of heat instead of production of ATP. The greatest proportion of heat derived from adipose tissue occurs in brown adipose tissue or brown fat; however, protein and carbohydrates also contribute to metabolic heat production. Other metabolic pathways that activate uncoupling proteins also contribute to heat generation, mainly thyrotropin-releasing hormone (TRH). Released by the hypothalamus in response to cooling of the preoptic area, TRH in turn
stimulates the anterior pituitary gland to release thyroid-stimulating hormone, which simulates increased release of thyroxine by the thyroid gland.6 Thyroxine increases cellular metabolism with a resultant increased production of heat as a by-product of this cellular work.

**Core Versus Peripheral Temperature and Patterns of Heat Loss**

Core body temperature is the temperature of an organism at which it was meant to operate and tends to refer to the temperature of organs and deep structures of the body that are well insulated and tightly regulated. Peripheral body temperature is the temperature that is measured closer to the surface of the body, can vary widely, and is heavily influenced by environmental temperatures. In veterinary medicine, rectal temperature is the most commonly measured temperature. The average rectal temperature measured in healthy dogs is approximately 102°F (38.8°C); however, circadian rhythmicity results in a normal daily range of 100.9° to 102.7°F (38.3°–39.3°C).13 Core temperature is, on average, approximately 0.72°F (0.4°C) higher than rectal temperature, but can be as much as 2.0°F (1.2°C) higher in healthy dogs at rest.14 The gold standard for core temperature measurement is in the pulmonary artery; however, this is not the hottest site in the body. Brain tissue has been consistently shown to have the highest tissue temperatures.15 It is important to have a comprehension of the differences in core versus peripheral temperature so that practitioners can understand how characteristic patterns of heat loss occur in patients during general anesthesia. Core temperature change during anesthesia occurs in 3 phases. During the first hour, there is an initial rapid decline in core temperature, next, over the following 2 hours, core temperature declines in a slower linear fashion, and finally, core temperature stabilizes and remains relatively unchanged (Fig. 1).14 The reason behind this predictable pattern in change in body temperature is a result of the core-to-peripheral temperature gradient and the vasodilation caused by general anesthetics. In awake animals, a temperature gradient of up to 4°C exists between the core and the periphery. This gradient is maintained mainly through peripheral vasoconstriction that keeps body heat in a central pool of blood and thus minimizes the amount of

![Figure 1](image-url)

**Fig. 1.** Graphical representation of the typical pattern of change in core temperature during general anesthesia. There is an initial rapid decline during the first hour, a slower linear decline over the following 2 hours, and then temperature plateaus and remains relatively unchanged.
heat that can be lost through the skin. During anesthesia, the first initial decline in core temperature is a result of peripheral vasodilation and redistribution of body heat. During the second, slower decline, heat loss is directly related to the inhibition of general metabolism and heat production by anesthetic drugs, and results in heat loss in excess of production. The plateau of core temperature after 3 to 4 hours of anesthesia can be seen when a thermal steady state is achieved.

**Mechanisms of Heat Loss and Hypothermia**

There are 4 main mechanisms of heat loss from the body. These include convection, conduction, radiation, and evaporation (Table 1).

- **Convection** is the loss of body heat to cooler air surrounding the body.
  - Example: Operating room environments where room air temperature may be set low for personnel comfort.
- **Conduction** is the loss of body heat to surfaces that are in contact with the body.
  - Example: Stainless steel surgical tables or other hard surfaces that have a temperature lower than the patient’s body temperature.
- **Radiation** is the loss of body heat to structures not in contact with the patient.
  - Example: Surgical room walls and equipment within the operating room that have a temperature lower than the patient’s body temperature.
- **Evaporation** is the loss of body heat from evaporating moisture from the body.
  - Example: Surgical scrub and alcohol placed directly on the patient and moisture lost from an open body cavity or respiratory secretions.

During general anesthesia, there are many factors that affect the rate of heat loss from each of these 4 mechanisms. These can be divided into environmental factors and patient factors.

**Environmental factors** include the following:

- Air temperature
- Surrounding object temperature
- Velocity of air movement
- Relative humidity

The difference between the patient’s temperature and the temperature of the air or surrounding objects creates a temperature gradient and affects the rate at which heat is lost. The greater the temperature gradient, the greater the rate at which heat is lost from the body. The velocity of air and the relative humidity have an effect on

<table>
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<tr>
<td>Convection</td>
<td>Transfer of heat from body to surrounding air</td>
<td>Low environmental air temperature, open body cavity</td>
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<tr>
<td>Conduction</td>
<td>Transfer of heat from body to objects in contact</td>
<td>Direct contact with cold, heat-absorbing structures such as stainless steel</td>
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<td>Radiation</td>
<td>Transfer of heat from body to objects not in contact</td>
<td>Low environmental temperatures, short or clipped hair coat, open body cavity</td>
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<td>Evaporation</td>
<td>Loss of heat from evaporative process</td>
<td>Excessive use of surgical scrub, alcohol, lavage solutions, hair coat soaked with urine or feces</td>
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evaporative heat loss. The greater the movement of air and the lower the humidity, the more evaporation occurs and thus more heat is lost.

Patient factors include the following:

- Surface area to body mass ratio
- Physical condition
- Fur type and length
- Disease and injury

As body surface area increases, greater conductive, convective, and radiation heat loss can occur through cutaneous loss. Small and toy-breed dogs are at greater risk because of a higher surface area compared with larger-breed dogs. Physical condition of the dog contributes to the rate of heat loss. Muscle can act as heat-generation centers and fat functions as subcutaneous insulation to reduce body heat loss. As can be expected, cachexic and extremely thin animals are at a greater risk for development of hypothermia. Fur type and length play an important role in heat loss in dogs, particularly in arctic breeds such as huskies and malamutes. Longer and thicker fur traps a layer of air next to the body that acts as an insulation to surrounding cooler air and can be particularly effective to reduce convective heat loss. Disease states that reduce metabolic rate or injuries that result in open wounds accelerate heat loss through all 4 mechanisms, as well as negatively impact endogenous heat production.

**Anesthetic Effects on Body Temperature**

In the perianesthetic period, hypothermia is exacerbated by the anesthetic impairment of the thermoregulatory centers in the hypothalamus. The thermosensitive neurons in the preoptic area of the anterior hypothalamus and the receptors found in the spinal cord, abdominal viscera, and great veins are impaired by most anesthetic and analgesic drugs. The whole-body oxidative metabolism and heat production mechanisms that maintain temperature are silenced. As a result, heat-generating oxidative metabolism is not increased in the face of a falling body temperature, and hypothermia ensues. In addition to the reduction of heat generation, during anesthesia, patients have a reduced ability to conserve previously generated body heat. Most agents used to provide general anesthesia, regional anesthesia, analgesia, or immobilization have been shown to negatively affect thermoregulation. Epidural and spinal anesthesia decrease the ability of the thermal centers in the brain to register a decrease in body temperature, as a result, appropriate responses to hypothermia (vasoconstriction, shivering) are blunted. Inhalant anesthetics cause dose-dependent vasodilation and increase the pooling of blood in the peripheral tissues. This increases the surface area of the blood to give up heat to the environment. Opioid analgesic drugs have a direct effect on the central thermostat by lowering the threshold that activates heat-conserving and heat-generating actions of the body, resulting in a colder baseline temperature.

**Deleterious Effects of Hypothermia**

Hypothermia can have severe detrimental effects to a patient during the perioperative period. In general, hypothermia can alter pharmacokinetics of anesthetic and analgesic drugs, cause dysfunction of organ systems, increase patient susceptibility to infection, reduce wound healing, and alter coagulation. Enzymatic reactions that are used in metabolism of drugs may be altered, affecting the duration of action of anesthetic drugs. Hypothermia prolongs the action of nondepolarizing paralytic agents. Inhalant anesthetic potency can be influenced by hypothermia. As patient
temperature decreases, inhalant anesthetic tissue solubility increases, resulting in increased anesthetic content in body tissues, including the brain, causing increased depth of anesthesia due to a relative anesthetic overdose.\textsuperscript{21,22}

Hypothermia can have profound effects on the cardiovascular system through several mechanisms. Alpha receptors show decreased affinity to norepinephrine with subsequent reduced vascular contractility and hypotension.\textsuperscript{23–25} Additionally, baroreceptor function decreases as hypothermia ensues, resulting in an inability to increase blood pressure and heart rate in response to changes in volume during anesthesia.\textsuperscript{26} Myocardial function can be affected by hypothermia. As body temperature decreases, blood viscosity increases and pH decreases, affecting contracting ability of cardiac myocytes. As the temperature continues to decrease, arrhythmias can develop including ventricular fibrillation.\textsuperscript{27,28} The respiratory system is also affected by hypothermia and is clinically characterized by decreased respiratory rate, minute ventilation, and tidal volume, with an increased risk of injury, including pulmonary edema, pneumonia, and acute respiratory distress syndrome.\textsuperscript{29,30}

Delayed recovery from anesthesia is a well-known consequence of hypothermia due to decreased central nervous system function; however, hypothermia causes other disturbances in the brain. Cerebral autoregulation is the ability of the brain to regulate blood flow in the face of changes in systemic blood pressure. Hypothermia inhibits the ability of the brain to maintain cerebral blood flow.\textsuperscript{31,32}

The immune response and the ability of tissue to heal are also affected by hypothermia. Immunosuppression occurs through inhibition of leukocyte migration, phagocytosis, and decreased synthesis of cytokines.\textsuperscript{33} Wound healing is delayed in hypothermia due to decreased inflammatory infiltrates, reduced growth factor production, and less collagen deposition.\textsuperscript{34} Hypothermia can even enhance the ability of cancer cells to proliferate.\textsuperscript{35}

The clotting system can be profoundly affected by hypothermia. Several processes in the coagulation cascade are impaired by decreased body temperature. Platelet function is affected through decreased aggregation, prothrombin and activated partial thromboplastin clotting times are prolonged, and fibrinolysis can be either accelerated or impaired.\textsuperscript{19,30}

**INDICATIONS FOR TECHNIQUES TO MINIMIZE HYPOTHERMIA**

Using techniques for reducing IPH can improve patient care and reduce side effects associated with hypothermia. The decision on when to use a specific technique depends on the length of the anesthetic event, the procedure, and the patient’s condition. In canine patients, techniques to minimize heat loss should be used for anesthetic periods longer than 20 minutes,\textsuperscript{36} and may be even more important in feline patients because of their generally smaller size. Additionally, heat loss minimization can be expected to be beneficial in very young, old, or severely ill animals, or those having major surgical or diagnostic procedures. It is also important to remember the IPH carries over into the recovery period: Continued warming therapy after anesthesia and surgery should be part of a standard anesthetic care protocol.

**TECHNIQUES AND MECHANISMS OF HEAT CONSERVATION**

Techniques for minimizing heat loss in anesthetized patients can be categorized as passive, active, or metabolic. Passive techniques use materials to cover the patient to prevent endogenous heat loss. Passive techniques tend to be minimally effective.\textsuperscript{36} Active techniques generate supplemental heat that is externally applied to the patient. Metabolic techniques induce the body to produce increased amounts of endogenous
heat through manipulation of metabolism. In veterinary medicine, passive and active techniques are most commonly used.

**Passive Techniques**

Passive techniques include the use of materials such as cotton towels, newspapers, plastic bubble wrap, and reflective blankets.\(^{36,37}\) Passive techniques reduce heat loss by counteracting convective and conductive heat loss. They function as an insulator and trap body heat next to the patient. Thus, material that is less permeable to heat, such as plastic or metallic fabrics that reflect heat back to the patient, may be more effective than materials that are more porous. Passive techniques are not nearly as effective as active techniques.

**Active Techniques**

Active techniques for heat conservation work through application of heat to the patient to reduce the gradient between the body and the environmental temperatures. Electric heating blankets, heat lamps, intravenous fluid warmers, warmed abdominal lavage fluids, circulating warm water pads, resistive polymer electric blankets, and forced warm air blankets are examples of active techniques.\(^{36,38–43}\) Intravenous fluid warmers appear to have minimal efficacy for combating hypothermia and must be placed on the intravenous fluid line as close to the patient catheter as possible. The use of warmed abdominal lavage solution over room temperature solution in patients undergoing celiotomy can increase the temperature of patients during anesthesia. **Lavage solutions** should be heated to 43°C and instilled into the abdomen for at least 2 to 6 minutes. Forced warm air blankets seem to be the most efficacious of all the active methods for thermal management in dogs and cats.\(^{36,43}\) Resistive polymer electric blankets have been demonstrated to be both equally and less effective compared with forced warm air blankets.\(^{44,45}\) Forced warm air blankets can be placed over or under a patient with the direction of the air flow toward the patient. Circulating warm water pads and resistive polymer electric blankets can be placed over or under a patient as well; in addition, because of their flexibility, they can be wrapped around the patient. However, there are drawbacks and limitations to the use of this type of equipment. Blankets and patient coverings can interfere with a surgical field and may have to be positioned on the patient in such a way that it limits the effectiveness. Applying supplemental heating units to the limbs is an effective way to provide heat and maintain access to surgical sites in the abdomen and thorax.\(^{39}\) **Forced warm air units may increase the chance of surgical site infection.**\(^{46,47}\) This is thought to occur through the intake of nonfiltered air or the buildup and emission of microbial contaminants into a surgical field. Equipment that contains ferrous metal is not compatible with certain types of imaging techniques, such as MRI.\(^{48}\) Additionally, techniques that use blankets or material that covers the patient can interfere with image acquisition and quality of standard radiography, ultrasonography, or computed tomography. Other limitations include cost of purchase, maintenance, replacement of blankets for forced warm air units or circulating warm water pads, inability to easily transport the equipment, and the need for nearby electrical outlets.

**Metabolic Techniques**

Metabolic techniques for hypothermia are unique in that they induce the body to produce more heat and thus keep itself warmer in the face of a cooling environment. A metabolic technique that has shown the most promise is the intravenous infusion of amino acids to patients undergoing anesthesia. The mechanism by which this increases body heat production is through stimulation of insulin release, which in turn
leads to protein synthesis, predominantly in skeletal muscle. Amino acids increase the sensitivity and activity of muscle to the anabolic, muscle-protein synthesis effects of insulin. During muscle-protein synthesis, heat is generated as a by-product and accumulates within the body. The increase in heat production through this mechanism is magnified when an exogenous source of amino acids is administered. Although this technique is not yet recommended for use in a veterinary clinical setting, studies in humans and dogs have demonstrated safety and effectiveness.

COMPLICATIONS

Complications associated with using techniques to reduce the severity of IPH are usually associated with the specific technique. Patient skin burns are one of the more severe complications and have been associated with heat lamps or defective or inappropriately operated active technique equipment. Because of the higher risk of burns with heat lamps, they are no longer recommended for use in hypothermic patients. Surgical wound infection can occur with dirty equipment and towels. Infection has been associated with the use of forced warm air blankets that are placed near the surgical field as a result of particles being blown into the surgical field. This can be avoided with proper placement of the blanket and isolation of the surgical field. Reusable blankets should be cleaned between patients and single-use blankets should be disposed of after use on a single patient to prevent nosocomial infections. Circulating warm water pads can leak and harbor infectious agents in the water tanks and should be thoroughly cleaned based on the manufacturer’s recommendations.

SUMMARY

IPH is one of the most common complications associated with general anesthesia of dogs and cats. The body’s ability to maintain normal temperatures is reduced due to the interactions of anesthetic and analgesic drugs as well as cooling conditions of the perioperative environment. If left untreated, hypothermia can have deleterious effects, including altered pharmacokinetics of anesthetic and analgesic drugs, dysfunction of organ systems, increased patient susceptibility to infection, reduced wound healing, altered coagulation, hypotension, and delayed recovery. Passive and active techniques can be applied to the patient to improve temperature status. Active techniques that apply supplemental heat to the body appear to be most effective.

REFERENCES


