Importance of Normothermia

Patients at Risk
- Very young
- Very old
- Very sick

Regulation Types
- Homothermic
  - Warm-blooded
  - Body temp. remains constant even though the surrounding temp. changes.
- Poikilothermic
  - Cold-blooded
  - Take on the temp. of the environment

Normal Interthreshold Temperature Range

Normal Thermoregulation
- Narrow presets...37 degrees C (+/- 0.2)
- Positive and negative feedback
- Three phase process:
  - Afferent thermal sensing
  - Central regulation
  - Efferent responses

Afferent Input
- Both “warm” and “cold” receptors
  - Brain
  - Spinal cord
  - Abdomen
  - Thorax
  - Skin
- Cold signals travel in A delta and unmyelinated C fibers
- Ascend to the brain in anterior spino-thalamic tracts
Central Control

- Hypothalamus integrates information from the CNS and periphery
- Autonomic responses determined by core input
- Behavioral responses primarily reflect skin surface input

Efferent Responses

- Increase heat production
  - Non shivering thermogenesis (minor in adults, major in infants)
  - Shivering (absent in infants, major in adults)

- Reduce heat loss
  - Cutaneous vasoconstriction
  - Closure of thermoregulatory arteriovenous shunts
  - Behavioral responses

Heating Responses

- Mainly chemical process.
- Exothermic oxidative process is fueled by food.
- CO₂ is a measure of heat production.
- Brown Adipose Fat.
- Average 70 kg adult
  - Metabolic heat production produces 70 kcal/kg/hr
  - Offset by normal hourly heat loss

Drop in Core Temperature

For 70 kg adult:

- every 58 kcal heat loss in excess of production = 1°C drop in core temperature;
- Specific heat of Body x Body wt. in kg = kcal required to maintain normothermia
  \[ 0.83 \text{ kcal/kg/°C} \times 70 \text{ kg} = 58 \text{ kcal} \]

Hypothermia

- Clinical state of subnormal body temperature in which the body is unable to generate enough heat for bodily function.
- Core temperature of 35°C (95°F).
- Cold signals travel to hypothalamus primarily via delta fibers transversing spinthalamic tracts in anterior spinal cord.
- Below 35°C shivering, autonomic and endocrinologic responses unable to compensate without external warming.

Signs of Hypothermia

- Early signs
  - Shivering
  - Decreased sweating
  - Vasoconstriction
- If allowed to continue
  - Altered mental state
  - Muscle weakness
Physiologic Effects of Hypothermia

- Mild hypothermia (32-35°C, 90-95°F)
  - CNS depression, decreased basal metabolic rate, tachycardia and shivering. Patient may have amnesia, ataxia and apathy.
- Moderate hypothermia (27-32°C, 80-90°F)
  - Further depression of consciousness, mild depression of vital signs, arrhythmias and cold diuresis.
- Severe hypothermia (<27°C, 80°F)
  - May be comatose, areflexic or significant depression of vital signs.

Hypothermia During Anesthesia

- Heat is lost to the environment
- Presets are “re-set”
- Compensatory mechanisms are dampened or eliminated
- Winter sets in...

How does anesthesia predispose to hypothermia

- Anesthetics alter thermoregulation
  - Prevent shivering
  - Produce peripheral vasodilation
- Volatile anesthetics impair thermoregulatory center of hypothalamus.
  - Have direct vasodilatory properties.

Causes and Patterns of Heat Loss

- Initial rapid decrease in core temperature
- Slow reduction in core temperature
- Core temperature stabilizes

Effects of General Anesthesia

- Not much effect on sweating pre-set
Effects of General Anesthesia

- How does anesthesia predispose to hypothermia?
  - Opioids reduce vasoconstrictive mechanism by sympatholytic properties.
  - Barbiturates cause peripheral vasodilation.
  - Muscle relaxants reduce muscle tone and prevent shivering thermogenesis.
  - Regional anesthesia produces sympathetic blockade, muscle relaxation and sensory blockade of thermal receptors.

Effects of Neuroaxial Anesthesia

- Vasoconstrictive and shivering thresholds are lowered.
- Thermal inputs from blocked segments are altered.
- Sedatives impair thermoregulatory control.
- Patients may not “feel” cold.

Reflect the temperature of the external environment.
Who is at risk for hypothermia?

- Elderly
  - Reduced autonomic vascular control
- Infants
  - Large surface area-to-mass ratio
- Burns
- Spinal cord injuries involving autonomic dysfunction
- Endocrine abnormalities

What is the function of shivering?

- Spontaneous, asynchronous, random contraction of skeletal muscles in an effort to increase the basal metabolic rate.
- Modulated by hypothalamus.
- Can increase body's heat production by 300%.
- Increase O₂ consumption (200%) and CO₂ production.
- Undesirable with coronary artery disease and pulmonary insufficiency.

What is the nonshivering thermogenesis?

- Increases metabolic heat production without producing mechanical work.
- Infants < 3 months cannot shiver and mount a caloric response by nonshivering thermogenesis.
  - Skeletal muscle and brown fat tissue are the major energy sources for this process, which does not occur in anesthetized adults.
  - Mobilization of free fatty acid from fat mediated by increases in noradrenaline.

What are the pathophysiologic effects of hypothermia?

- Pulmonary
  - ↑ PuR and ↓ hypoxic pulmonary vasoconstriction resulting in ↑ VQ mismatch & hypoxemia.
  - ↓ ventilatory drive
    - PCO₂ ↓ 50% per 8°C ↓ in temperature, thus little respiratory stimulus to breathe.
    - ↓ bronchomotor tone, ↑ anatomic dead space.
    - ↓ PH by 0.015 units per °C ↓ in temperature.

- Vascular
  - ↑ SVR and CVP.
  - ↓ reliability of pulse oximetry and IABP.

- Cardiac
  - ↑ O₂ consumption by up to 200%, thus ↑ myocardial O₂ demand.
  - ↓ HR, & CO

- Renal
  - ↓ Renal blood flow (RBF), glomerular filtration rate (GFR)
  - ↓ protein catabolism & diuresis with spilling of urinary nitrogen. Cold diuresis due to impaired reabsorption may lead to hypovolemia.
  - ↓ ability to concentrate or dilute urine.

- Hepatic
  - ↓ hepatic blood flow, metabolic and excretory function.
What are the pathophysiologic effect of hypothermia?

- Central nervous system
  - ↓ CBF, ↑ cerebral vascular resistance
  - ↓ cerebral metabolic O₂ consumption by 7% per °C in temperature.
  - Sedation occurs at 33°C and cold narcosis at 30°C.
  - ↓ MAC resulting in delayed emergence, drowsiness and confusion.

- Hematologic
  - ↓ platelet function, visceral sequestration and platelet aggregation result in thrombocytopenia.
  - ↓ clotting factor activity with impaired coagulation and ↑ fibrinolysis.
  - ↑ blood viscosity by 3% for each °C ↓ in temperature.
  - ↓ plasma volume by 25% for each 11°C because of cold diuresis and impaired sodium reabsorption.

- Metabolic
  - ↓ BMR and tissue perfusion resulting in metabolic acidosis.
  - Acute hyperkalemia a risk in rewarming.
  - ↓ insulin level may result in hyperglycemia and decreased insulin responsiveness.
  - ↓ O₂ consumption and CO₂ production by 8% per °C of temperature.

- Intraocular pressure
  - ↓ in aqueous humor production and vasoconstriction.

- Healing
  - ↓ in immune system may increase risk of infection.
  - ↓ O₂ delivery to wound by triggering thermoregulatory vasoconstriction.

- Intraocular pressure
  - ↓ in aqueous humor production and vasoconstriction.

Hypothermia Effects on EKG

- Mild hypothermia
  - Bradycardia

- Moderate hypothermia
  - ↑ PR interval, QRS complex and QT interval.
  - ↓ 32°C may be an elevation of the junction of the QRS and ST segment known as the hypothermic hump or J wave. Size ↓ as temp ↓. Seen best in lead II and V6. Not specific to hypothermia but seen in hypothalamic lesions and cardiac ischemia.

- Profound hypothermia
  - ↓ 30°C - nodal rhythms
  - ↓ 28°C - PVCs, atrioventricular blocks, atrial and ventricular fibrillation.
  - A-fib and V-fib ↓28°C unresponsive to atropine, countershock, or pacing. Resuscitative efforts need to continue until the patient is rewarmed.
Pharmacologic Effect of Hypothermia

- ↓ hepatic and renal blood flow cause ↓ metabolism and excretion of drugs.
- ↑ protein binding.
- ↓ MAC by about 5-7% per °C, but ↓ CO and ↑ blood solubility result in no change in speed of inhalation induction.
- ↑ Duration of neuromuscular blocking drugs because of ↓ metabolism.

Benefits of Mild Hypothermia

- Substantial protection against ischemia and hypoxia (1-3 degrees).
- May be indicated for carotid endarterectomy or neurosurgery.
- Malignant hyperthermia is more difficult to trigger and is less severe.

Causes and Patterns of Heat Loss

- **Radiation**: major source of heat loss, temperature gradient dependent
- **Conduction**: minor (adjacent surfaces)
- **Convection**: wind chill (moving conduction)
- **Evaporation**: heat lost through wounds, can be significant

Mechanisms of Heat Loss

- **Radiation**: dissipation of heat to cooler surroundings
- **Conduction**: accounts for about 60% of heat loss
- **Convection**: depends on cutaneous blood flow and exposed body surface area.
- **Evaporation**: heat lost through wounds, can be significant

Hypothermia delays discharge from the postanesthesia care unit and may prolong the need for mechanical ventilation.
Mechanisms of Heat Loss

- Convection
  - Accounts for about 15% of heat loss.
  - Depends on air flow over exposed areas.
  - Loss
    - 10 kcal/hr

- Evaporation
  - Accounts for 20% of heat loss due to latent heat of evaporation (energy required to vaporize liquid from serosal and mucosal surfaces)
  - Depends on exposed surface area and relative humidity of ambient air.
  - Loss
    - 12-16 kcal/hr from skin and respiration
    - up to 400 kcal/hr from exposed viscera and body cavities
    - 6-8 kcal/m² from skin prep solutions

- Conduction
  - Depends on transfer of heat between adjacent surfaces.
  - Accounts for 5% of total heat loss.
  - Depends on temperature gradient and thermal conductivity.
  - Loss
    - IV fluids at 20°C: 17 kcal/L
    - Blood at 7°C: 9 kcal/unit
    - 1 unit of refrigerated blood or 1 liter of room temperature crystalloid ↓ body temperature about .25°C

- Redistribution
  - Direct result of general anesthesia;
  - Transfer of heat from warmer core to colder periphery.
  - Loss
    - 46 kcal for 1st hour of general anesthesia
    - 17 kcal for subsequent hours.

- Major Causes of Heat Loss in OR
  - Cold rooms
  - Cold IVs
  - Prepping solutions
  - Exposure of patient

- Cutaneous heat loss proportional to exposed surface area.
- General anesthetics cause Vasodilitation and ↓ heat production.
- Loss of hypothalamic responsiveness due to volatile anesthetics results in inability to mount a caloric response to ↓ body temperature.
- NM block agents prevent shivering.
- < 10% heat loss through respirator tract.
Hypothermic Disease Processes

- Hypothyroidism
- Hypothalamic lesions
- Age
  - Elderly and very young at increased risk due to poor temperature regulation.
  - BMR ↓ 1%/year of age after 30.
  - Infants have ↓ ability to shiver.

Challenges in Management

- Initial reduction in core temperature is difficult to prevent (thermoregulatory effect). Hint: try pre-warming.
- Surgeons often resist raising ambient temperatures.
- Vasoconstriction goes both ways.

Interventions to Prevent Heat Loss

- PreWarming
- Airway warming
  - Passive: HMEs
  - Active: heaters
- Fluid warmers…it’s all about the same
- Cutaneous warming
  - Room temperature
  - Passive insulation
- Forced air, the undisputed champion...

Passive Insulation I

Passive Insulation II

Stuff That Really Works...
Methods of Rewarming

**Passive**
- Uses body's ability to provide heat by minimizing exposed areas.
- Hypothalamic mechanisms must be intact and glycogen stores available because it relies on shivering thermogenesis.

**Active**
- Includes using warmed IV fluids, radiant heat lamps, and warming blankets (especially forced air blankets).
- Air rewarming less effective because heat content of gases is poor.
- Heated irrigation or extracorporeal circulation.

Methods of Rewarming

Core Temperature Afterdrop, a secondary decline in core temperature with rewarming, may result from the return of cold blood from the periphery.

Acceptable Temperature Monitoring Sites

- Skin - may vary from core temperature by 3-4°C.
- Axilla - approximately 1°C below core.
- Rectum - does not reflect rapid change.
- Esophagus - lower 1/3 of esophagus reflects core and blood temperature.
- Nasopharynx - reflects brain temperature.
- External auditory meatus - reflects core temperature.
- Bladder catheter - approximates core temperature with high urine output.
- Pulmonary artery catheter - reflects core temperature.

Prevent Hypothermia in OR

- Warm ambient room temperature
  - All patients become hypothermic at common OR temperatures.
- Cover exposed areas to reduce conductive and convective losses.
  - Full body coverage with warmer on high for 2 hours can increase core temperature 1°C.
- Warm IV fluids or use fluid warmers.
  - Fluids may be warmed up to 40-42°C.
  - Reverses -17 kcal insult and adds 5 kcal of positive heat.
Prevent Hypothermia in OR

■ Heated humidifiers to minimize evaporative losses and warm compressed gases.
■ Maintain closed or low-flow semiclosed circuits to decrease evaporative losses and conserve anesthetic vapors.
■ Warming blankets for conductive transfer of heat.

Prevent Hypothermia in OR

■ Radiant warmers and heat lamps
  ■ Especially with pediatric patients who have high surface area-to-weight ratio and cannot mount a caloric response.
  ■ Irrigate with warm solutions.

Hyperthermia

Rise in body temperature of 2°C per hour.
■ Uncommon in OR
■ Usual cause sepsis or stress response.
■ Hypothalamic lesions and hyperthyroidism less common.
■ Malignant hyperthermia or catecholamine surge possible.
■ Occasionally overly vigorous rewarming.

Heat Exhaustion

■ Syndrome of volume depletion and heat stress that result in mild hyperpyrexia, somatic complaints (N&V, lightheadedness), dehydration but mental status unchanged.
■ Active cool therapeutic with good prognosis.

Heat Stroke

Body temperature above 40°C or 106°F with associated changes in mental status.
■ Heat dissipation mechanism overwhelmed.
■ Risk of multi-system organ failure.

Hyperthermic Conditions

■ Malignant Hyperthermia
■ Hypermetabolic states
  ■ sepsis, infection, thyrotoxicosis, pheochromocytoma
■ Hypothalamic lesion secondary to trauma, anoxia, or tumor
■ Neuroleptic malignant syndrome
■ Transfusion reaction
■ Medications
Drugs Associated with Hyperthermia
- Sympathomimetic drugs
- Monoamine oxidase inhibitors
- Cocaine
- Amphetamines
- Tricyclic antidepressants - ↑ BMR & Heat
- Anticholinergics - Vasodilitation and ↓ sweating
- Antihistamines - ↓ sweating

Pharmacologic Effects
- Increase BMR and hepatic metabolism
- ↓ half-life of anesthetic drugs.
- ↑ anesthetic requirements.

Treatment
- Cooling blankets
- Cool IV fluids
- Antipyretics
- Vasodilators may increase conductive heat loss
- Determine cause

Looking at the Big Picture...
- Fluid warmer can make a difference.
- Forced air blankets are the most effective at putting heat into the system.

Conclusions...
- Heat loss during surgery is nearly unavoidable.
- Prevention of hypothermia is preferable to treatment, and is cheaper.
- Hypothermia may eventually influence reimbursement.
- Use the things that work.
- Discourage those that don’t.

Questions?