

Continuing Medical Education Article—Patient Safety

Prevention of Perioperative Hypothermia in Plastic Surgery

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This article was commissioned by the Patient Safety Steering Committee of the American Society for Aesthetic Plastic Surgery (ASAPS) to cover the important but underappreciated topic of hypothermia. As part of its mission, this committee is continuing a series of campaigns and projects focusing on specific patient safety topics in aesthetic surgery. These campaigns are designed not only to educate ASAPS members, but also to involve related organizations so that nurses, office staff, and our other partners in patient care can work together with us to create an integrated Culture of Safety. The committee's first campaign focused on the prevention of venous thromboembolism. Future campaigns will cover such important patient safety topics as the management and prevention of postoperative nausea and vomiting, perioperative management of the patient with obstructive sleep apnea, perioperative glucose control, and prevention of surgical site infections, among others.

ASAPS' commitment to patient safety is represented by the "Culture of Safety" symbol shown above. The triangle represents both safety and the Aesthetic Society, the orange color is a universally recognized signal for "caution" and "safety," and the word "culture" reflects our belief that patient safety is an ongoing concern that must permeate every level of care provided by the aesthetic surgery team.

Beginning on January 1, 2005, ASAPS and the American Society of Plastic Surgeons (ASPS) instituted a Patient Safety CME requirement of 20 credits for their members, to be fulfilled over a 3-year cycle. One Patient Safety CME credit can be obtained by completing the examination that follows this article.

Learning Objectives

The reader is presumed to have a broad understanding of plastic surgical procedures and concepts. After studying this article, the participant should be able to:

1. Explain how and why hypothermia develops in the perioperative environment.
2. Describe the potential complications and consequences that may be induced by perioperative hypothermia.
3. Evaluate the various approaches for preventing perioperative hypothermia and know which ones are most effective.

Physicians may earn 1 AMA PRA Category 1 credit™ by successfully completing the examination based on material covered in this article. The examination begins on page 572. ASAPS members can also complete this CME examination online by logging onto the ASAPS Members-Only Web site at <http://www.surgery.org/members> and clicking on "Clinical Education" in the menu bar.

While inadvertent perioperative hypothermia has received serious attention in many surgical specialties, few discussions of hypothermia have been published in the plastic surgery literature. This article reviews the physiology of thermoregulation, describes how both general and regional anesthesia alter the normal thermoregulatory mechanisms, indicates risk factors particularly associated with hypothermia, and discusses the most effective current methods for maintaining normothermia.

Hypothermia is typically defined as a core body temperature of $\leq 36^{\circ}\text{C}$ ($\leq 96.8^{\circ}\text{F}$), though patient outcomes are reportedly better when a temperature of $\geq 36.5^{\circ}\text{C}$ is maintained. Unless preventive measures are instituted, inadvertent hypothermia occurs in 50% to 90% of surgical patients, even those undergoing relatively short procedures lasting one to one-and-a-half hours. During either general or regional anesthesia, a patient's natural behavioral and autonomic responses to cold are unavailable or impaired, and the combination of general and neuraxial anesthesia produces the highest risk for inadvertent perioperative hypothermia. Unless hypothermia is prevented, the restoration of normothermia can take more than 4 hours once anesthesia is stopped.

Consequences of hypothermia are serious and affect surgical outcomes in plastic surgery patients. Potential complications include morbid cardiac events, coagulation disorders and blood loss, increased incidence of surgical wound infection, postoperative shivering, longer hospital stays, and increased costs associated with surgery.

Measures for preventing hypothermia are emphasized in this article, especially those proven most effective in prospective and controlled clinical studies. Perhaps the most important step in maintaining normothermia is to pre-warm patients in the preoperative area with forced-air heating systems. Intraoperative warming with forced-air and fluid warming are also essential. Other strategies include maintaining an ambient operating room temperature of approximately 73°F (22.8°C), covering as much of the body surface as possible, and aggressively treating postoperative shivering. None of these measures can be adequately employed unless a patient's core body temperature is monitored throughout the perioperative period.

Prevention of perioperative hypothermia is neither difficult nor expensive. Proper preventive measures can reduce the risk of complications and adverse outcomes, and eliminate hours of needless pain and misery for our patients. (Aesthetic Surg J 2006;26:551–571.)

Inadvertent perioperative hypothermia has received serious attention in many surgical specialties because it can lead to complications, slower recovery, and poorer outcomes. The growing awareness of the importance of hypothermia as a patient safety concern has produced a sharp rise in the number of clinical studies published during the last decade that focused on defining its consequences in surgical patients and identifying the most effective strategies for its prevention. Scores of prospective, randomized, and controlled studies all came to similar conclusions: what happens to the body as its core temperature drops is *not* benign. Furthermore, a little effort on the part of surgeons and operating room (OR) staff can prevent hypothermia from developing or at least minimize its effects.

As part of the ongoing American Society for Aesthetic Plastic Surgery (ASAPS) campaign to improve patient safety in plastic surgery, this article explains why hypothermia should never occur in our patients. Current methods of hypothermia prevention are discussed, and those proven to be most effective receive emphasis. Warming strategies include *passive* measures, such as using blankets or drapes, and raising the ambient temperature, and *active* methods, such as forced-air warming, resistive-heating blankets, fluid warming systems, and amino acid infusion. To understand the effectiveness of these techniques, one must first understand why hypothermia so frequently develops in a surgical

setting. Thus, the article first describes normal thermoregulatory mechanisms, how these mechanisms are impaired by both general and regional anesthesia, particular risk factors associated with hypothermia, and its many adverse consequences.

Inadvertent perioperative hypothermia occurs in 50% to 90% of all surgical patients unless active warming measures are employed.^{1,2} These figures are not hard to accept when considering the classic signs of hypothermia: shivering, piloerection, and peripheral vasoconstriction (indicated by cold extremities). Think of the number of patients encountered in a postanesthetic care unit (PACU) with these symptoms and a sense of the scope of perioperative hypothermia becomes clear. Any plastic surgeon who has had a patient who shivered in the surgical recovery area has had a hypothermic patient.

Complaints of feeling cold and/or shivering are common among surgical patients who may be hypothermic before surgery in the preoperative area where the ambient temperature is typically low and patients have been fasting for many hours, which depletes metabolism of heat energy that comes from digestion.³ Large numbers of patients say that feeling cold was the worst part of their surgical experience, and they tend to rate it higher than postoperative pain as a source of discomfort. This alone is reason enough to closely monitor patients' core temperatures and maintain normothermia throughout the perioperative period.

Hypothermia in the Plastic Surgery Literature

In a survey that asked clinical and research anesthesiologists to rank risk factors for developing perioperative hypothermia, plastic surgery with large exposed body areas was ranked 11 out of 40 items on the list.⁴ The need to maintain normothermia as a means of improving patient safety has barely begun to register in the plastic surgery literature. Most clinical studies and reviews of perioperative hypothermia are reported in the anesthesia literature and are understandably unfamiliar to most plastic surgeons unless they are actively searching out this information. In fact, a PubMed and plastic surgery-specific journal search for articles that contained at least one paragraph on hypothermia found only 7 articles published since 2001, most of which dealt with lipoplasty.⁵⁻¹¹ None of the articles included a comprehensive discussion of the issue, and some of the information they contained is incorrect and perhaps even dangerous. Although hypothermia discussions in the plastic surgery literature have been woefully inadequate, we can be encouraged by the fact that at least the subject is beginning to receive some attention.

What Is Hypothermia?

Different sources have given somewhat different definitions of mild hypothermia, but leading researchers in the field typically cite a core body temperature of $\leq 36^{\circ}\text{C}$ ($\leq 96.8^{\circ}\text{F}$) as hypothermia.¹²⁻¹⁸ Technically, hypothermia begins where normothermia ends, and normothermia ranges between $\geq 36.5^{\circ}\text{C}$ and $\leq 37.5^{\circ}\text{C}$ (97.7°F to 99.6°F), with an average of 37°C or 98.6°F .¹⁹ This range exists because body temperature has a natural diurnal variation, with core temperature being lower in the morning and higher in the late afternoon/evening.¹ Based on this information, the most precise definition of hypothermia is a core temperature of 36.4°C or below. At this temperature, cellular, tissue, and organ dysfunction may begin to develop.¹⁹

Most clinical studies of hypothermia have focused on a core temperature of 36°C as the dividing line between normo- and hypothermia. Mild hypothermia, which is most likely to develop during surgery, ranges between 33°C or 34°C ¹²⁻¹⁷ and 36°C . Severe hypothermia is a core temperature $\leq 28^{\circ}\text{C}$, with spontaneous ventricular fibrillation starting at about 25°C and cardiac stand-still occurring at 21°C .²⁰ Plastic surgeons are unlikely to encounter severe hypothermia, which is most often associated with prolonged environmental exposure or severe trauma. The need to induce therapeutic hypothermia,

which can play a valuable role in cardiac surgery, neurosurgery, and transplantation,²⁰ also is not a scenario typically faced by our specialty.

The Physiology of Thermoregulation

Human beings, like other mammals, are designed to maintain a constant body temperature regardless of their surroundings. Body heat content is controlled through behavioral and autonomic means.^{15,19} For humans, behavioral responses are most sensitive to skin surface temperature and result in actions such as raising or lowering the ambient temperature or adding or removing layers of clothing. Autonomic responses are governed by input from multiple systems, including the skin surface, deep cavity tissues and organs, the spinal cord, the hypothalamus, and other portions of the brain. When body temperature becomes too low, a physiologic response is triggered to prevent heat loss through vasoconstriction and to increase heat production through shivering, which can raise the metabolic rate by two to three times its normal value.^{1,21} When body temperature becomes too high, the physiologic response is to promote heat loss through vasodilation and sweating.

The hypothalamus is the primary thermoregulatory control center in mammals. Behavioral responses to temperature changes are controlled in the posterior hypothalamus, and autonomic responses are controlled in the anterior (preoptic) portion of the hypothalamus.¹⁵ Autonomic responses to heat and cold are primarily determined by thermal input to the hypothalamus from the core, which consists of the viscera, the central nervous system, and the great vessels.¹ The core comprises about half the body's mass; the other half is a peripheral thermal buffer that interacts with the environment and maintains a constant temperature for the core's vital organs. The tissues and processes of the core organs generate much more metabolic heat than do the resting muscles of the periphery.¹⁶

For our purposes, two terms are important for understanding how thermoregulatory processes work: *threshold*, and *interthreshold range* (also called the set point).^{1,15,18,19} The *threshold* is the core temperature that triggers a thermoregulatory response to heat (sweating) or cold (shivering). The *interthreshold range* is the narrow range, $\approx 0.2^{\circ}\text{C}$, at which the core temperature does *not* trigger an autonomic thermoregulatory response. When the core temperature either rises or falls outside the interthreshold range or set point, thermoregulatory mechanisms activate either sympathetic vasodilation to get rid of heat or vasoconstriction to

conserve heat. Neither option is available during general anesthesia.

Typically, the peripheral tissues are 2°C to 4°C cooler than the core; the difference between these two thermal compartments is the *temperature gradient*. This gradient is maintained by tonic vasoconstriction of the arteriovenous shunts of the fingers and toes.¹⁶ Metabolic heat is constrained to the core by vasoconstriction; in contrast, vasodilation permits heat to flow from the core to the periphery. According to the Second Law of Thermodynamics, heat can only flow down a temperature gradient, not up.¹⁶ Thus, heat in the periphery cannot be moved or transferred to the core.

Hypothermia and Anesthesia

Inadvertent hypothermia is so prevalent during surgery because the interthreshold range widens when anesthesia is induced. With general anesthesia, this range increases from $\approx 0.2^\circ\text{C}$ to $\approx 4.0^\circ\text{C}$ —a 20-fold increase. During regional anesthesia, there is a 3- to 4-fold increase in the interthreshold range.^{15,18} This expanded range means that the normal thermoregulatory response of vasoconstriction—which is the major means by which the body tries to conserve heat—is essentially disabled, so that the body's defenses for warming the core are not triggered. Furthermore, behavioral mechanisms for temperature control are not available during anesthesia.

The correlation between anesthesia and hypothermia does not primarily come from the cold environment and minimal covering. When healthy volunteers wearing minimal or no clothes are placed in a cold (20°C) OR, they will maintain a normal core temperature if they do not receive anesthesia.^{1,18} Although a cold room contributes to hypothermia, it is not the root cause. Instead, the major role is played by the inhibition of thermoregulatory defenses during anesthesia.

Three phases of hypothermia development with general anesthesia

Different intravenous and inhaled anesthesia agents have somewhat different effects on thermoregulation, but all of them impair autonomic responses to cold and heat.^{1,18,19} Research has identified three phases of hypothermia progression during general anesthesia: (1) core-to-peripheral heat redistribution, (2) linear core temperature decline, and (3) core temperature plateau (Figure 1). To implement the correct protocols for preventing perioperative hypothermia, all three phases must be understood.

Phase 1: Core-to-peripheral heat redistribution. The first phase of hypothermia development is generally confined to the first hour of anesthesia, during which time the core temperature drops 1°C to 1.5°C unless patients are actively warmed. Assuming that a patient begins surgery with a core temperature of 37°C, that patient is then likely to be hypothermic ($\leq 36^\circ\text{C}$) 60 minutes after anesthesia induction. During this phase, metabolic heat production is reduced by 20% to 40%.^{16,18,22} At the same time, some cutaneous heat loss occurs that is attributable to factors such as a low ambient temperature, cool antiseptic prepping solutions, or unwarmed fluids, although this heat loss probably accounts for only about 5% of the total during Phase 1. Mean body temperature and body heat content remain essentially constant in this first hour.^{16,19}

The rapid decline in core temperature during Phase 1 takes place because anesthesia stimulates peripheral vasodilation. At the same time, when the interthreshold range widens from $\approx 0.2^\circ\text{C}$ to $\approx 4^\circ\text{C}$, vasoconstriction becomes unavailable.¹⁶ When the thermoregulatory shunts become vasodilated, the heat that is normally confined to the core thermal compartment is redistributed to the periphery.¹ As the interthreshold range widens with the induction of anesthesia, the temperature gradient between the core and the periphery extends beyond the normal 2°C to 4°C difference. The natural response is to compensate by transferring heat down the temperature gradient. As the distal extremity temperature rises, the core temperature falls. This core-to-peripheral heat redistribution accounts for $\sim 80\%$ of the decline in core temperature during the first hour of anesthesia in adults. Infants and children experience little heat redistribution because their small extremities make them primarily “core.”

Warming techniques for Phase 1. Heat redistribution can be eliminated or minimized by warming patients for about 1 hour prior to their arrival in the operating room. Prewarming techniques do not change the heat content of the core; instead, they add heat to the periphery. Since the peripheral tissues are normally 2°C to 4°C cooler than the core, enhancing the heat content of the periphery nearly equalizes the core and peripheral temperatures, thereby decreasing the temperature gradient between the two thermal compartments. Thus, heat does not flow out of the core and down the temperature gradient. Prewarming patients before surgery is especially important for thinner patients, who become hypothermic more quickly than those with more body fat. Active warming with forced air or a resistive-heating blanket

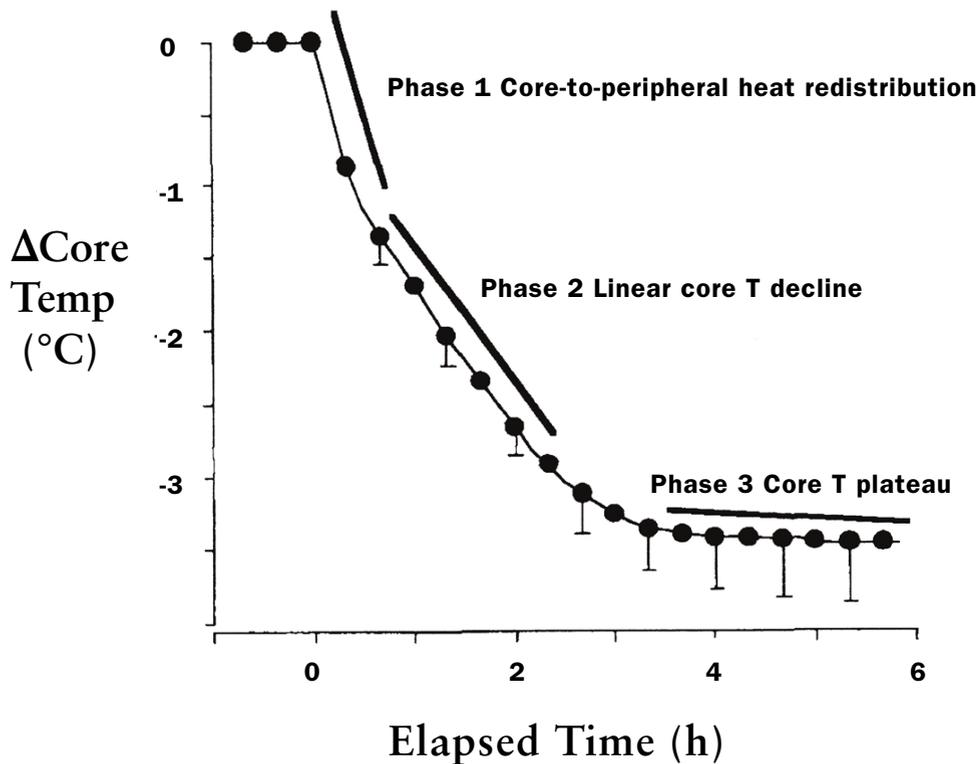


Figure 1. The hypothermia curve that is typical during general anesthesia unless patients are actively warmed. During the first hour (Phase 1) the core temperature decreases 1°C to 1.5°C as heat from the core is redistributed to the periphery. Thus, patients are likely to be hypothermic after 1 hour ($\leq 36^\circ\text{C}$). In Phase 2, the core temperature continues a linear decline until it reaches Phase 3, when the body reaches a temperature plateau as vasoconstriction is triggered. By this phase, hypothermia is a significant problem. From Sessler,¹⁶ with permission.

should be restarted as soon as possible in the OR and continued for the duration of surgery in most cases.

Phase 2: Linear core temperature decline. The second phase of hypothermia develops between hours 1 and 3 of anesthesia, during which time the core temperature declines another degree or two. Core-to-peripheral heat redistribution is still occurring because of the anesthetic-induced vasodilation. However, core heat loss through redistribution contributes to only about 43% of the continuing core temperature decline in Phase 2, compared with the 80% of Phase 1.¹⁶ This linear phase of hypothermia is additionally characterized by the fact that heat loss is greater than metabolic heat production during anesthesia.

In this phase of the linear core temperature decline, continued core cooling is exacerbated by lower ambient temperatures, larger body area exposure, lengthier procedures, larger incisions, and the cool fluids used to irrigate them. Thus, plastic surgery patients most at risk are those undergoing procedures such as abdominoplasty, circumferential body lift, large-volume lipoplasty, and recon-

struction with flaps, among others. The key point is that long and large surgeries involve greater hypothermia risks.

Warming techniques for Phase 2. During Phase 2, passive insulation plus active warming measures, such as forced-air and fluid warmers, are most effective for countering continued core cooling. In this linear phase, body morphology is irrelevant, and both thin and obese patients will experience core temperature decline at about the same rate.^{13,18}

Phase 3: Core temperature plateau. The third phase of hypothermia develops after 2 to 4 hours of anesthesia. When the core temperature reaches 34° to 35°C , the linear decline slows and a kind of thermal steady-state, or plateau, emerges under general anesthesia.^{16,18} Body heat content will continue to decline, but a separation between the core and peripheral thermal compartments develops to retain the remaining metabolic heat in the core. At 34°C to 35°C , the patient is sufficiently hypothermic for autonomic responses to reemerge and trigger protective vasoconstriction. Constriction of the arteriovenous shunts in the fingers and toes is activated

at this time and can be quantified by subtracting the skin temperature of the fingertip from the skin temperature of the forearm to obtain the temperature difference.²³ When the difference exceeds 4°C, significant vasoconstriction is occurring. Over time, a normal core-to-peripheral temperature gradient is reestablished as vasoconstriction reduces cutaneous heat loss from the extremities.¹⁸ However, vasoconstriction cannot transfer heat from the periphery to the core because heat cannot flow up the temperature gradient.

Warming techniques for Phase 3. When patients reach the temperature required to trigger vasoconstriction in the plateau phase, maintaining normothermia is no longer an option. The only option is to recover from hypothermia. It is much easier to prevent loss of heat than to regain it during anesthesia, and both active and passive warming methods are much less effective in Phase 3. To maintain normothermia, warming must begin before and continue throughout surgery.

Regional anesthesia and hypothermia

The use of regional anesthesia in plastic surgery is not unusual in lower body procedures. Unfortunately, hypothermia is often unrecognized in patients receiving neuraxial anesthesia (spinal or epidural) because the core temperature is not routinely monitored. In addition, patients do not feel cold and rarely shiver. However, hypothermia is nearly as prevalent in patients receiving neuraxial anesthesia as in those receiving general anesthesia. Consequently, monitoring core temperature and implementing warming measures to prevent hypothermia are just as important for these patients.

The interthreshold range widens significantly (three to four times normal value) during administration of regional anesthesia.^{15,24} Some studies have determined that the typical decrease in core temperature resulting from regional anesthesia is slightly less than that found with general anesthesia, and is in the range of $\approx 0.8^\circ\text{C} \pm 0.3^\circ\text{C}$ during the first hour of surgery and $\approx 1.2^\circ\text{C} \pm 0.3^\circ\text{C}$ over 3 hours.¹⁶ Other studies comparing patients receiving regional or general anesthesia found no real differences between the two groups. For example, patients who underwent radical prostatectomy that lasted an average of 100 minutes all received intraoperative blankets and warmed fluids. The mean core temperature for the regional anesthesia group was $35.0^\circ\text{C} \pm 0.1^\circ\text{C}$ versus $35.2^\circ\text{C} \pm 0.1^\circ\text{C}$ for the general anesthesia group.²⁵ Thus, both groups were comparably hypothermic.

Regional anesthesia inhibits central thermoregulatory control in much the same way as general anesthesia. In

addition, the peripheral sympathetic and motor nerves are blocked as nerve conduction is disrupted to more than half the body.¹⁵ With no thermal information from the lower extremities reaching the hypothalamus, the normal activation of regional defenses against cold—such as vasoconstriction and shivering—are impaired.

In both types of anesthesia, the Phase 1 core-to-peripheral heat redistribution occurs during the first hour of surgery, followed by the Phase 2 linear decline of core temperature during hours 2 and 3. However, without the ability to vasoconstrict in the lower extremities, the Phase 3 core temperature plateau cannot be reached under regional anesthesia, and the linear decline in core temperature progresses without reemergence of thermoregulatory defenses.^{16,18} Heat loss may even accelerate, possibly due to a combination of impaired vasoconstriction and lower limb vasodilation.¹⁹ Thus, hypothermia can become even more serious with neuraxial anesthesia, especially during lengthy surgery.

With regional anesthesia, the body does retain some ability to regulate temperature above the block, but the level of spinal blockade is important. One study found that the higher the block, the greater the core temperature decline: for each additional dermatome level, the core temperature decreased an additional 0.15°C .²⁶ Other findings included the fact that within 45 minutes after a spinal blockade was administered, the mean drop in core temperature was $>1^\circ\text{C}$. By the end of surgery, the mean core temperature was 1.5°C below baseline, and the mean temperature upon admission to the PACU was $35.1^\circ\text{C} \pm 0.6^\circ\text{C}$. Patients in this study received warmed fluids and passive warming with a drape or blanket, but no prewarming or active intraoperative warming was used. The result was hypothermia in almost all patients receiving spinal blockade.

Another study of neuraxial anesthesia examined patient temperatures on their arrival in recovery.²⁷ The types of surgery were wide ranging (arthroscopy, cystoscopy, lumbar decompression, knee and hip arthroplasty, and major vascular surgery). Seventy-seven percent of patients were hypothermic when they reached the PACU ($<36^\circ\text{C}$), and 22% had a core temperature $<35^\circ\text{C}$. Active warming measures were used in only 31% of the patients, and only 27% had any temperature monitoring—and only for the upper body skin. The authors concluded that hypothermia is very common in patients receiving neuraxial anesthesia, but it goes undetected because of the absence of monitoring and a lack of suspicion or knowledge about hypothermia.

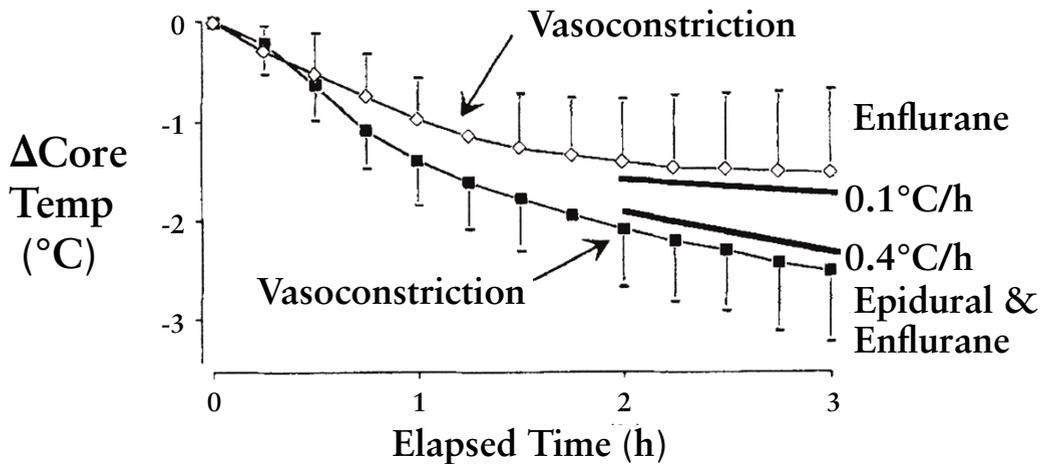


Figure 2. This graph illustrates what happens to core body temperature when the thermoregulatory effects of neuraxial anesthesia are superimposed on top of general anesthesia. Top line, general anesthesia alone; bottom line, combined anesthesia. In this controlled study, the general-only group had reached the core temperature plateau phase after two hours of anesthesia, while the general + regional group continued the Phase 2 core temperature decline. Vasoconstriction is triggered later with spinal anesthesia, in this instance approximately one hour later than with general anesthesia. From Sessler,¹⁶ with permission.

Attempts to maintain normothermia are just as important for regional anesthesia as for general anesthesia. The same is true for the need to monitor core temperature. Active warming with forced air prior to and during surgery should become standard practice for neuraxial anesthesia. Furthermore, prewarming the lower extremities to $\approx 38^{\circ}\text{C}$ is recommended as the best way to eliminate or minimize the core-to-peripheral heat redistribution that occurs during the first hour of surgery.¹⁸ If the core temperature then starts to decline in the second hour, the patient will be starting from a more normothermic level; consequently, the degree of hypothermia will be less serious.

Combined general and neuraxial anesthesia

The combination of general and spinal anesthesia produces the greatest risk for inadvertent perioperative hypothermia.⁴ Numerous plastic surgery journal articles have reported on epidurals being used in conjunction with general anesthesia, primarily for the purpose of postoperative pain relief in patients undergoing circumferential body lift, abdominoplasty, lipoplasty, and gluteal augmentation. According to the hypothermia literature, this practice is not recommended.

When both types of anesthesia are used, the regional effects are superimposed over and above all the thermoregulatory effects of general anesthesia (Figure 2).¹⁶ In addition, vasoconstriction in the legs is blocked, and the vasoconstriction threshold is lowered by $\approx 1^{\circ}\text{C}$ compared to patients who receive general anesthesia only.

The arteriovenous shunt vasoconstriction that is necessary for recovering from hypothermia occurs nearly one hour later and at a lower core temperature in patients who receive both types of anesthesia. Furthermore, because the Phase 3 core temperature plateau is impaired by an epidural, patients receiving combined anesthesia continue to experience a core temperature decline at a rate of $0.4^{\circ}\text{C}/\text{hour}$.²⁸ The result is that the amount of core cooling is significantly greater in patients receiving combined anesthesia.

Local anesthesia and sedatives

Local anesthesia does not interact with the temperature control centers of the hypothalamus, so it does not produce thermoregulatory effects.¹⁹ However, sedatives do impair thermoregulation.^{16,18} The degree of the effects, however, is not clear. For example, it has been reported that intramuscular injection of midazolam (Versed) within 30 minutes of surgery produces a dose-dependent decrease in core temperature of 0.3°C to 0.6°C , regardless of whether general anesthesia is induced.²⁹ This study of volunteers concluded that midazolam contributed to core-to-peripheral heat redistribution.

Another study investigated administration of intramuscular midazolam at a dose of either $0.04\text{ mg}/\text{kg}^{-1}$ or $0.08\text{ mg}/\text{kg}^{-1}$, or no premedication. All three groups had a significant decline in core temperatures.³⁰ However, those who received no premedication had a more significant drop than did those receiving midazolam 30 minutes prior to surgery. A comparison of the two

midazolam groups found that the higher dosage correlated with a larger decline in core body temperature during surgery, as well as a lower core temperature at the time of anesthesia induction. These results are comparable to a similar study of droperidol.³¹ More research is needed on the impact sedatives have on perioperative hypothermia, but the message thus far suggests that mild sedation is preferable to deep sedation.

Return to normothermia after anesthesia

Concentrations of volatile anesthetics in the brain decrease rapidly after anesthesia is stopped, at which time the protective thermoregulatory responses begin to reemerge. However, restoration of normothermia may take more than 4 hours.^{1,16} For example, patients undergoing colon surgery and allowed to become hypothermic (mean final intraoperative core temperature of $34.4^{\circ}\text{C} \pm 0.4^{\circ}\text{C}$) regained normothermia at a rate of $\approx 0.5^{\circ}\text{C}/\text{h}$ during the first three postoperative hours and $0.3^{\circ}\text{C}/\text{h}$ for the subsequent two hours.³² The core-to-peripheral temperature gradient exceeded 4°C for more than 3 postoperative hours, even though hypothermic patients have significant vasoconstriction.

Evidence regarding the return to normothermia following neuraxial anesthesia is contradictory. One study determined that patients receiving spinal blockade rewarmed more quickly after surgery than did patients who had general anesthesia: $1.2^{\circ}\text{C} \pm 0.1^{\circ}\text{C}/\text{h}$ versus $0.7^{\circ}\text{C} \pm 0.2^{\circ}\text{C}/\text{h}$, respectively.³³ Another comparison study of spinal versus general anesthesia patients concluded that the spinal group remained hypothermic ($<36^{\circ}\text{C}$) significantly longer than the general anesthesia group, with 62% of the spinal patients still being hypothermic after 2 hours, compared to 44% of general anesthesia patients.²⁵

The shivering so often seen in a PACU is almost always preceded by core hypothermia and peripheral vasoconstriction. The many hours of hypothermia that follow surgery are very uncomfortable hours for patients. The integration of simple and inexpensive methods available to maintain normothermia can prevent many hours of misery for patients.

Temperature Monitoring

The most accurate measurements of core temperature come from the pulmonary artery, tympanic membrane, nasopharynx, and distal esophagus.⁴ The pulmonary artery may be the most accurate, but it is not a practical location. Research studies of hypothermia use the tympanic membrane as the “gold standard” of measurement

because of its convenience, noninvasiveness, and close proximity to the blood vessels that perfuse the hypothalamus. During general anesthesia, core temperature is frequently measured at the distal esophagus with the probe inserted at the time of intubation.

Measurements obtained from noncore sites, such as the bladder, rectum, axilla, skin, or mouth, correlate poorly with core temperature, although the core temperature can be reasonably well estimated from these sites if one understands the typical differences between noncore and core readings.³⁴ In addition, the rectum is a good location for obtaining measurements during neuraxial anesthesia,¹⁴ although rectal and bladder temperatures tend to lag behind (are higher than) core temperature. The skin, axilla, and mouth are the least accurate measurement sites and produce readings lower than the core.

Two types of tympanic membrane thermometers are available. The type used in research (and many ORs) consists of disposable aural probes with thermocouples at the tips. Proper positioning requires the patient to be awake as the probes are inserted until the patient feels the thermocouple touch the tympanic membrane and detects a gentle rubbing of the attached wire.¹⁴ The ear canal is then occluded with cotton, the probe secured with tape, and the ear covered with a bandage. The second type of tympanic membrane thermometer uses infrared technology to measure infrared radiation from the tympanic membrane and ear canal.¹⁴ Infrared thermometers are convenient, noninvasive, clean, fast, inexpensive, and commonly available in preoperative and postoperative areas. Although the accuracy of these devices seems to be inferior to thermocouple probes, it improves if the thermometers are used properly. For both types of tympanic membrane thermometers, accuracy is higher if both ears are measured and the readings are averaged.¹⁴

The type of thermometer used by plastic surgeons tends to depend on what is available in their surgical facilities. Any device known to be accurate for measuring core temperature is fine. Preoperative and postoperative measurements are typically done with infrared tympanic thermometers, and they can be trusted if used according to the manufacturer's guidelines. The most important point is to regularly measure core temperature before, during, and after surgery as part of the routine for maintaining normothermia.

One other caution about measurements is necessary. Even mild hypothermia can lengthen the response time—from 130 to 215 seconds—of pulse oximeters used on fingers.³⁵ Oximeters placed on the forehead or ear are not affected by hypothermia.

Risk Factors for Perioperative Hypothermia

As mentioned earlier, plastic surgery that involves large exposed areas is in itself a risk factor for perioperative hypothermia, ranking 11 out of 40 items in a survey that asked anesthesiologists to rate the degree of risk for a variety of surgical factors.⁴ Many other highly ranked risk factors on the list are also regularly encountered by plastic surgeons. We are not likely to perform surgery on neonates (the number 1 risk factor) but number 5 was surgery on patients older than 65. It is not unusual for plastic surgeons to operate on older patients, especially for facial procedures. Even though patients older than 65 do not seem “geriatric,” they are physiologically older with respect to the functioning of thermoregulatory mechanisms, and extra precautions are therefore needed.

Other hypothermia risk factors that were highly ranked include a low ambient OR temperature (ranked 2), burn injuries (3), the combination of general plus neuraxial anesthesia (4), a preoperative core temperature lower than 36.5°C (6), a thin body type (7), and blood loss >30 mL/kg (8).⁴ This list indicates that our typical patient population may be at high risk for the development of inadvertent perioperative hypothermia. Consequently, the need to be proactive in efforts to maintain normothermia should not be considered optional.

Thin patients are at greater risk for hypothermia development because body fat is a better insulator than muscle. Higher body fat content is especially protective during the first hour of anesthesia, when core-to-peripheral heat redistribution occurs. Research has determined that during this Phase 1 period, patients with 36% to 50% body fat were comparable to patients prewarmed with forced air and remained warmer throughout surgery than did patients in two other study groups: 10% to 24% or 25% to 35% body fat.¹³ After the first hour of surgery, patients in all three groups cooled at comparable rates. This study determined that thin patients tend to become hypothermic after about 30 minutes of anesthesia compared with obese patients, who were not hypothermic after one hour. However, the obese patients did become hypothermic after the first hour (during Phase 2), although their core temperature did not decline as much as thinner patients, who experienced a mean drop of approximately 2.7°C in core body temperature in the 150 minutes after anesthesia induction.¹³

This difference in core-to-peripheral heat redistribution reflects the fact that obese patients tend to remain in a state of vasodilation all the time as a way to shed excess metabolic heat. This does not mean that obese

patients do not need active warming measures in the perioperative period, because they do. However, the need for more aggressive warming, especially prewarming before surgery, is even more important for thinner patients.

Consequences of Inadvertent Perioperative Hypothermia

The adverse events associated with mild inadvertent perioperative hypothermia are numerous, the most serious of which include cardiac events^{15,36,37} and increased mortality.³⁸ Table 1 lists identified complications and consequences reported in the literature. Space prevents discussion of all these consequences, but results from studies of special concern to plastic surgeons are summarized below, since increased bleeding, wound infections, and postoperative shivering all can have adverse effects on patient outcomes. Some studies have investigated whether any benefits are associated with a supranormal core temperature of 38°C to 39°C, but none have been found.¹⁵ Hyperthermia is accompanied by numerous adverse events that are beyond the scope of this article.

Coagulation disorders and blood loss

Obtaining hemostasis is known to be more difficult in hypothermic surgical patients. Sessler¹⁷ summarized some of the reasons why. Although platelet numbers are normal in mildly hypothermic patients, platelet function is seriously impaired, as are enzymes of the coagulation cascade. The increase in bleeding times seen in association with hypothermia may result from delayed platelet activation (the initiator of wound healing), with the availability of platelet activators somehow reduced, since thrombin generation declines as blood temperature drops.^{12,39} Coagulation tests, including prothrombin time and partial thromboplastin times, tend to be normal in hypothermic patients, but these tests are typically performed at 37°C. When performed at the patient's core temperature, prothrombin and partial prothromboplastin times are prolonged.⁴⁰

According to Sessler,¹⁷ fibrinolytic activity is also negatively affected by hypothermia. The fibrinolytic system regulates clot formation by balancing hemostatic plug formation and blood flow restoration after a clot has formed. This fibrinolytic mechanism relies on the conversion of plasminogen to its activated enzymatic form, plasmin. Preliminary studies suggest that fibrinolysis is normal during hypothermia, with the coagulopathy induced by hypothermia caused by impaired clot formation rather than excessive clot degeneration.

Table 1. Consequences of mild inadvertent perioperative hypothermia

Morbid cardiac events, including incidences of ventricular tachycardia, are 3 times more likely at core temperature of $\leq 1.3^{\circ}\text{C}$ below normal ^{15,36}
Increased cardiovascular stress in young, healthy volunteers at core temperature of 36°C , indicated by 220% increase in plasma noradrenaline, 68% increase in adrenaline, 23% increase in cardiac output, 16% increase in heart rate, and 25% increase in rate-pressure product ³⁷
Increased blood viscosity and higher systematic vascular resistance ^{1,37}
Increased mortality of trauma patients at 24 h ³⁸
Increased incidence of surgical wound infections ^{44,48,49}
Delayed wound healing and decreased collagen synthesis ⁴⁴
Impaired tissue oxygen tension that is needed for healing and oxidative killing by neutrophils ⁴⁴
Increased intraoperative blood loss and requirements for transfusion of blood or blood products ⁴¹⁻⁴⁴
Reduced platelet function, delayed activation of the coagulation cascade, and decreased rate of clot formation ^{1,7,15,17,19,39,40}
Prolonged prothrombin and partial thromboplastin times ^{7,17,39,40}
Decreased synthesis of muscle protein ^{1,15,19}
Reduced generation of reactive oxygen species and neutrophil phagocytosis ⁴⁵
Delayed lymphocyte activation and cytokine production ⁴⁶
Negative nitrogen balance due to excess urinary excretion and reduced kidney perfusion ^{3,17}
Increased postoperative shivering and excessive sympathetic nervous system stimulation ^{21,32,50-52}
Decreased drug metabolism, including general anesthetics and muscle relaxants ^{1,15,19,54,55}
Longer duration of hospitalization ⁴⁴
Longer stay in PACU ⁵³⁻⁵⁶
Increased costs associated with surgery ⁵³

One recent prospective controlled study conducted by Cavallini et al⁷ examined whether hypothermia affected blood coagulation in plastic surgery patients undergoing breast augmentation or reduction, rhinoplasty, or lipoplasty. Thirty-eight patients were passively warmed with standard drapes (control group) and another 38 were actively warmed during surgery with forced-air and countercurrent fluid warming (treatment group). Mean surgery duration was >2 hours for both groups (148 minutes for controls and 154 minutes for the treatment group). The mean core temperature was $34^{\circ}\text{C} \pm 1.0^{\circ}\text{C}$ for the controls and $36^{\circ}\text{C} \pm 0.6^{\circ}\text{C}$ for the treatment group. Normothermic patients maintained normal coagulation function, but the controls had significantly longer activated partial thromboplastin times and bleeding times, which probably resulted from reduced function of platelet aggregation. Cavallini et al⁷ concluded that maintaining normothermia should reduce bleeding-related complications in plastic surgery.

Blood loss and hypothermia have been investigated in several studies of patients undergoing hip arthroplasty, which is typically a procedure involving significant intraoperative blood loss. A study by Schmied et al⁴¹ determined that a decrease in core temperature of 1.6°C increased blood loss by 30% and significantly increased the need for transfusion. Similar results were found in studies by Winkler et al⁴² and Widman et al.⁴³

The prospective, randomized study by Winkler et al⁴² is particularly interesting because it demonstrates the clear benefits of maintaining a core temperature higher than 36°C . Hip arthroplasty patients who were aggressively warmed to 36.5°C had significantly less intraoperative blood loss than those conventionally warmed to 36°C , with mean values of 488 mL and 618 mL, respectively. Patients in both groups received warmed intravenous fluids and active warming with upper- and lower-body forced-air heaters. The temperature of the warmers was adjusted to keep patients at the target tem-

peratures of 36°C or 36.5°C. Hematocrit values were significantly higher in the aggressive warming group, especially at the end of surgery, and their core and skin temperatures were significantly higher at 3 hours postoperatively. Among the conventionally warmed patients, 53% required blood transfusions (86 units), compared to 39% of the aggressively warmed patients (62 units).

Wound healing and infections

Perioperative hypothermia is known to impair multiple immune functions. As examples, natural-killer cell activity and cell-mediated antibody production are diminished by even mild hypothermia, as are superoxide anion production and macrophage motility.^{12,44-46} Wenisch et al⁴⁵ studied two groups, one actively warmed and one allowed to become hypothermic. They determined that the production of oxidative intermediates declined as core temperature declined. Specifically, the mean values for generation of reactive oxygen species were reduced by 56% and neutrophil phagocytosis by 72% at the lowest intraoperative core temperature of 33°C, which occurred 1 hour after anesthesia induction in a small number of patients allowed to become hypothermic. Neutrophil oxidative function is one of the most important defenses against bacteria most likely to cause surgical wound infections. In the Weinisch study,⁴⁵ normal neutrophil function returned when normothermia returned. Another investigation found that $\approx 1^\circ\text{C}$ core hypothermia during surgery suppressed activation of lymphocytes and reduced the production of cytokines for up to 2 postoperative days.⁴⁶

The decisive period for establishment of an infection is short, within a few hours of bacterial contamination.⁴⁷ When antibiotics are administered within just three hours of contamination, they can effectively eliminate most infections, but they are ineffective when given outside the decisive period. The correlation between hypothermia and infection may be related to the fact that surgical patients become hypothermic within this decisive period, because their natural mechanisms for fighting infection are weakened.

Mild perioperative hypothermia has been associated with an increased incidence of surgical wound infections in several prospective, randomized, and controlled clinical studies. Kurz et al⁴⁴ investigated 200 patients who underwent colorectal procedures that lasted approximately 3 hours, with half the group allowed to become hypothermic (mean core temperature of $34.7^\circ\text{C} \pm 0.6^\circ\text{C}$) and the other half kept normothermic with forced-air and fluid warming (mean core temperature of $36.6^\circ\text{C} \pm$

0.5°C). The core temperature difference between the two groups remained significant for >5 hours after surgery. The wound infection frequency in the hypothermic group was 19%, versus 6% in the normothermic group. All infections were culture positive, and ASEPIS scores (an indication of infection severity) were significantly higher in the hypothermia group. Many other statistically significant differences existed between the two groups. In the hypothermic patients, the need for blood transfusion was significantly higher; they experienced significantly more postoperative shivering and thermal discomfort; and collagen deposition at the wounds was much slower. The number of days to first eating solid food, suture removal, and discharge was significantly longer in the hypothermic patients, even if they did not have an infection.

Kurz et al⁴⁴ suggested that the vasoconstriction and impaired immunity associated with hypothermia might explain the increased frequency of infection. Thermoregulatory vasoconstriction decreased oxygen delivery and lowered the partial pressure of oxygen in tissues, which reduced resistance to bacteria and microbial killing ability. Intraoperative vasoconstriction was experienced by 74% of hypothermic patients, compared with 6% of normothermic patients. Because less tissue oxygen was available at the wound, oxidative killing by neutrophils was diminished. Oxygen depletion might also have decreased the strength of healing wounds and delayed scar formation, as indicated by the slower collagen deposition in the hypothermia group.

Other investigations support the findings of the Kurz study. Hypothermia was found to be a significant independent risk factor for surgical wound infection, with a relative risk of 6.3 among a group of cholecystectomy patients ($n = 261$).⁴⁸ The mean duration of surgery was approximately one hour in this study. No active warming measures were used, and 60% of patients were hypothermic when they reached the PACU (mean core temperature of $35.4^\circ\text{C} \pm 0.4^\circ\text{C}$). The difference in infection frequency was highly significant, with 11.5% of hypothermic patients developing a surgical infection versus 2% of normothermic patients.

Another randomized controlled study of the effects of prewarming on wound infection frequency by Melling et al⁴⁹ determined that 14% of patients who were not prewarmed developed infections, compared with only 5% of prewarmed patients. The 416 patients in this study underwent short (~ 50 minutes), "clean" surgeries (breast, varicose vein, or hernia surgery), and the mean postoperative core temperature for all patients was

36.4°C. Nevertheless, the prewarmed patients had significantly higher postoperative core temperatures.

Similar to the findings of Winkler et al,⁴² which demonstrated reduced blood loss when core temperatures were kept above 36.5°C, the Melling study⁴⁹ suggests that keeping patients above 36.5°C may lower the frequency of infections. Significantly fewer prewarmed patients received postoperative antibiotics (7% versus 16% of those not prewarmed) or were given preoperative prophylactic antibiotics (26% versus 34% not prewarmed). The significant difference in the surgical wound infection frequency seems related to the active prewarming measures undertaken, rather than to the use of antibiotics. Thus, the hour before surgery may be as important as the postoperative period for reducing infection risk. The authors of this report raised the intriguing question of whether prewarming surgical patients might be a replacement for the use of prophylactic antibiotics in short and clean surgeries.

Postoperative shivering

Postanesthetic shivering (PAS) occurs in 40% to 65% of patients receiving volatile anesthesia, with a much higher frequency in hypothermic patients.^{19,21} Shivering is an involuntary, oscillatory activity that doubles metabolic heat production by 200% in an attempt to elevate core temperature.^{17,21} It normally starts when the preoptic hypothalamus is cooled and arteriovenous shunt vasoconstriction is triggered as an autonomic response to cold.⁵⁰ Postanesthetic shivering is activated when thermoregulatory control reemerges and the shivering threshold moves toward normal.²¹ Not all hypothermic patients shiver, and some normothermic patients do, although shivering in the latter case results from other factors, such as pain that elicits shivering-like tremors. Furthermore, not all patients with PAS complain of feeling cold.⁵⁰ Because thermoregulatory control is impaired by age, PAS is rare in patients older than 60 years.^{17,21} In addition to younger age, other factors associated with PAS include a longer duration of surgery and a lower core temperature; the lower it is, the longer the shivering will last.⁵⁰

Adverse effects of postoperative shivering

Surgical pain is aggravated by shivering, as muscles contract and pull on incisions, but PAS causes more than discomfort. It increases numerous physiologic processes, including oxygen consumption (by ~200%),^{17,51} carbon dioxide production,^{1,19} cardiac output, hypertension, tachycardia, release of catecholamine,^{1,19} and intraocular and intracranial pressure.²¹ Shivering also interferes with

patient monitoring techniques. The increased metabolic heat production causes a rise in heart rate, mean arterial pressure, and the rate-pressure product, which means that myocardial oxygen demand is greatly increased. Postanesthetic shivering can therefore be dangerous for patients with cardiopulmonary diseases.⁵⁰

Treatment

If PAS does occur, active cutaneous warming with forced air should be started immediately, with the goal of heating as much skin surface as possible. For PAS following regional anesthesia, warming the skin above the spinal block is most important.² Antishivering drugs also may be useful, to reduce the physiologic demands that PAS places on the body. Several drugs have antishivering effects but also reduce metabolic heat production, and therefore must be used in conjunction with active warming methods.²¹ The opioid meperidine seems to be the drug of choice because of its effectiveness against both shivering and pain.⁵² In most patients, 50 mg of intravenous meperidine stops shivering within 5 minutes.¹ Other drugs that reduce shivering include tramadol, dexmedetomidine, clonidine, and nefopam.

Increased costs associated with hypothermia

A meta-analysis of 20 reports (n = 1575 patients) on mild perioperative hypothermia suggested that hypothermia might increase surgery costs by \$2500 to \$7000 per surgical patient (in 1999 dollars).⁵³ Increased costs derive from significantly longer hospital stays; a significantly increased need for more transfusions of red blood cells, plasma, and/or platelets; a significantly increased incidence of wound infections; and a significantly higher incidence of myocardial infarction. The longer time hypothermic patients spend in a PACU and on mechanical ventilation often is related to slower drug metabolism, including general anesthesia, sedatives, and muscle relaxants.^{1,15,19,54,55}

A prospective, randomized study of 150 patients undergoing major abdominal surgery was designed to evaluate how much longer hypothermic patients spend in the PACU versus normothermic patients.⁵⁶ The two groups were similar with respect to preoperative core temperature and ambient temperature of the OR (22°C). One group (controls) had no active warming and became hypothermic, with a mean core temperature of 34.5°C on arrival at the PACU. The other group (treatment) was actively warmed to maintain a core temperature >36°C, for a cost of approximately \$30 per patient. Discharge from the PACU was found to be significantly delayed by hypothermia. When a

Table 2. Recommended protocol for hypothermia prevention during general or regional anesthesia

Actively prewarm patients in preoperative area for ~1 hour with forced-air heating or resistive-heating blanket.

Keep the ambient temperature of the operating room at a minimum of 73°F.

Monitor core temperature throughout administration of general and regional anesthesia.

Cover as much body surface area as possible with blankets or drapes to reduce radiant and convective heat loss through the skin.

Actively warm patients intraoperatively with forced-air heaters or resistive-heating blanket to prevent heat loss and add heat content. Rearrange covers every time patient is repositioned to warm as much surface area as possible.

Minimize repositioning time as much as possible so that the active warming method can be quickly continued.

Warm intravenous fluids and/or infiltration fluids if large volumes are used. Warm incision irrigation fluids.

Aggressively treat postoperative shivering with forced-air heater or resistive-heating blanket and consider pharmacologic intervention.

core temperature $>36^{\circ}\text{C}$ and a score of 13 on commonly used measures were required for discharge, the hypothermic patients needed about two hours longer in the PACU, the cost of which far exceeds the \$30 needed for active perioperative warming.

Strategies for Prevention of Perioperative Hypothermia

Maintaining normothermia obviously offers multiple benefits for patients, including lower rates of infection, quicker wound healing, less bleeding and transfusion need, and faster recovery from anesthesia. These reasons alone are enough to advocate the prevention of perioperative hypothermia, but added to them is the enhanced patient comfort that normothermia provides. There is no reason for patients to feel cold at any point in the perioperative period. Postoperative shivering is a special kind of misery because it heightens surgical pain, fatigues muscles, and places unnecessary cardiovascular and respiratory stress on the body. Maintaining normothermia can completely change a patient's perception of surgery for the better. Thus, the prevention of hypothermia is both a patient safety and satisfaction issue.

Patients should be kept at a minimum core temperature $>36^{\circ}\text{C}$ throughout the perioperative period. Even more benefits may accrue with a temperature above 36.5°C —the lower end of the normothermia range. A variety of measures for preventing hypothermia are available, and numerous well-designed studies have evaluated their effectiveness when used alone or in combination with other warming methods. Combined methods are typically needed to maintain normothermia, especially during surgery that lasts longer than 1 hour, and mul-

iple approaches are available so that surgeons can choose what works best for them. A recommended protocol for preventing hypothermia with combined methods appears in Table 2. The use of combination measures is known to be safe, with no reported cases of elevated core temperatures (hyperthermia) developing.

Warming methods found to be ineffective

Before describing the warming methods that should be used, we can dispense with some that researchers agree are not very effective for preventing hypothermia. Although they may contribute small amounts of heat, they are not really worth the time or effort and are therefore not generally recommended.

Contrary to popular opinion, not much heat is lost through the head, so special efforts to cover the head are unnecessary. Because most body heat content is lost through the extremities, warming efforts should be concentrated on the periphery.¹

Heating the airway with heaters/humidifiers is unlikely to change body heat content because only a very small percentage of heat is lost through respiration.^{1,14,18} The cutaneous heat loss that results from antiseptic fluids applied to the skin and allowed to evaporate is not a major factor in hypothermia development. Thus, the warming of skin preparation solutions is unnecessary.^{1,14,18}

Radiant heating devices, such as infrared lamps or thermal ceilings, are not useful for adults because they can heat only small areas of skin and must be positioned too far away from patients. Furthermore, they cannot prevent convective heat losses¹⁷ and require the skin to be exposed.^{1,14} Radiant heaters can be useful in an emer-

gency room setting, where patients are often exposed for diagnostic and treatment purposes.

The use of circulating water mattresses beneath patients is ineffective because very little heat is lost from the body surface lying on the operating table.^{17,19} Water mattresses placed over or around patients would be useful, but they are then too stiff and awkward to work around. In addition, pressure-heat necrosis and burns to the body surface lying on a water mattress have been reported.^{17,19} Most OR tables are covered with several inches of padded foam or gel, which are excellent insulators, and heat loss through the surface next to the table is not a real issue.

Ambient temperature settings

As discussed earlier, perioperative hypothermia primarily results from the inhibition of thermoregulatory defenses during anesthesia rather than a cold environment.^{1,8} Nevertheless, a warmer ambient temperature makes an important contribution to the process of maintaining normothermia and reduces the amount of heat lost by the body surface through radiation and convection.^{14,19,57}

The minimum OR temperature recommended in the literature is 22°C (71.6°F), and most researchers agree that an ambient temperature of at least 23°C (73.4°F) is better.¹⁹ Sessler¹⁸ recommends an OR temperature of 25°C (77°F). One study by El-Gamal and colleagues⁵⁷ determined that nearly all cases of perioperative hypothermia could be eliminated if OR temperatures were 26°C (79°F). Half the 40 orthopedic patients in this series were between 20 and 40 years old, and the other half were 60 to 75 years old. No preoperative or intraoperative warming methods were used, yet the mean core temperature upon arrival in the PACU was 36.4°C for the older group and 36.7°C for the younger patients. Only 4 of the 40 patients had a core temperature <36°C.

Most people would not want to work in a 79°F OR, although this temperature would not have been unusual in the days before air conditioning. El-Gamal et al⁵⁷ mention that many OR staff become uncomfortable at a temperature >22°C, and staff discomfort could lead to inattention, errors, or a decline in performance. Increased sweating by staff could also compromise a sterilized field. In our practice, the standard OR setting is 73°F (22.8°C). In the senior author's experience (V.L.Y.), the warmer temperature gets uncomfortable only when performing lipoplasty, which requires a great deal of physical exertion on the part of the surgeon.

When we first began raising the temperature in the OR, complaints from the staff were common, but they have gradually adapted to the warmer environment.

Our 73°F temperature setting is based on recommendations from health-related government agencies and the American Institute of Architects' standards for ORs in the United States.⁵⁸ These standards include a temperature between 68°F and 73°F, a relative humidity of 30% to 60%, air movement from "clean to less clean" areas, and a minimum of 15 total air changes per hour, with at least three air changes of outdoor air per hour.

Passive warming methods

Passive insulation methods include surgical drapes, cotton blankets, plastic bags, and reflective covers (foils or "space blankets"). All are comparably effective insulators because they trap heat in the layer of air between the patient and the insulator.¹⁴ All insulators reduce cutaneous heat loss, although not to a significant degree.¹⁹ While passive warming insulation helps conserve heat, only active warming can add heat content to the body. No study has found that passive warming alone can maintain normothermia in surgical patients.

Multiple layers of insulators (blankets, drapes, reflective covers) do not increase benefits proportionally. For example, a single layer of insulation reduces cutaneous heat loss by ~30%, but three layers reduces heat loss by only 18% more.⁵⁹ Heated cotton blankets have not been found to be more effective than nonheated blankets, because the heat dissipates within 5 to 10 minutes.⁵⁹ Although heated blankets do provide comfort before and after surgery, nursing staff must constantly warm and replace them. Active warming measures do not require the same degree of staff attention.

In a comparison study, Fossum et al⁶⁰ found that patients prewarmed for 45 minutes with forced air arrived in the OR warmer and remained significantly warmer throughout surgery compared to patients prewarmed for 45 minutes with a warmed cotton blanket. In a prospective, randomized, and controlled study, knee replacement patients were assigned to receive either (1) multiple layers of cotton blankets, (2) a blanket covered with a reflective blanket, or (3) forced-air heating.³ Only the upper body and trunk were covered during the surgeries, which lasted about 1.5 hours in an OR with a mean temperature of ≈19°C. There was a statistically significant difference between the active and passive warming methods, with the forced-air group having a mean core temperature of 36.5°C ± 0.06°C. Both passive warming groups had mean core temperatures ~0.5°C lower.



Figure 3. Forced-air warmers should be used in the preoperative, intraoperative, and postoperative periods. They are available for the full body, upper body, and lower body, such as the Bair Hugger shown here. These systems are efficient, inexpensive, and easy to use. Photo courtesy of Arizant, Inc. Used with permission.

Active warming methods and new technologies

By far, the most common active warming method is forced-air heating, with a system such as the Bair Hugger (Arizant Healthcare Inc., Eden Prairie, MN; [Figure 3](#)) or ThermoCare (Gaymar Industries, Orchard Park, NY). These devices are readily available in surgical suites, are cheap to use, and are the most effective way to prevent hypothermia. Forced-air systems work by radiant shielding and convection to generate heat and also prevent its loss.¹⁷ The key to maximizing the effectiveness of forced-air heating is to warm as much skin surface as possible rather than to excessively heat one area.^{14,17}

Forced-air warming systems and circulating water mattresses came on the market in the 1990s. However, circulating water mattresses are rarely used because they are less effective for preventing hypothermia than forced-

air heating.^{1,18} Some surgeons have been reluctant to adopt forced-air warming for fear that it might increase the risk of infection, but the system's filters eliminate bacteria in the heated air, and there is no evidence that they contribute to infections.¹⁷

Within the past few years, two new active warming techniques have been introduced. One is a resistive-heating blanket made of a carbon fiber and powered by batteries so that it can be moved with the patient. One example is called the Geratherm OP-System (Artemis Medical, UK). The system consists of 6 heating segments that can be connected to accommodate the desired size for a patient or procedure. An arm/shoulder blanket and leg bags are also available. These devices have washable covers that have an antibacterial coating, are fluid resistant, and can be sterilized or disinfected. Early studies found

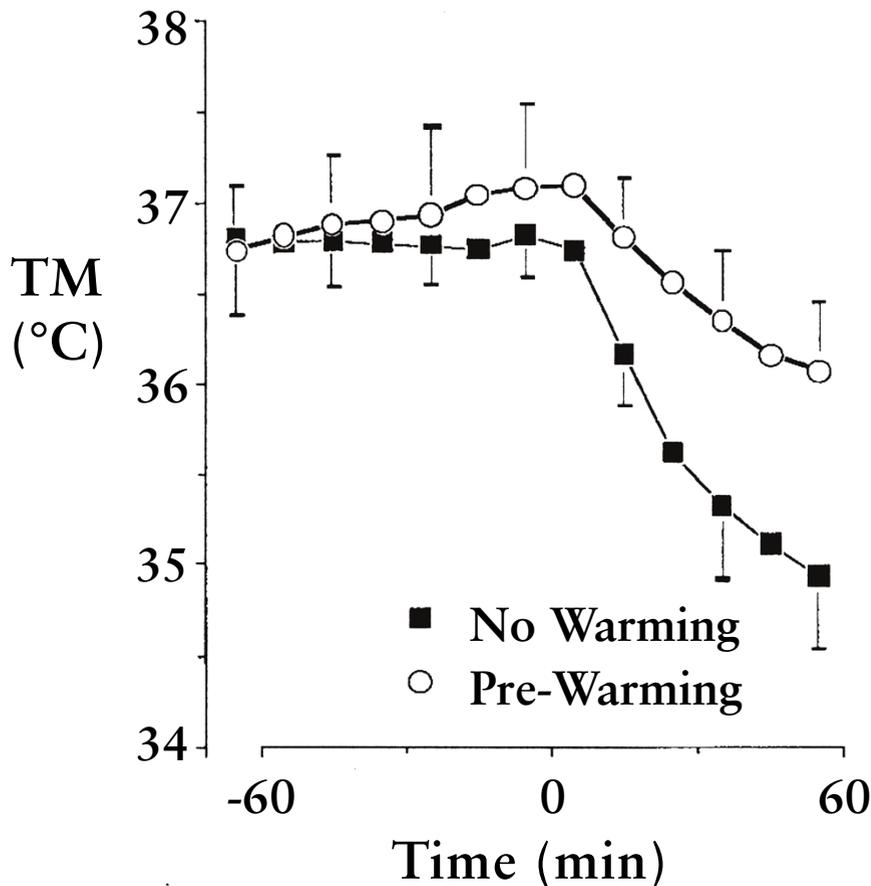


Figure 4. A study of volunteers compared the effects of active prewarming with forced air versus only passive warming with blankets. Patients in both groups were normothermic when anesthesia was induced (time point 0) according to core temperature measurements taken at the tympanic membrane (TM). The group that was not actively prewarmed was hypothermic within 30 minutes after anesthesia induction, and significant core-to-peripheral heat redistribution occurred within the first 60 minutes. During this same period, the prewarmed patients remained normothermic and redistribution hypothermia was prevented. From Sessler,¹⁷ with permission.

resistive-heating blankets to be as effective as forced-air warming,^{14,61} and they may ultimately become less expensive because no disposables are required.

The other new warming system is a modification of the circulating water mattress. Called *circular water warming systems*, they are garments placed beneath the body and wrapped around the torso, legs, shoulders, and upper arms. One version, manufactured by MTRE Advanced Technologies (Or Akiva, Israel), contains temperature sensors and a computer-controlled unit that heats water to a programmed setting. At least one study found this garment to be more effective than forced-air warming.⁶²

Preoperative warming with forced-air heating.

For both general and regional anesthesia, the magnitude of the core-to-peripheral heat redistribution that occurs in unwarmed patients during the first hour of surgery depends on the patient's initial thermal state, or

how much body heat content the patient has when anesthesia is induced.^{16,62} Prewarming with forced air does not typically raise the core temperature, but it does increase body heat content, particularly in the extremities. This additional heat content effectively reduces the risk of hypothermia due to the core-to-peripheral heat redistribution (Figure 4) because the temperature gradient is less wide. By preventing Phase 1 of hypothermia development, the benefits of prewarming continue throughout surgery.²² If core temperature begins to decline in Phase 2, it will start from a higher temperature.

The hypothermia literature is in agreement that prewarming is the key to maintaining normothermia in most patients. Active prewarming is easy to incorporate into the preoperative routine, and it is greatly appreciated by patients, who frequently complain of being cold in the preoperative holding area.

The study by Melling et al,⁴⁹ which found a significantly higher rate of wound infections among patients who were not prewarmed, evaluated two types of prewarming: local and systemic. Local warming was performed with a noncontact radiant heat dressing placed over the planned incision area for a mean of 45 minutes. (This dressing is not further described.) Systemic warming was accomplished with a forced-air heating blanket used for a mean of 39 minutes. Both methods significantly increased patients' heat content by the time of anesthesia induction, although forced-air raised it higher.

Another benefit of actively prewarming patients is the thermal support provided during the period after a patient leaves the preoperative area but before the actual surgery begins.⁶³ There is typically a gap in warming measures when anesthesia is induced, catheters are placed, and patients are prepped and positioned. Heat will be lost before warming measures are started after a patient is moved into the OR. If patients are prewarmed, they will have more heat content to carry them through this gap.

Experts recommend 1 hour of prewarming with forced-air heating. A shorter aggressive warming period may produce counter-productive sweating, in which heat is released from the body.¹⁹ An experiment conducted with volunteers to evaluate the optimal time of prewarming found that peripheral compartment heat increases by clinically important amounts within 30 to 60 minutes at medium (38°C) and high (43°C) settings.⁶⁴ At 2 hours, study subjects were uncomfortably warm, and some began to sweat. Thirty minutes of forced-air prewarming will markedly reduce core-to-peripheral heat redistribution during anesthesia, but 1 hour will basically eliminate it because the heat gain doubles during the second half hour. Since medium versus high settings did not produce much difference, the authors recommend starting with a high (43°C) setting for at least 30 minutes and switching to medium if patients complain of being too warm during the remainder of the prewarming session.

The prewarming duration can be adjusted according to the patient and procedure. A longer prewarming time will benefit patients having lengthy procedures or large incisions. Patients with little body fat should be prewarmed as much as possible because their core temperature will decline more quickly when anesthesia is induced. For short procedures, obese patients may not need to be prewarmed because of their natural excess heat content. Patients undergoing lipoplasty should be prewarmed for one hour, because surgery may be lengthy and large areas will be exposed.

Intraoperative warming with forced-air heating

Hypothermia-induced complications begin intraoperatively. All the prospective and controlled studies reviewed for this article found that patients who receive intraoperative active warming have significantly higher core temperatures compared to those passively warmed. In addition, forced-air heating is effective when only a small surface area is available for warming.⁶⁵

Intraoperative forced-air warming takes on special importance for procedures that last 2 or more hours. Whereas preoperative warming concentrates on adding heat content to the periphery, intraoperative warming raises the core temperature by $\approx 0.75^\circ\text{C}/\text{h}$. A prospective, randomized study has compared preoperative and intraoperative forced-air warming in patients undergoing abdominal surgery under general anesthesia.⁶⁶ One group received 45 to 60 minutes of prewarming plus intraoperative warming; one group received intraoperative warming only; and a control group received only passive warming with two cotton sheets. Surgery duration ranged from 2.5 to 3 hours for all groups. Interestingly, the mean core temperature of all patients when they arrived in the preoperative area was near 35°C , which supports the belief that patients tend to be hypothermic before surgery begins. The group warmed before and during surgery remained normothermic throughout. The intraoperative-only warming group became hypothermic during surgery but was normothermic by the end. The unwarmed group remained hypothermic throughout surgery. None of the warmed patients had postoperative shivering, and almost all patients in the two warming groups were extubated significantly sooner than controls, which indicates a quicker recovery from anesthesia.

Irrigation, intravenous and infiltration fluid warming

Heat is lost from incisions through both evaporative and radiative processes. The heat loss from evaporation of fluids used to irrigate incisions can be significant,¹⁸ especially for incisions in the core area, which applies to a large percentage of plastic surgery procedures.⁸ The larger the incision, the larger the volume of irrigating fluids used. This is likely to be a major source of heat loss in circumferential body lift, abdominoplasty, and breast reconstruction with flaps (among other procedures). Irrigation fluids should be warmed to 40°C in a temperature-controlled warming oven to minimize heat lost through evaporation.

Unwarmed intravenous fluids require body tissues to transfer their heat to warm them, which results in reduced

heat content in those tissues. This transfer is not the best way for tissues to expend their heat content.¹⁶ One unit of refrigerated blood or 1 L of crystalloid solution given at room temperature causes body temperature to decline $\approx 0.25^\circ\text{C}$ per bag.¹⁷ This potential source of heat loss becomes important when unwarmed fluid volumes exceed 2 L/h.¹⁸ Although fluid warming does not warm patients to a significant extent, it can help maintain normothermia when used in conjunction with more active measures, such as forced-air heating. Fluid warming alone is not recommended as a way to prevent hypothermia.

Three types of technology are available for warming intravenous fluids. Dry heat, water bath, and countercurrent heat exchange technologies are all comparable at low flow volumes. For higher flow rates, countercurrent systems, which use a circulating water bath surrounding the infusion tubing, are superior for quickly warming large fluid volumes. The length of tubing and infusion rate influence the temperature to which fluids are heated. The goal is to deliver the fluids at $\approx 37^\circ\text{C}$ for typical flow rates (0.5 to 1 L/min⁻¹). For 8 cm of tubing, the warmer should be set at 40°C to 42°C to compensate for the distance.

Prospective, randomized, and controlled studies of intravenous fluid warming have been conducted with patients undergoing general and regional anesthesia. In these studies, patients who received warmed fluids had higher core temperatures than patients receiving room temperature fluids.⁶⁷⁻⁶⁹ In relatively short surgeries lasting between 1 and 1.5 hours, patients with warmed fluids remained normothermic without any active warming (mean core temperature of 36.3°C), whereas patients with unwarmed fluids had a mean core temperature of 35.6°C .²⁷ In another study of lengthy abdominal surgery, lasting ~ 6 hours, all patients were warmed with intraoperative warming blankets, but the warmed fluids group had a significantly higher mean core temperature ($36.7^\circ\text{C} \pm 0.2^\circ\text{C}$) than those receiving unwarmed fluids ($35.8^\circ\text{C} \pm 0.2^\circ\text{C}$).⁶⁵ Another study determined that a combination of forced-air heating and fluid warming was more effective than either forced air or fluid warming alone. Only the combination of methods was able to maintain a constant core temperature $>36^\circ\text{C}$.⁶⁸

In plastic surgery, tumescent lipoplasty poses special problems for fluid warming because of the large fluid volumes involved in infiltration. The difficulty of maintaining normothermia in patients undergoing lipoplasty was demonstrated by Kenkel et al,⁵ who performed large-volume lipoplasty requiring about 5 hours of surgery and 6.5 hours of general anesthesia. Measures taken to maintain normothermia included raising the OR

temperature, using warming blankets and intraoperative forced-air heating, draping to minimize exposure, and warming infiltration and intravenous fluids. Despite all these efforts, the mean core temperature was $35.5^\circ\text{C} \pm 0.4^\circ\text{C}$, and 2 of the 5 patients studied dropped below 35°C . The only preventive measure not used was prewarming with forced air, which may have prevented the patients' hypothermia.

A controlled study of warmed infiltration solutions in lipoplasty procedures compared patients who received fluids infiltrated at 24°C or at 37°C .⁸ No active warming method was used to prevent hypothermia during the surgeries that lasted approximately 3.5 hours under epidural anesthesia. There was a significant difference between the two groups, with mean core temperatures of $35.7^\circ\text{C} \pm 1.3^\circ\text{C}$ in the warmed fluids group versus $34.9^\circ\text{C} \pm 1.1^\circ\text{C}$ in the unwarmed fluids group. Both lipoplasty studies involved patients in their 20s and 30s with significant body fat. Yet hypothermia was common even with warmed fluids.

Pharmacologic warming methods

Some pharmacologic vasodilators have been found useful in minimizing hypothermia. For example, one study determined that nifedipine could reduce the decline in core temperature by half during the first hour of surgery.⁷⁰ The drug administration routine described is to have patients take 20 mg of long-acting nifedipine 12 hours before surgery and another 10 mg sublingual dose 1.5 hours before surgery.

Amino acid infusion

During the last decade, infusion of amino acids has been investigated as a method of preventing perioperative hypothermia. A balanced mixture of 19 amino acids called Vamin 18 infused at a rate of 126 mL/h may be given before and after anesthesia induction.^{43,71} The amino acids promote endogenous thermogenesis via an increased metabolic rate. Amino acid infusion is usually well tolerated and routinely used in intensive care unit patients, burn victims, and trauma patients.

A study of abdominal surgery patients undergoing procedures that lasted about 1.5 hours under general anesthesia compared patients given amino acids (treatment group) with controls.⁷¹ No active warming measures were used in either group. There was a significant decline in the core temperature of controls compared to the treatment group ($0.8^\circ\text{C} \pm 0.1^\circ\text{C}/\text{h}$ versus $0.5^\circ\text{C} \pm 1^\circ\text{C}/\text{h}$, respectively). Core temperature at awakening was also significantly different: $35.7^\circ\text{C} \pm 0.1^\circ\text{C}$ in controls

versus $36.5^{\circ}\text{C} \pm 0.1^{\circ}\text{C}$ in treated patients. Postoperative shivering occurred in all controls, but in only three of 45 patients in the treatment group. In addition, the amino acid group was released from the hospital an average of 2.7 days earlier than controls. A study of hip arthroplasty patients used a similar study design and found similar results with regional anesthesia.⁴³ Blood loss was also measured in these patients, and the group receiving amino acids lost significantly less blood during surgery. The authors concluded that amino acid treatment was beneficial in patients receiving regional anesthesia, though not as much as in general anesthesia.

Raising core temperature about 0.5°C with amino acid infusion may not be worth the added expense, especially since inexpensive and long-proven methods of maintaining normothermia are readily available (personal written communication, David Sessler, July 17, 2006). Nevertheless, this approach to "internal heating" is intriguing. Perhaps amino acid infusion could play an important role for patients who have undergone gastric bypass and therefore lack normal protein absorption and have nutritional deficiencies, but this issue needs to be investigated.

Conclusion

Preventing perioperative hypothermia is neither difficult nor expensive. In many medical specialties and surgical settings, measures to maintain normothermia are established as routine perioperative care for every surgery performed under general or regional anesthesia, regardless of surgery duration.

Perioperative hypothermia is not irrelevant to plastic surgery. It is associated with serious complications such as surgical site infections, slower wound healing, coagulation disorders, and increased bleeding. The PAS caused by hypothermia presents its own problems for plastic surgery patients. In addition to the metabolic, cardiac, and respiratory consequences of PAS, it may adversely affect outcomes. Bruising and/or hematoma may occur more frequently or be worsened by shivering, especially since bleeding time is prolonged by hypothermia. This could be especially important for facial procedures such as face lift or blepharoplasty. Flap perfusion may be compromised by PAS and the vasoconstriction of hypothermia. Shivering could also magnify postoperative pain. It is difficult to imagine what PAS must feel like to a patient who has undergone a transverse rectus abdominus muscle (TRAM) flap breast reconstruction, circumferential body lift, or abdominoplasty. The best way to avoid PAS hypothermia-induced complications is to maintain normothermia.

A combination of warming measures is usually required to prevent hypothermia. At a minimum, the goal is to maintain a core temperature of at least 36.1°C ; studies suggest that $\geq 36.5^{\circ}\text{C}$ offers additional benefits and further enhances patient safety. Prospective, randomized and controlled trials of prewarming have determined that prewarming is the key to maintaining normothermia, and that forced-air warming or use of resistive-heating blankets should commence about one hour before surgery begins. A recent report of a round-table discussion on safety and complications in body contouring for massive weight loss patients said that aggressive warming measures should be instituted when the core temperature reaches 35°C .⁶ However, if active warming measures are instituted only when the patient's temperature starts dropping or has reached 35°C , the battle against inadvertent perioperative hypothermia has largely been lost.

The aforementioned body contouring report on massive weight loss patients indicates the lack of collective knowledge about hypothermia in plastic surgery. Achieving the goal of always maintaining normothermia will require a change in both our thinking and practice. Change is not easy for some, and resistance to instituting new protocols is perhaps inevitable in ORs. However, once new protocols are in place, it should become obvious that maintaining normothermia is neither difficult nor disruptive to routines. Our patients will appreciate the effort, and the risks of postoperative complications and adverse consequences will be greatly reduced. ■

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