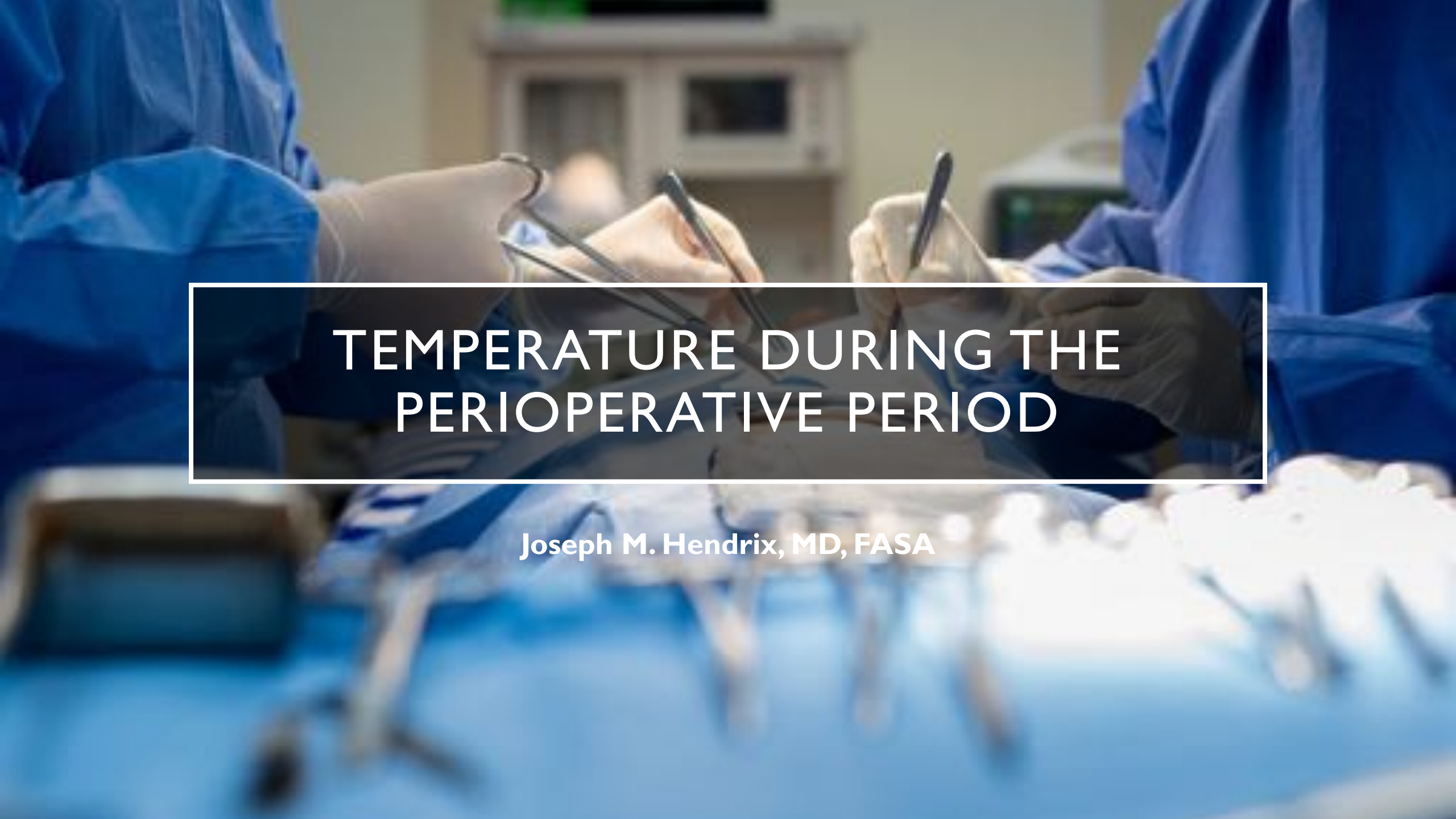




TEMPERATURE DURING THE PERIOPERATIVE PERIOD

Joseph M. Hendrix, MD, FASA

OUTLINE

- Objectives
- Background
- Key terms – normothermia, hypothermia, and hyperthermia
- Physiology of thermoregulation
- Hypothermia during the perioperative period
- Managing normothermia during the perioperative period
- Conclusions



EDUCATIONAL OBJECTIVES

The objective of this presentation is to help you understand:

- The physiology of thermoregulation
- The effects of anesthesia on thermoregulation
- The importance of perioperative normothermia
- Measures and guidelines for perioperative temperature management.

BACKGROUND

- Undergoing surgery is a stressful event for both the body and the mind.
- Surgery causes major physiological changes that require continuous monitoring by the surgical team.
- When anesthesia is involved in the procedure, many physiological parameters are affected – including temperature.
- Hypothermia during the perioperative period is a common complication that can lead to serious adverse effects.



WHAT ARE NORMOTHERMIA, HYPOTHERMIA, AND HYPERTHERMIA?

Normothermia:

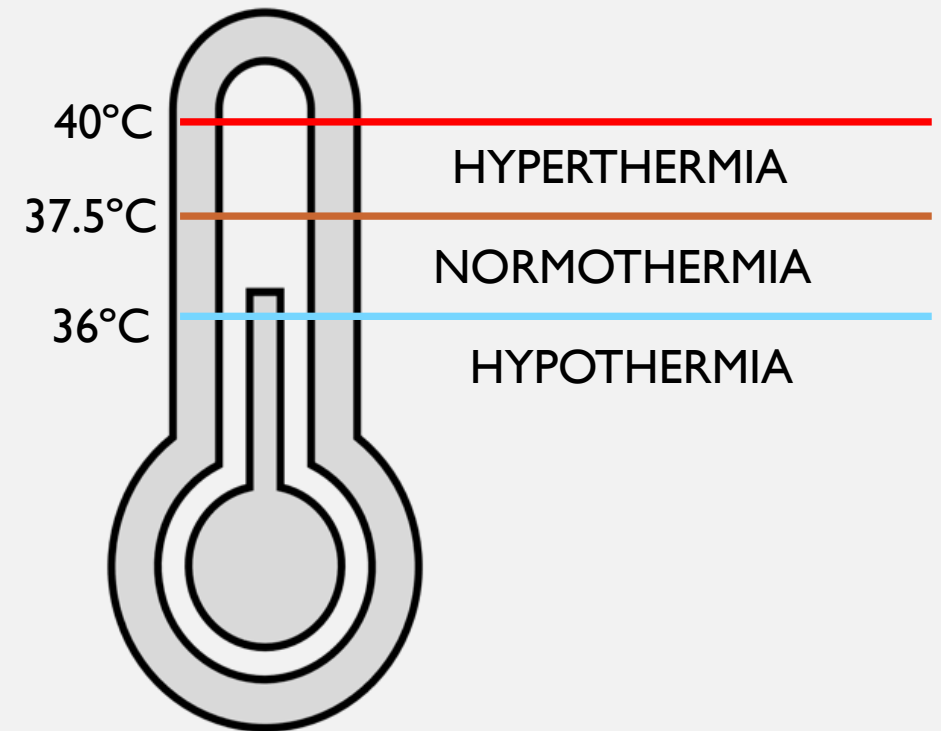
A condition of normal body temperature where the activity of body cells is not reduced nor increased.

Hypothermia:

A body core temperature of less than 36°C

Hyperthermia:

A body core temperature that is elevated beyond normal limits. Typically a temperature greater than 37.5°C, which can become life threatening at temperatures over 40°C.



PHYSIOLOGY OF THERMOREGULATION

- **Thermoregulation** is the mechanism by which the hypothalamus centrally regulates the body temperature at a stable level.
- Thermoregulation happens in three phases:
 1. Afferent input
 2. Central regulation
 3. Efferent responses

PHYSIOLOGY OF THERMOREGULATION

1. Afferent Input

1. Nerve signals indicating cold or warm temperatures are perceived by specialized thermal receptors that travel through the lateral spinothalamic tract of the anterior spinal cord until they reach the hypothalamus.

2. Central Regulation

1. In the hypothalamus, central processing and regulation begin by altering metabolic heat production and environmental heat loss by promoting behavioral responses.
2. Behavioral responses include moving from sun to shade, dressing appropriately, voluntary movement, assuming positions that oppose skin surfaces, or altering ambient temperature.

PHYSIOLOGY OF THERMOREGULATION

3. Efferent Responses

- Central processing and regulation can also alter metabolic heat production with other efferent responses.
- Efferent responses include autonomic regulations including:
 - ✓ Cutaneous vasoconstriction
 - ✓ Non-shivering thermogenesis
 - ✓ Shivering
 - ✓ Vasodilation
 - ✓ Sweating
- Thresholds for efferent responses vary depending on sex, circadian rhythm, women's menstrual cycles, exercise, food intake, hypo- and hyper- thyroid states, and more.
- The range in which autonomic defenses are not activated is called the interthreshold range.
- In unanesthetized humans, a change in core body temperature of as little as 0.4°C can trigger an effector response. However, under general anesthesia, the effectors are not engaged until the change is up to 4°C .

PHYSIOLOGY OF THERMOREGULATION

3. Efferent Responses

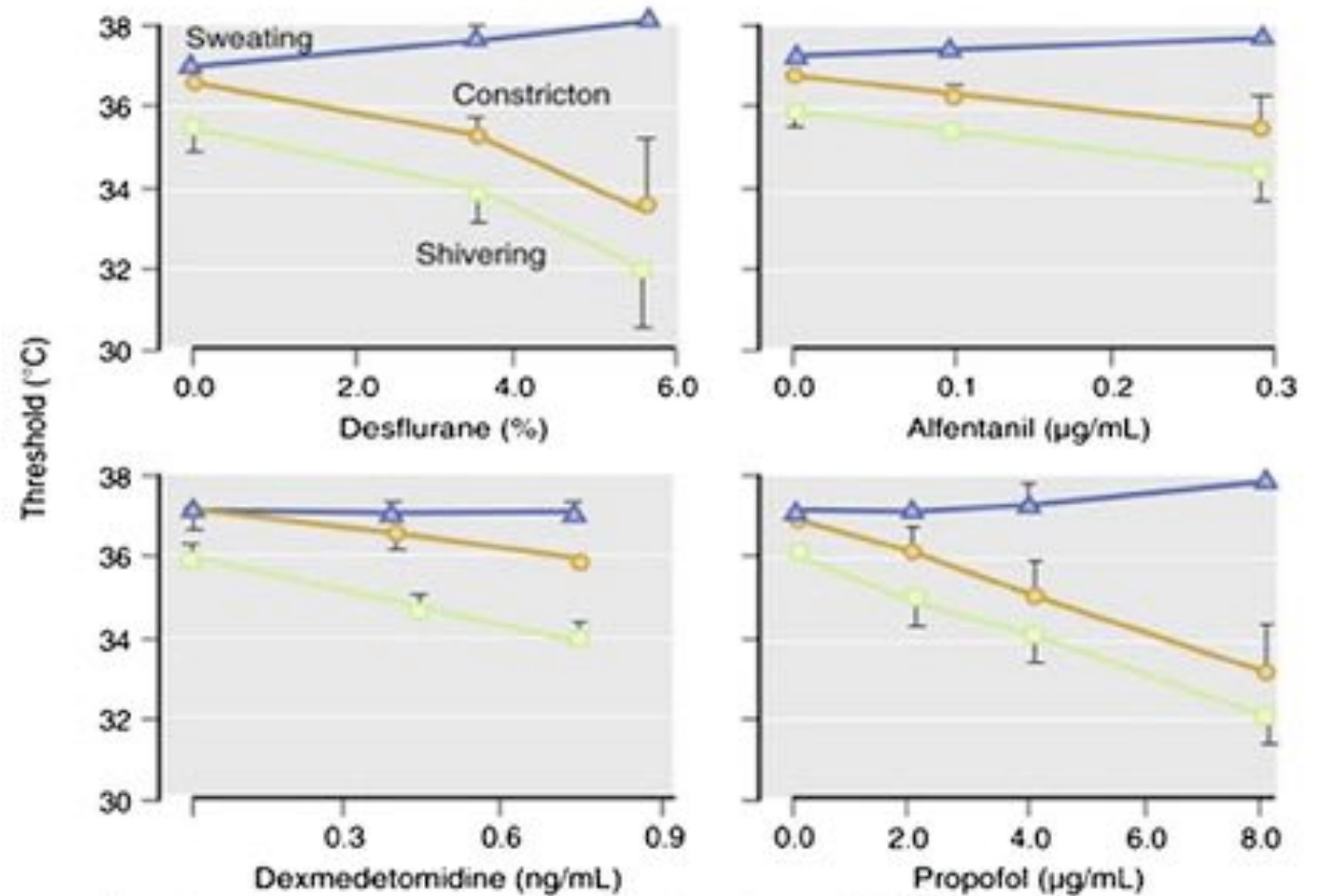
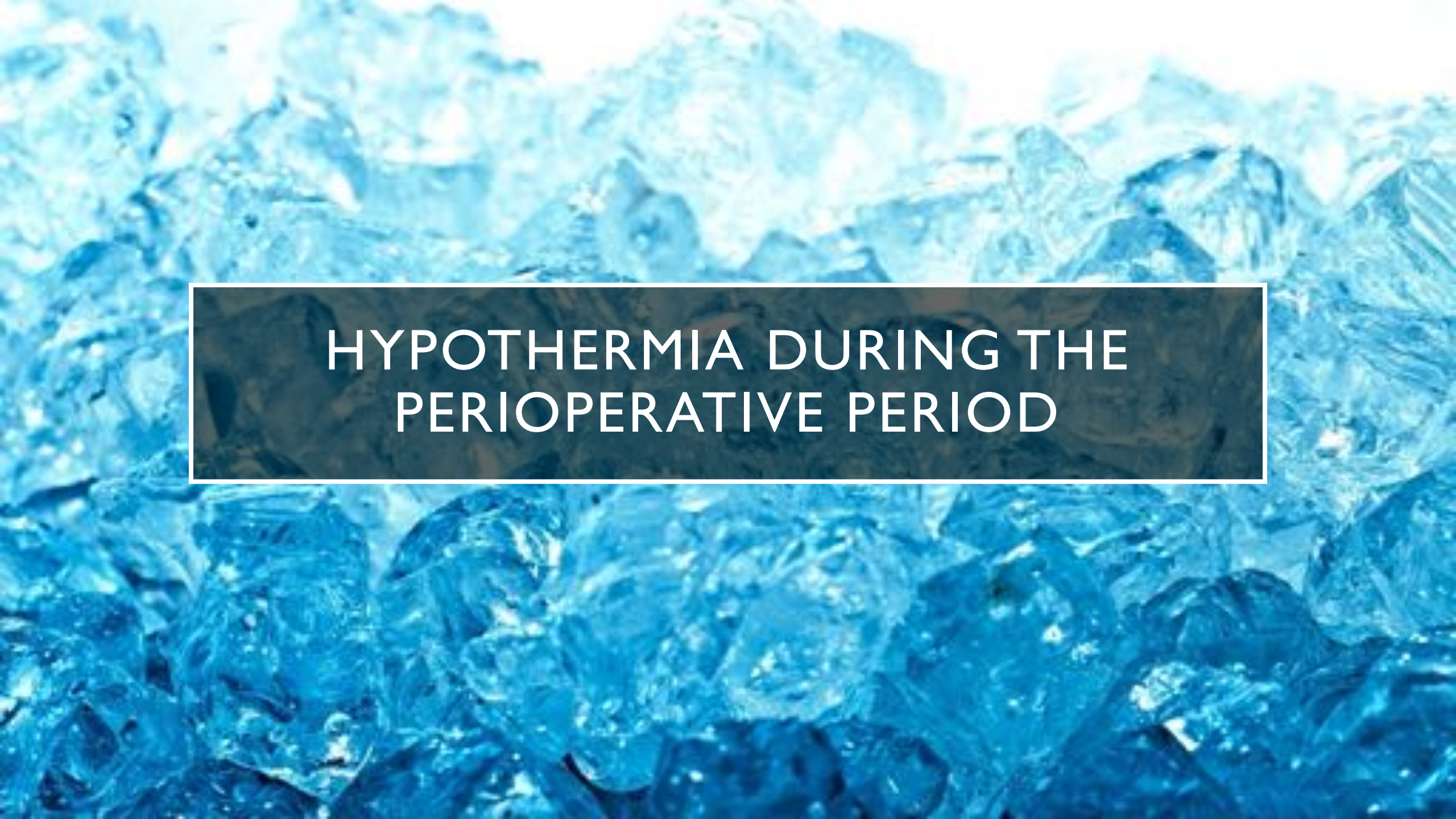


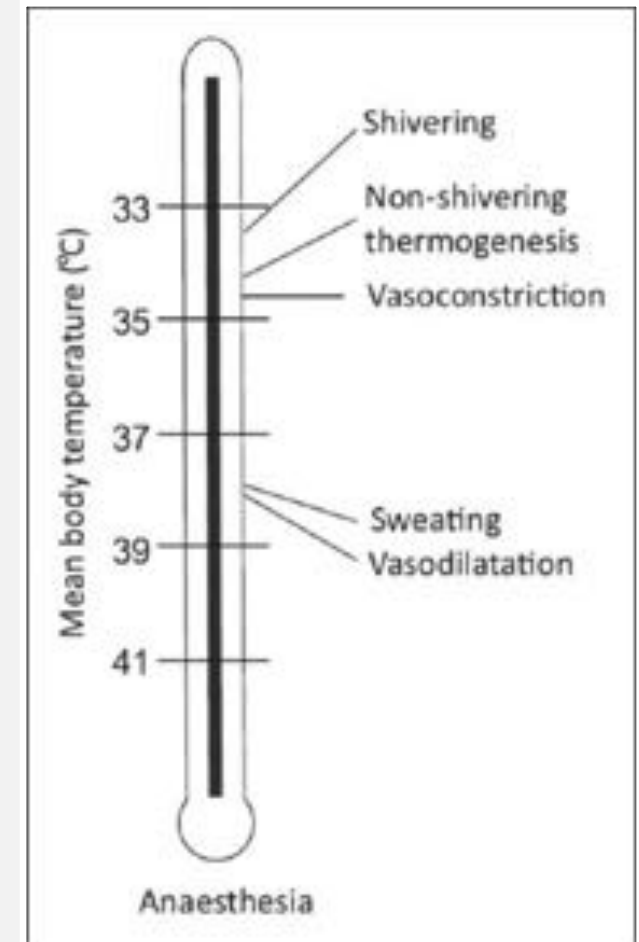
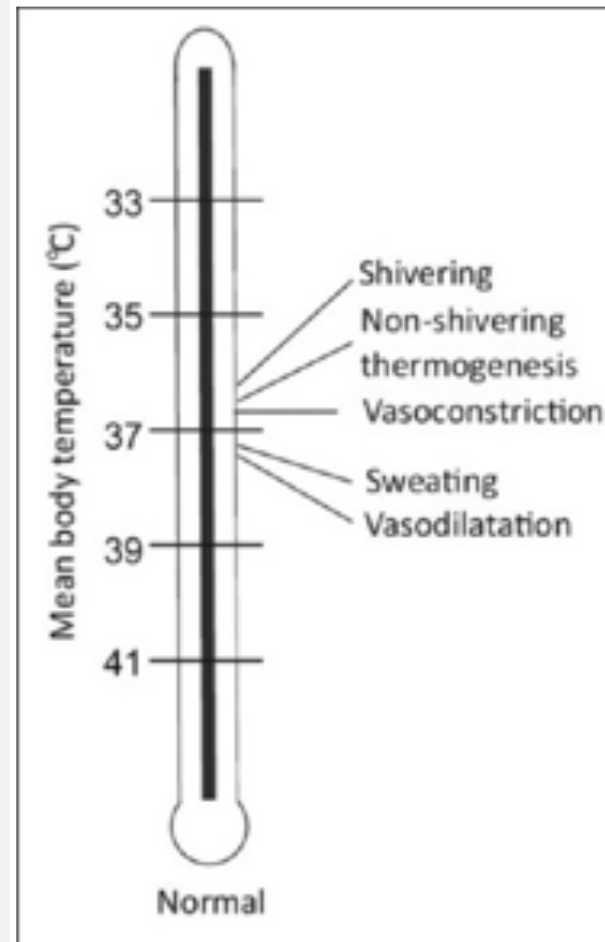
Fig. 1. Effect of anesthetic agents on thermoregulation.

The background of the slide is a close-up photograph of numerous ice cubes. The ice is a vibrant blue color, likely due to the way light interacts with the frozen water. The cubes are irregular in shape, with sharp edges and facets that catch the light, creating a textured and crystalline appearance. The lighting is bright, highlighting the transparency and the internal structure of the ice.

HYPOTHERMIA DURING THE PERIOPERATIVE PERIOD

THERMOREGULATION UNDER ANESTHESIA

- When under anesthesia, the body solely relies on autonomic responses and external temperature management for thermoregulation.
- Autonomic responses are altered because warm response thresholds are **increased** while cold response thresholds are **reduced**.



CAUSES & MECHANISMS HYPOTHERMIA UNDER ANESTHESIA

Cause of Hypothermia	Mechanism
Operating Room Environment	Set OR temperature and humidity, exposure of body surface, cold irrigation fluid, skin preparation
Cold IV fluids	1 unit of cold RBC can decrease body temperature by 0.25-0.35°C, cold crystalloid fluids decrease body temperature
Anesthesia	Anesthesia-induced redistribution of heat from core to periphery. Volatiles, muscle relaxants, IV sedatives/anesthetics, vasodilators, and regional anesthesia also reduce body temperature.
Surgical technique	Exposure of body cavity and duration of surgery.

CAUSES & MECHANISMS HYPOTHERMIA UNDER ANESTHESIA

Michael Hernandez, MD, Thomas W. Cutter, MD, MEd, Jeffrey L. Apfelbaum, MD. Hypothermia and Hyperthermia in the Ambulatory Surgical Patient. Clin Plastic Surg 40 (2013) 429–438
<http://dx.doi.org/10.1016/j.cps.2013.04.015>

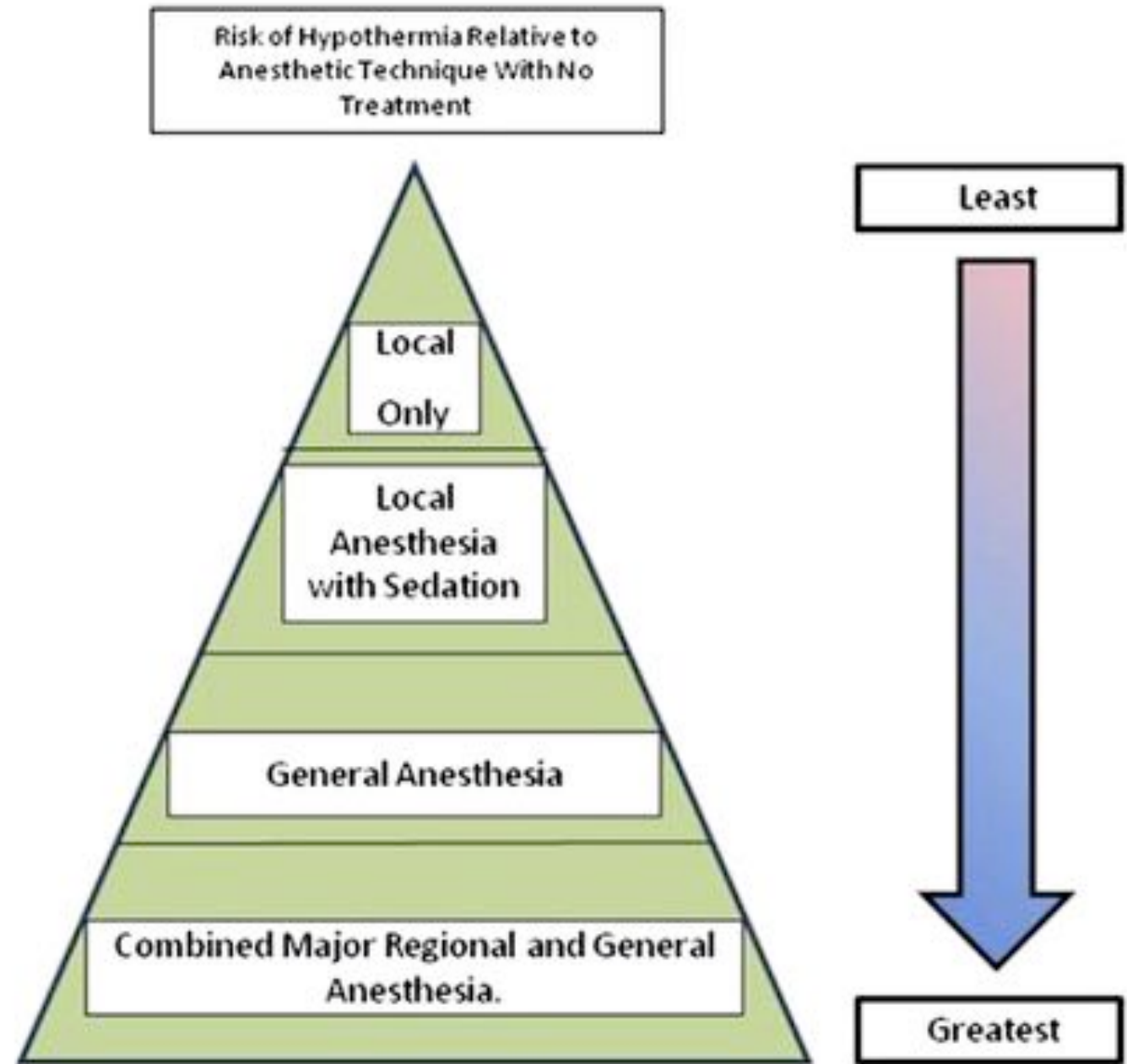
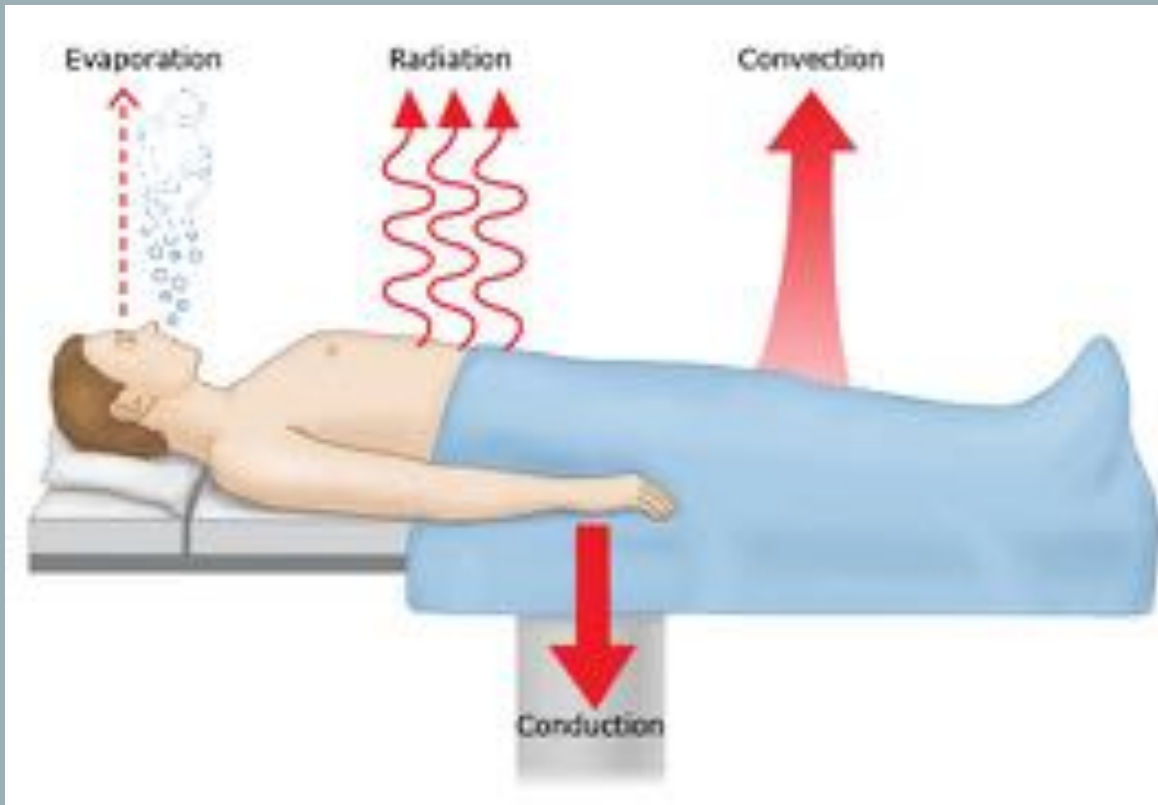


Fig. 2. Risk of hypothermia.

DOMINANT SOURCES OF HEAT LOSS DURING SURGERY



Conduction

- Negligible since patients are in direct contact with a foam pad beneath them, which is an excellent insulator.

Evaporation

- Skin: <10% of metabolic heat produced in adults
- Respiratory System: trivial amounts are lost. (may be high with dry anesthetic gases. Humidifiers and low fresh gas flows can limit loss)
- Surgical wound: has never been quantified.

Convection

- Occurs when the layer of still air adjacent to skin is disturbed. Losses can be substantial in operating rooms with laminar flow.

Radiation

- Heat leaves the body and radiates to all surfaces around the individual.

GENERAL ANESTHESIA HYPOTHERMIA

- Hypothermia during general anesthesia occurs from a combination of anesthetic induced impaired thermoregulation which can lead to many physiological effects such as:
 - Vasodilation
 - Inhibition of vasoconstriction
 - Reducing metabolic rate by 20-30% and from the exposure to the surgical cold environment.
- This phenomenon happens in 3 phases.

PHASE I: INITIAL RAPID DECREASE



In the first hour, the body core temperature falls 0.5-1.5°C



Instead, peripheral temperature increases from 33°C to 35°C.



This process accounts for 81% of core temperature fall, arriving under 36°C.

Source: Matika, R. et al. (2017). The importance of body temperature: An anesthesiologist's perspective. 4(1): 9-12. Bindhu B. et. al. (2017). *Temperature Management Under General Anesthesia: Compulsion or Option*. 33(3): 306-216. Ruetzler, K. and Kurz, A. (2018). *Consequences of perioperative hypothermia*. 157: 687-697. Sessler, D. *Perioperative Temperature Management*. (UpToDate).

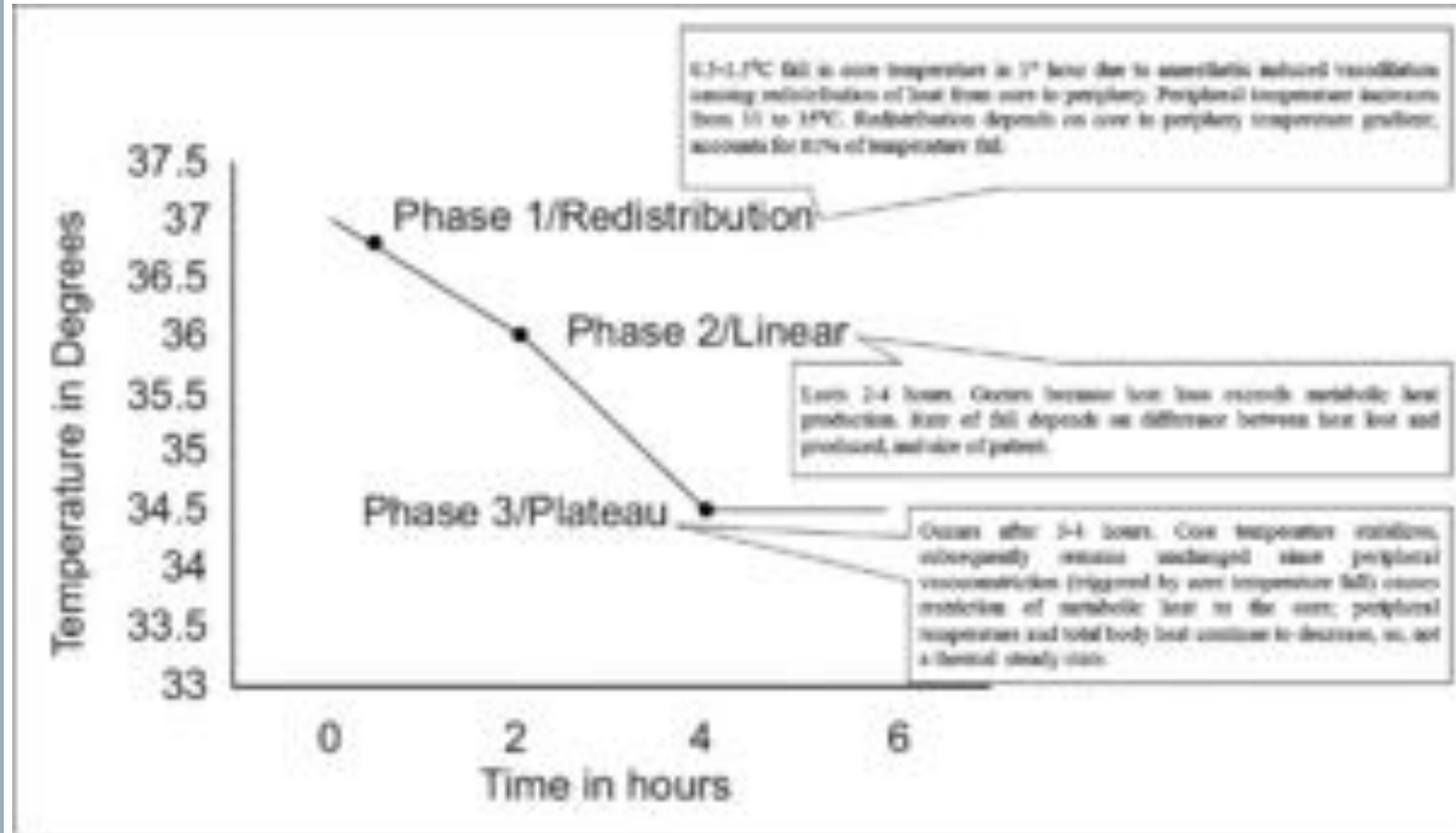
PHASE 2: SLOW LINEAR REDUCTION

- The decrease in body temperature continues because heat loss exceeds metabolic heat production.
- Here, the main routes of heat loss to the environment are usually radiation and convection.
- This phase lasts from 2-4 hours, arriving at approximately 34.5°C.

PHASE 3: PLATEAU PHASE

- After 3-4 hours, thermoregulatory vasoconstriction is activated, making core temperature stable without further decrease.
- This process effectively retains metabolic heat in the core tissues.
- Heat loss from peripheral tissues continues, making body heat content and peripheral temperature continue to decrease even though body core temperature remains constant.

HYPOTHERMIA PHASES



HYPOTHERMIA AND NEURAXIAL ANESTHESIA

- Neuraxial anesthesia (or local anesthesia) also has similar effects on thermoregulation.
- Temperature thresholds alteration is proportional to the number of spinal segments blocked, decreasing core temperature by 0.5-1°C.
- Hypothermia may not plateau since nerve block inhibits peripheral vasoconstriction.

RISK FACTORS FOR HYPOTHERMIA



Prolonged surgery



Extremes of age (old or young)



Extensive burns



Lower preoperative temperature



Severe trauma



Major intraoperative fluid shifts

Source: Bindhu B. et. al. (2017). *Temperature Management Under General Anesthesia: Compulsion or Option*. 33(3): 306-216. Sessler, D. (2008). *Temperature Monitoring and Perioperative thermoregulation*. 109(2): 318-338. Sessler, D. *Perioperative Temperature Management*. (UpToDate). Matika, R. et al. (2017). *The importance of body temperature: An anesthesiologist's perspective*. 4(1): 9-12.

CONSEQUENCES OF HYPOTHERMIA

Temperature (°C)	Effect
30-35	Physiological attempts to increase temperature, generation of heat: shivering, peripheral vasoconstriction
35-36	Tachycardia
≤35	Bradycardia, low platelet count, impaired platelet function, impaired coagulation cascade, altered clearance of various medication
≤33	ECG changes: increased PR-interval, widening of QRS complex, increased QT interval
≤32	Mild arrhythmias
≤30-31	Depressed consciousness, lethargy, coma
≤30	“Hibernation” – shivering ceases, marked decreases in rate of metabolism.
≤28-30	Increased risk of tachyarrhythmias, beginning with atrial fibrillation

CONSEQUENCES OF HYPOTHERMIA

Table 1
Causes and Physiological
Consequences of Perioperative
Hypothermia

Definition of hypothermia

Core body temperature lower than 36° C (96.8° F)

Causes of hypothermia

- Cold OR suite
- Administration of unwarmed IV fluids
- Medication-induced vasodilatation
- Decreased metabolic rate
- Anesthesia-induced impairment of the hypothalamic thermostat
- Exposure of body cavities
- Heat loss from the lungs to warm inhaled gases

Consequences of hypothermia

- Increased energy expenditure as a result of increased oxygen consumption
- Shivering due to hypothermia, which increases oxygen consumption by 400% to 500%
- Increased mortality particularly in patients < 55 years of age who experience prolonged hypothermia
- Decreased production of interleukin 2 (ie, a key mediator in various immune responses)
- Increased risk for cardiac events (eg, increased blood pressure, myocardial ischemia) for patients with coronary artery disease
- Increased need for transfusion of red blood cells, plasma, and platelets
- Dysfunction of extrinsic and intrinsic pathways of the coagulation cascade
- Increased incidence of surgical wound infection
- Increased need for postoperative mechanical ventilation
- Reduced medication metabolism with an increased duration of action
- Decreased production of new tissue and decreased repair of injured tissue compared to patients who are normothermic

TABLE 1. Consequences of Hypothermia

Increased

- energy expenditure because of increased oxygen consumption
- incidence of surgical wound infection
- need for postoperative mechanical ventilation
- need for transfusion of red blood cells, plasma, and platelets
- mortality rates, particularly in patients < 55 years of age who experience prolonged hypothermia
- risk for cardiac events (eg, hypertension, myocardial ischemia) in patients with coronary artery disease

Decreased

- production of interleukin 2, a key mediator in various immune responses
- medication metabolism with an increased duration of action
- production of new tissue
- repair of injured tissue compared with patients who are normothermic

Shivering that increases oxygen consumption by 400% to 500%

Dysfunction of extrinsic and intrinsic coagulation cascade pathways

Adapted from Goode KK, Verble JA, Secrest J, Norwood BR. Preoperative hypothermia—the chilling consequences. AORN J. 2006;83(5):1055-1066

Source: Bindu, B. et. al. (2017). *Temperature Management Under General Anesthesia: Compulsion or Option*. 33(3): 306-316. AGNES JARDELEZA, RN; DENISE FLEIG, MSN, RN, APN, PCNS-BC; NANCY DAVIS, MA, RN; RANDY SPREEN-PARKER, PhD, RNC. The Effectiveness and Cost of Passive Warming in Adult Ambulatory Surgery Patients. AORN J 94 (October 2011) 363-369. doi:10.1016/j.aorn.2011.03.010. Good KK, Verble JA, Secrest J, Norwood BR. Postoperative hypothermia—the chilling consequences. AORN J. 2006;83(5):1054-1066.

MANAGING NORMOTHERMIA DURING THE PERIOPERATIVE PERIOD

NORMOTHERMIA BENEFITS

Normothermia provides diverse medical benefits that improve surgery outcomes including:

Decrease in
surgical
wound
infection

Lower blood
loss

Lower risk
for
complication

Reduced
hospital stay

Decrease
use of
prophylactic
antibiotics

Lower cost
and patient
discomfort

therefore

Normothermia should be a major priority during the perioperative period.

Sources: Sajid, M. et. al. (2009). *The role of perioperative warming in surgery: a systematic review*. 127(4): 231-237, Kurz, A. et al. (1996). *Perioperative Normothermia to Reduce the Incidence of Surgical-Wound Infection and Shorten Hospitalization*. 334: 1209-1216., Melling, AC. et al. (2001). *Effects of preoperative warming on the incidence of wound infection after clean surgery: a randomized controlled trial*. 358(9285): 876-880. Wong, PF. et al. (2007). *Randomized clinical trial of perioperative systemic warming in major elective abdominal surgery*. 94(4): 421-426.,

RISKS OF INFECTION

SSIs increase postoperative hospitalization by an average of 4 days, resulting in an increased attributable cost of US\$8000–25,000 for each patient (Hart et al., 2011).

A recent review summarized that there was a significant benefit of actively warmed patients over non-actively warmed patients in the incidence of SSIs and complications (risk ratio 0.36, 95% confidence interval (CI) 0.2–0.66, $p = 0.0008$) (Madrid et al., 2016).

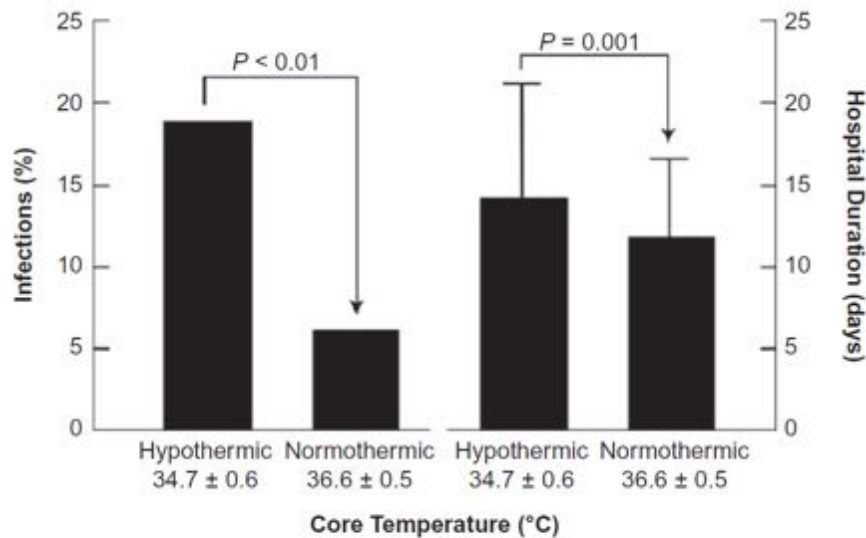


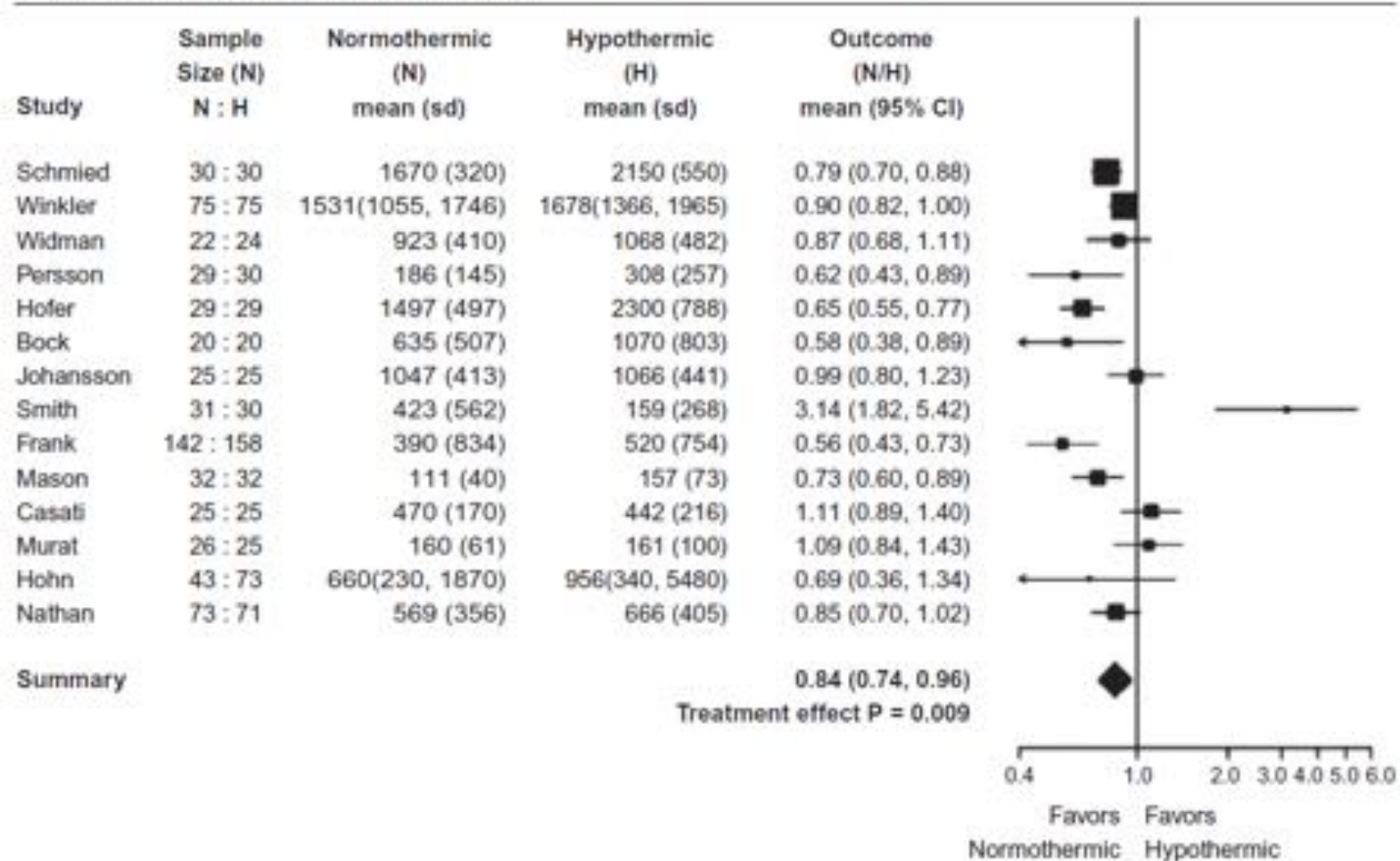
Fig. 41.4. Hypothermia, wound infection and duration of hospitalization. (Reproduced with permission from Kurz A, Sessler DI, Lenhardt R (1996) Perioperative normothermia to reduce the incidence of surgical-wound infection and shorten hospitalization. Study of Wound Infection and Temperature Group. *N Engl J Med* 334: 1209–1215. Copyright © Massachusetts Medical Society.)

BLOOD LOSS

Although there are many divergent results from several retrospective studies, two randomized trials have confirmed that a reduction of only approximately 0.5oC core temperature increases blood loss by 200–300 mL in patients undergoing hip arthroplasty (Winkler et al., 2000).

A comprehensive meta-analysis of randomized controlled trials by Rajagopalan et al. (2008) Compared normothermic patients with patients experiencing perioperative hypothermia (34–36oC). Fourteen studies were included in order to assess the relationship between hypothermia and blood loss: mild hypothermia Increased blood loss by approximately 16%.

Total blood loss meta-analysis and forest plot

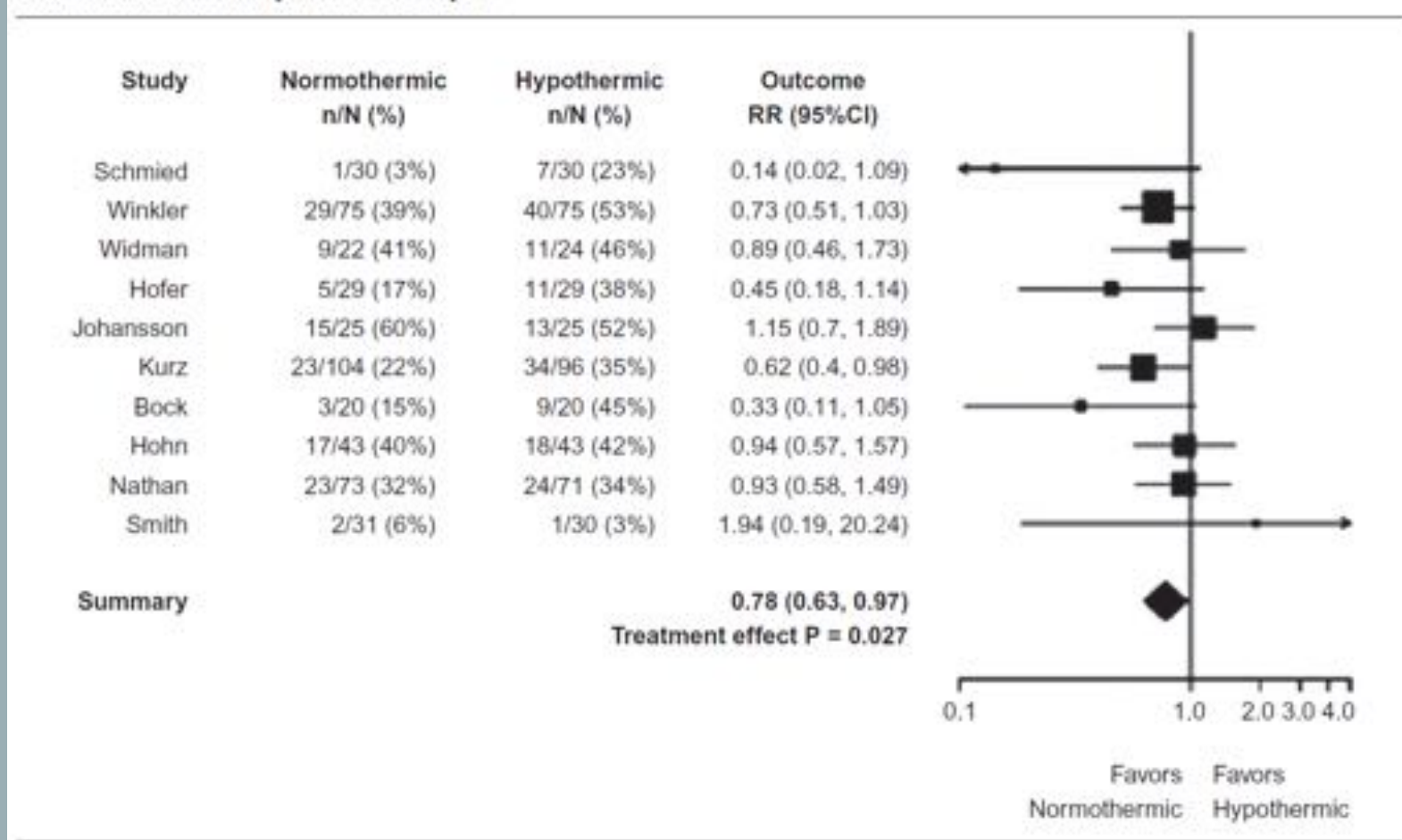


From Rajagopalan S, Mascha E, Na J, et al. (2008) The effects of mild perioperative hypothermia on blood loss and transfusion requirement. *Anesthesiology* 108: 71–77.

Treatment effect is expressed as ratio of geometric means of blood loss for normothermic (N) versus hypothermic (H) patients. Results indicate an estimated 16% (95% confidence interval (CI) 4%, 26%) lower average blood loss in normothermic versus hypothermic patients, $p < 0.009$.

BLOOD LOSS

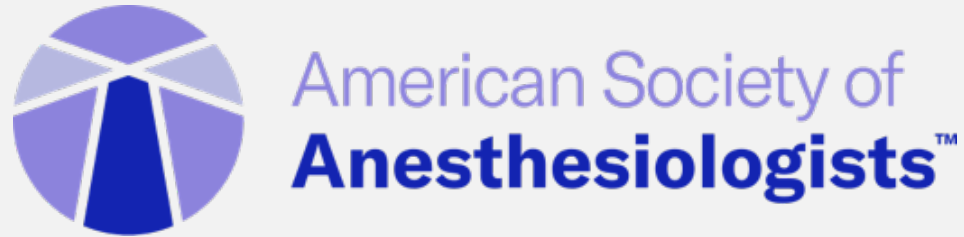
Transfusion meta-analysis and forest plot



Reproduced from Rajagopalan S, Mascha E, Na J, et al. (2008) The effects of mild perioperative hypothermia on blood loss and transfusion requirement. *Anesthesiology* 108: 71–77.

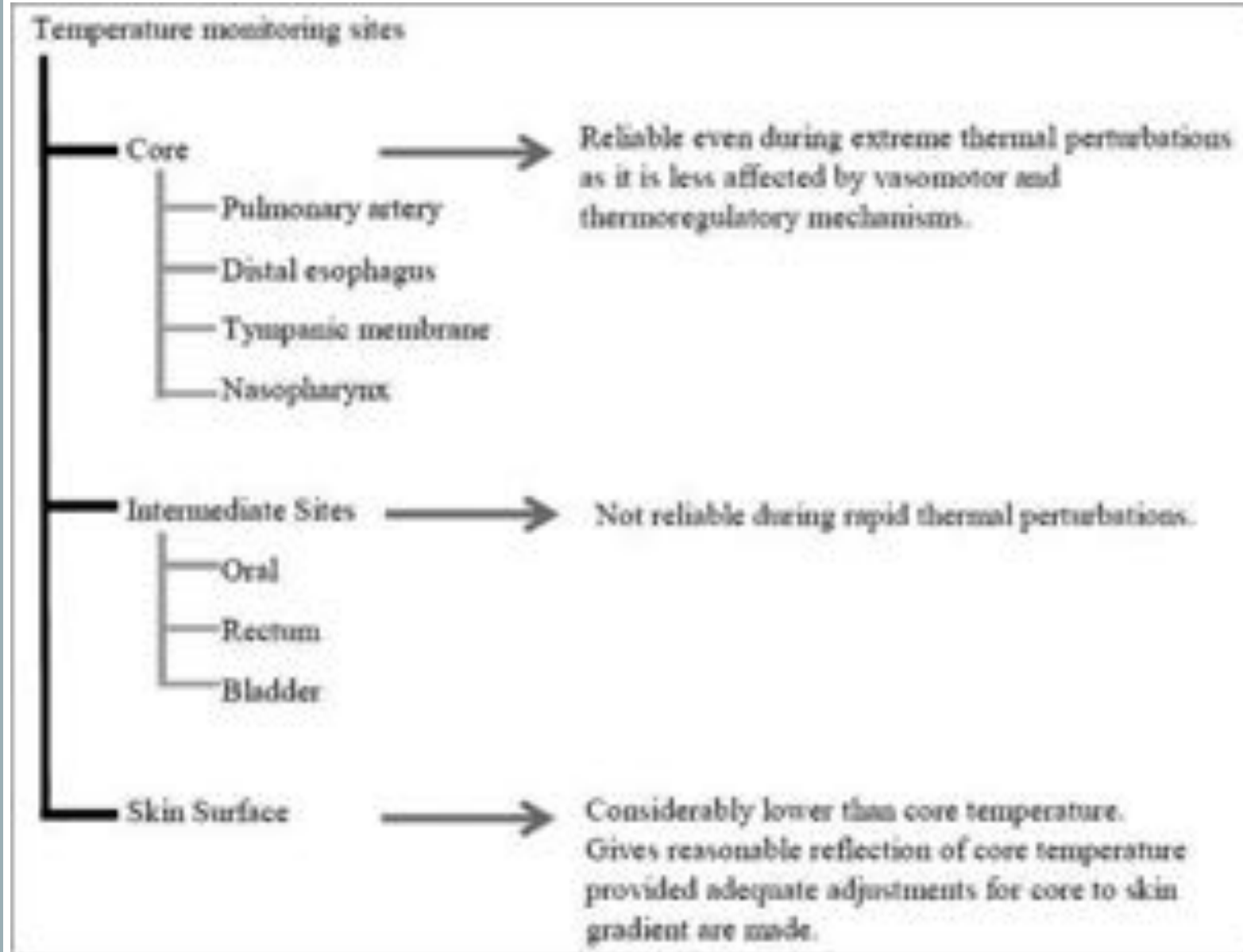
Treatment effect is expressed as the relative risk (RR) of transfusion in normothermic versus hypothermic patients. Normothermia is associated with 22% less risk of transfusion than hypothermia (95% confidence interval (CI) 3%, 37%), $p = 0.027$. n , number transfused; N , number of patients.

ASA RECOMMENDATIONS



- The American Society of Anesthesiologists (ASA) standards suggest that:
 - Core body temperature should be measured or reliably estimated in most patients given general anesthesia for more than 30 minutes
 - Temperature should also be measured or reliably estimated during regional anesthesia when changes in body temperature are intended, anticipated, or suspected.
 - Unless hypothermia is specifically indicated (e.g., for protection against ischemia), efforts should be made to maintain intraoperative core temperature at more than 36°C.

SITES FOR TEMPERATURE MONITORING



SITES FOR TEMPERATURE MONITORING

Table 1

Overview of the most common core temperature measurement techniques.

Position	Invasiveness	Speed	Complications	Accuracy	Patient discomfort
Axillary	None	Slow	None	Very low	Low
Forehead	None	Slow	None	Very low	Low
Temporal artery	None	Fast	None	Low	Low
Oral/sublingual	Low	Medium	Aspiration	Low	Low
Ear (IR)	Low	Fast	Tymp. perforation	Low	Low
Ear (direct tympanic)	Medium	Medium	Tymp. perforation	Good	Medium
Rectal	Medium	Medium	Intestinal perforation	Good	Medium
Nasopharyngeal	Medium	Fast	Epistaxis	Very good	High
Esophagus	High	Fast	Esophageal perforation	Very good	Very high
Bladder	High	Fast	Bladder perforation, UTI	Very good	No additional loss of comfort if bladder catheter is indicated
Zero heat flux (active)	None	Slow	None	Very good	medium
Heat flux/double sensor	None	Slow	None	Very good	Low
Thermography	None	Fast	None	Low	Low
Brain temperature tunnel	None	Fast	None	n/a ^a	Low
Pulmonary artery	Very high	Fast	Multiple	Reference temperature	Very high
Intracerebral temperature	Very high	Fast	Multiple	Reference temperature	Very high

^a Not enough studies for verdict.

Source: Oliver Kimberger: Temperature monitoring in the OR: State of the art and a 2012 update. Trends in Anaesthesia and Critical Care 3 (2013) 8e12., Bindu, B. et. al. (2017). *Temperature Management Under General Anesthesia: Compulsion or Option*. 33(3): 306-316.

ACHIEVING NORMOTHERMIA

- In order to achieve normothermia throughout the perioperative period, experts recommend separating this period into three phases:
 - Preoperative phase
 - Intraoperative phase
 - Postoperative phase
- Specific measures are applied in each phase to accomplish the objective.

Table 5: Comparison of various cutaneous active warming devices

Device	Mechanism of action	Advantage	Disadvantage	Remarks
Circulating water mattresses	Conduction	No ambience warming	Take 2-3 times longer than forced air warmers, nearly ineffective, cover only posterior surface, need unimpeded high thermal contact with well-perfused skin, pressure point ischemia, limited warming capacity in lateral or lithotomy positions	Heated water is passed within a mattress, more effective and safer when placed over patients rather than under them
Circulating water garments	Conduction	Can transfer large amounts of heat, outperform forced air warmers, low risk of burns, no ambience warming	Bulky, risk of water leakage	Access both anterior and posterior surfaces of body
Forced air warmers	Convection	Readily available, completely eliminate heat loss, remarkably safe, reduce convective and radiant heat losses, fast warm up time, high warming capacity, do not cause burns, useful for rewarming	Can disrupt laminar air flow patterns, may harbor microbial pathogens, can contaminate surgical site, costly, warm ambience	Heated air is distributed through a specially designed blanket that circulates warm air around body, efficacy depends on blanket properties and surface area covered
Resistive heating devices	Conduction	Reusable, energy efficient, easy to clean, cost effective, good alternative to forced air warmers, do not interfere with surgical site	Can cause burns, long warm up time	Low voltage electric current is passed through semiconductive polymer or carbon fiber systems to generate heat
Negative pressure water warming systems			Can cause burns, role in intraoperative setting questionable since already vasodilated	Apply subatmospheric pressure with a thermal load improving subcutaneous perfusion and opening AV shunts, promote periphery to core transfer of heat
Radiant heaters	Radiation	Fast warm-up time, good warming capacity	Bulky, warm ambience, risk of burns	Used in postanesthesia recovery room

AV=Arteriovenous

- Bindu, B. et al. (2017). Temperature management under general anesthesia: Compulsion or option. *Journal of Anesthesiology Clinical Pharmacology*, 33(3), 306-316. Retrieved from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5672515/>

PREOPERATIVE PHASE



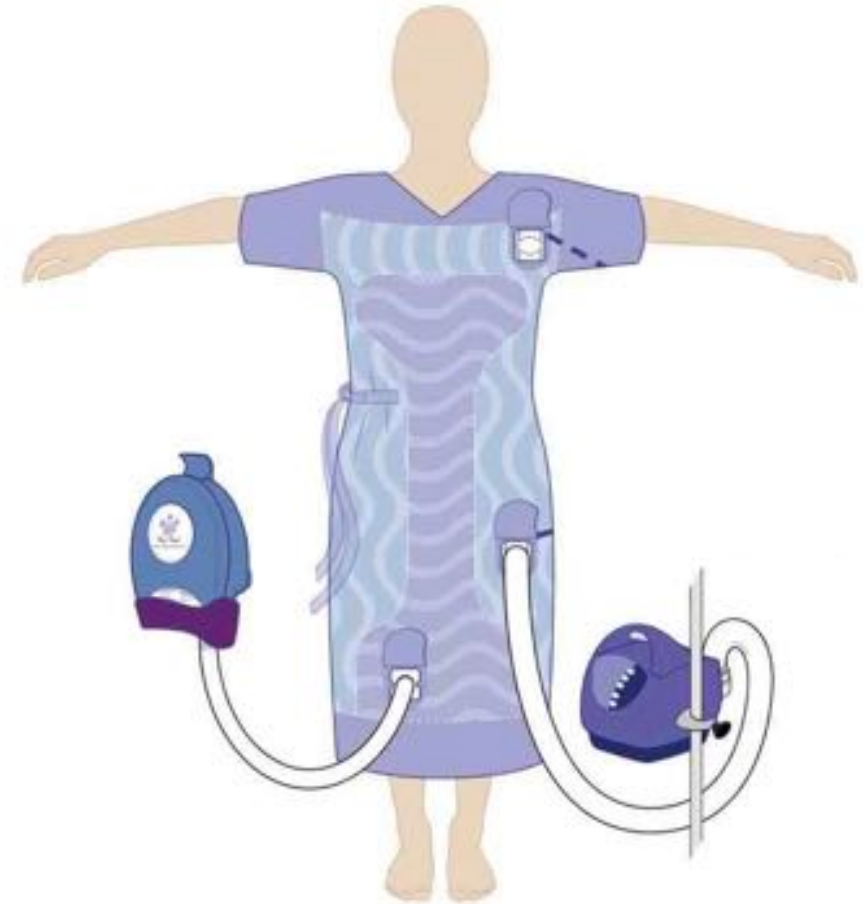
Measure the patient's temperature on admission



Cabinet warmed blankets



Forced warm air



Source: Matika, R. et al. (2017). The importance of body temperature: An anesthesiologist's perspective. 4(1): 9-12. Perioperative Normothermia Initiative Summary. Bindu, B. et. al. (2017). *Temperature Management Under General Anesthesia: Compulsion or Option*. 33(3): 306-316. Ruetzler, K. and Kurz, A. (2018). *Consequences of perioperative hypothermia*. 157: 687-697. Sessler, D. *Perioperative Temperature Management*. (UpToDate).

INTRAOPERATIVE PHASE

- **Ambient room temperature**
 - For non-trauma cases: room temperature should be set to 24°C.
 - Record room temperature in medical record.
 - Room temperature may be adjusted following prepping and draping of the patient as the patient's core temperature allows (if core temperature is above 37°C).
 - Almost 60% of heat loss can occur via radiation. The amount of heat loss depends on the fourth power of the temperature difference between the objects. If the operating room temperature is decreased by 2°C, heat loss will be increased by a factor of 16 (2^4)
- **Peri-induction and intraoperative management**
 - Forced air warmers should be applied and forced air turned to 40°C prior to induction and patient preparation.
 - Upper and lower forced air warming devices should be applied as soon allowed by the case and air temperature set as close as possible to 24°C prior to prepping the patient and maintained throughout case.
 - Intraoperative fluids and irrigation should be warmed to as close to 37°C as possible.

INTRAOPERATIVE PHASE

- Responding to possible concerns from operative team
 - 2015 study of surgeons performing standardized laparoscopic surgical procedures under two conditions, 19°C and 26°C, did not negatively impact technical performance despite surgeons' increased complaints about temperature at higher room temperature
 - 2018 study of operating room nurses, surgeons and anesthesia team performing clinical and cognitive tasks under three conditions, 21°C, 23°C, and 26°C, found no difference in performance based on room temperature

FLUID WARMING DEVICES

Device	Advantage	Disadvantage	Comments
Warming cabinets	Cheap & simple	Cooling of fluids with low flow rates	Fluid must be kept overnight to ensure uniform warming
Countercurrent warming system	No loss of heat even with low flow rates, efficient in delivering warm fluid at patient end compared to other fluid warming devices	Infection, air embolism, dilutional electrolyte disturbances if there is a leak in tubing.	Warm nonsterile water flowing around an inner sterile infusion lumen.
Blood warmer		Hemolysis causing reduced O ₂ carrying capacity, electrolyte disturbances	Maximum operating temperature is 43°C
Dry Heat Technology	Rate of heating is controlled and adjusted as per flow rate. Even small temperature changes can be sensed. Has been used with good success, no risk of contamination.		Uses aluminum plates to warm fluid near patient end.

POSTOPERATIVE PHASE

- Patients should be immediately covered with either warm blankets or a forced air device depending on the core temperature at the end of the case.
- Forced air warmers can continue to be used as well as other patient warmers including but not limited to:
 - Circulating water mattresses
 - Circulating water garments
 - Resistive heating devices
 - Negative pressure water warming systems
 - Radiant heaters

CONCLUSIONS



Control and management of body core temperature during the perioperative period are still overlooked by many physicians.



This can increase the risk of developing serious complications like hypothermia which can negatively affect patient outcomes.



Maintaining normothermia and following established, standardized guidelines approved by national organizations during this period should be established as a major priority for anesthesiologists and related personnel.

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