Body temperature and control

MD 532 109 : Skin and related connective tissues

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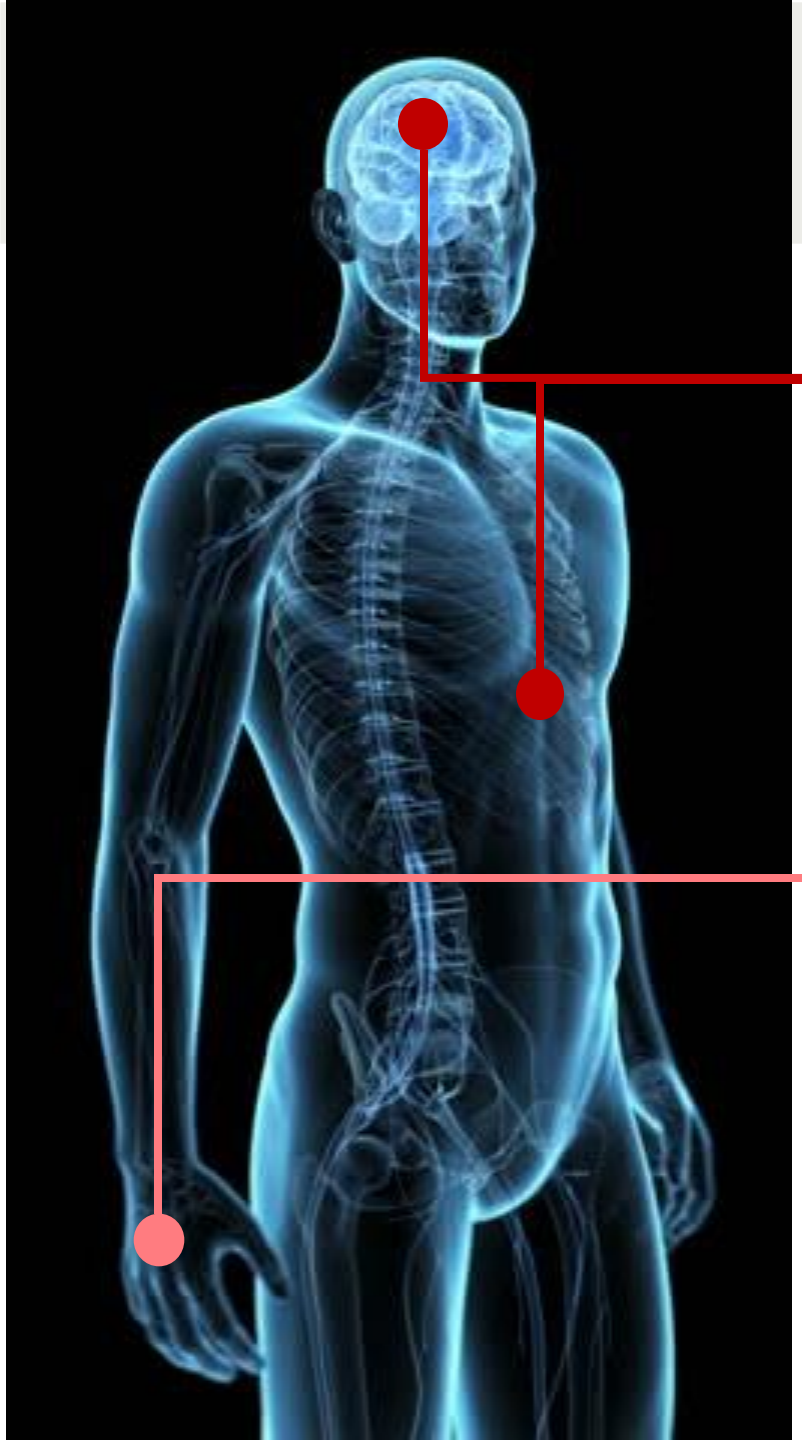
CONTENTS

- Normal body temperature
- Factors affecting body temperature
- Body temperature measurement
- Mechanism of heat loss and production
- Body temperature regulation
- Abnormality of thermal regulation

Objectives

- Define normal body temperature and factors affecting body temperature
- Describe body heat loss and heat production mechanisms
- Explain the temperature-regulating mechanisms
- List the abnormalities of body temperature



A range of normal body temperature

Core temperature

- *The temperature of the deep internal tissues of the body*

  Ex; brain, thorax, abdomen, heart, lungs, liver, and kidneys

- *Very constant, within ± 0.6°C*

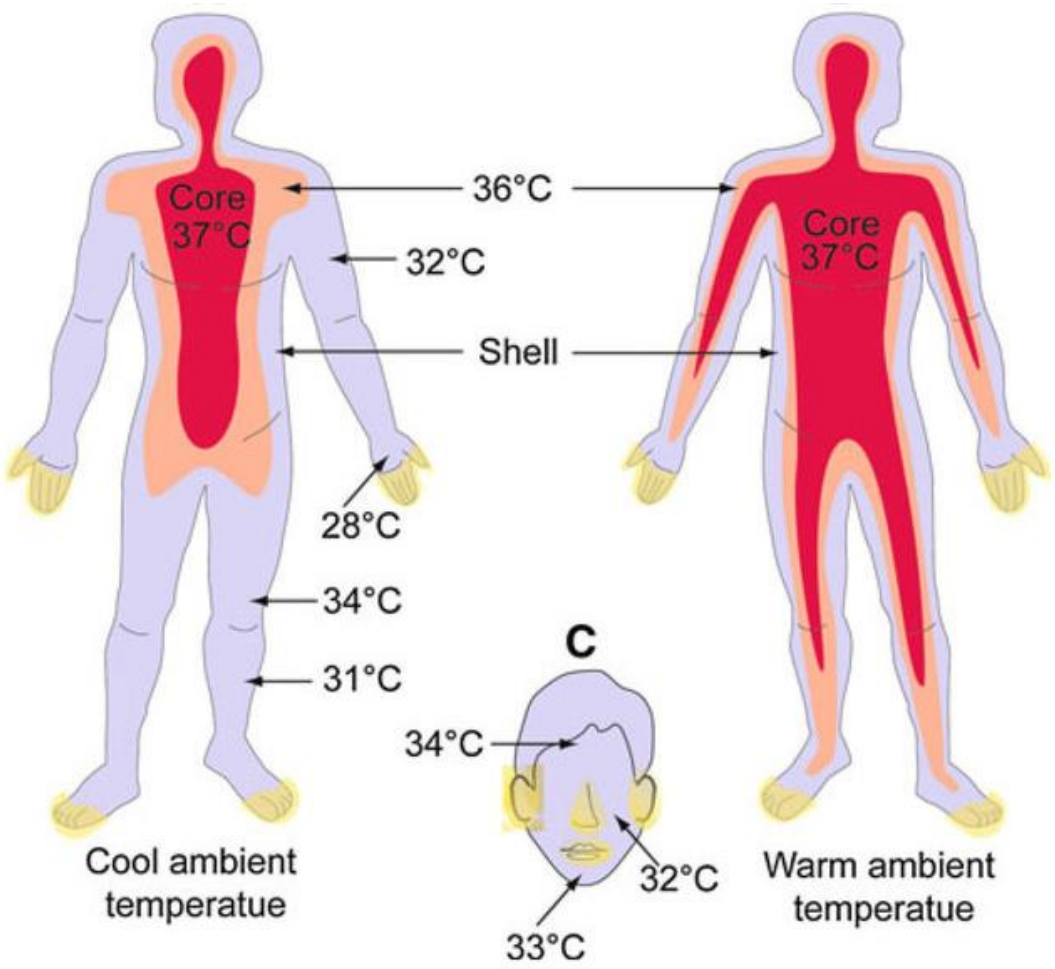
Peripheral (skin) temperature

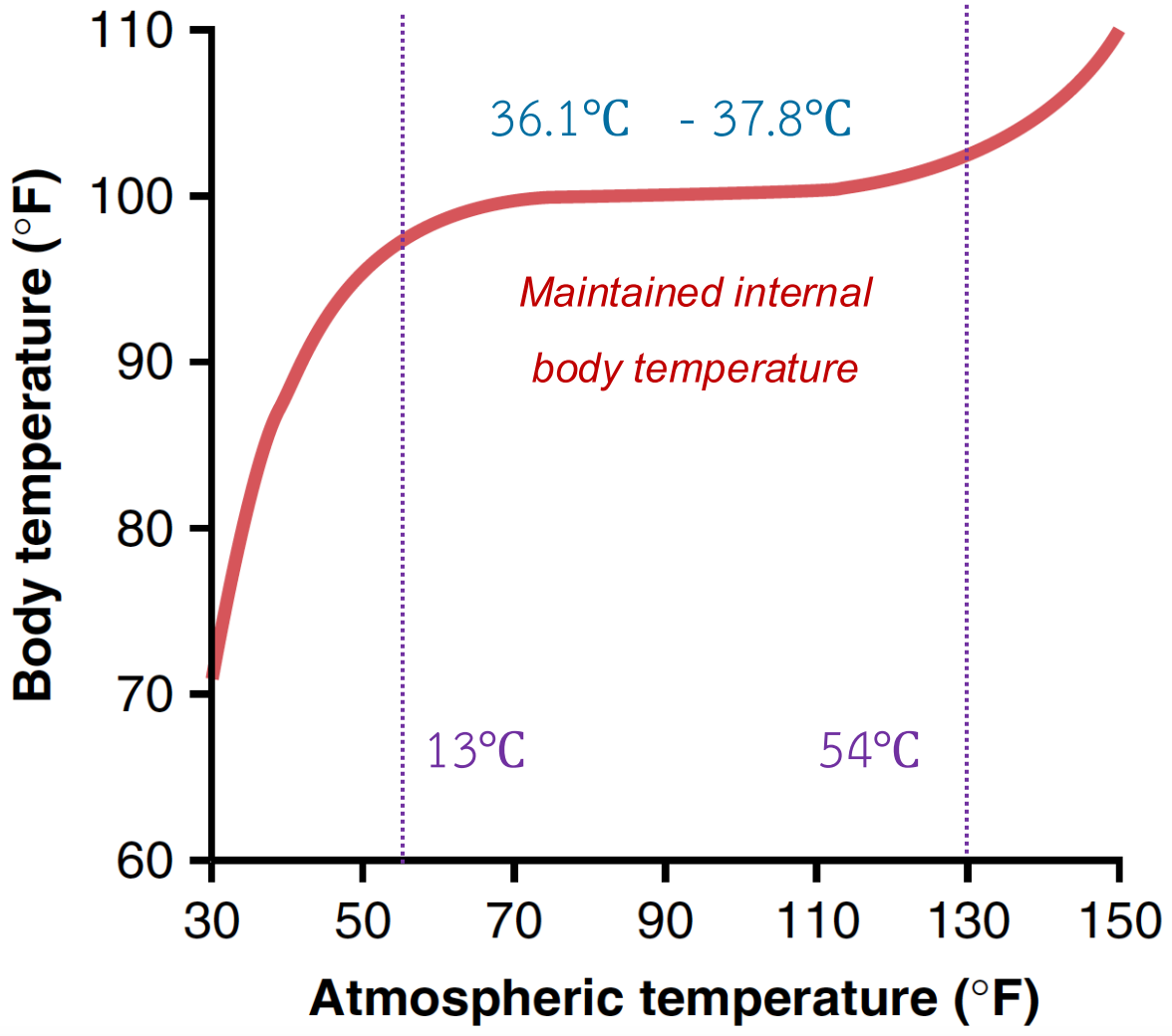
- *The temperature of peripheral organs of the body*

  Ex; skin, subcutaneous tissues, limbs

- *Rises and falls with the temperature of the surroundings*

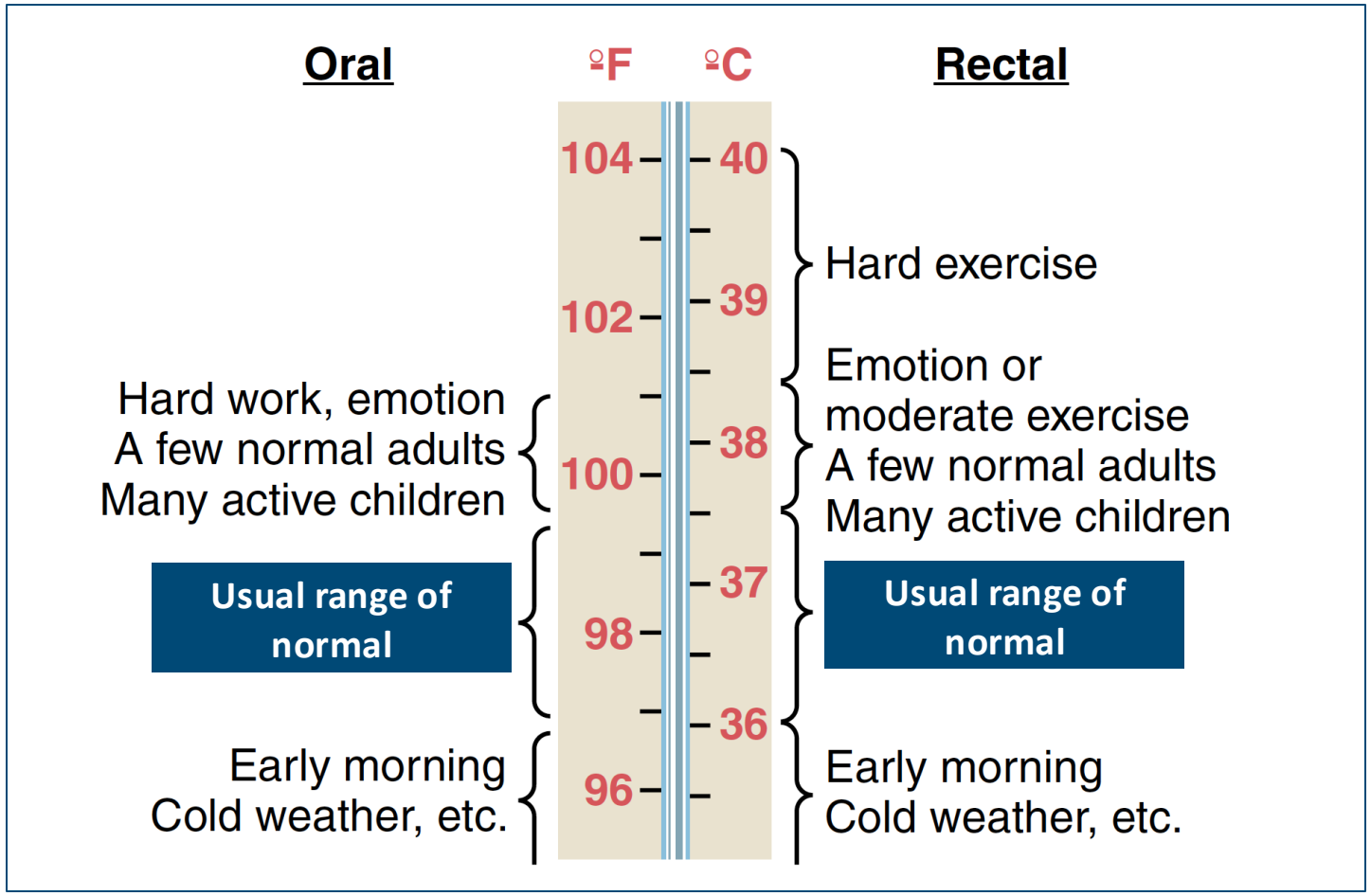
The body temperature in different temperature





A range of normal body temperature

" No single core temperature "

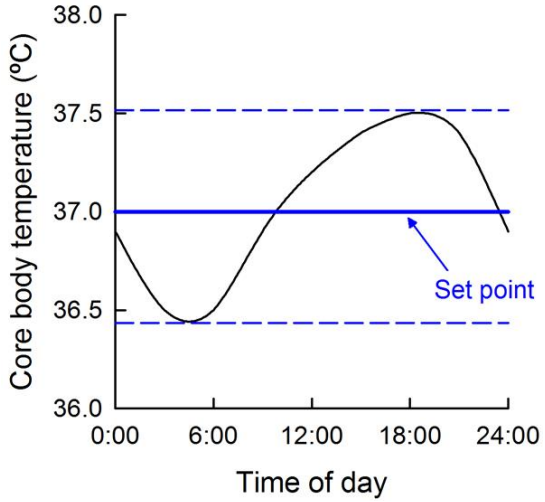


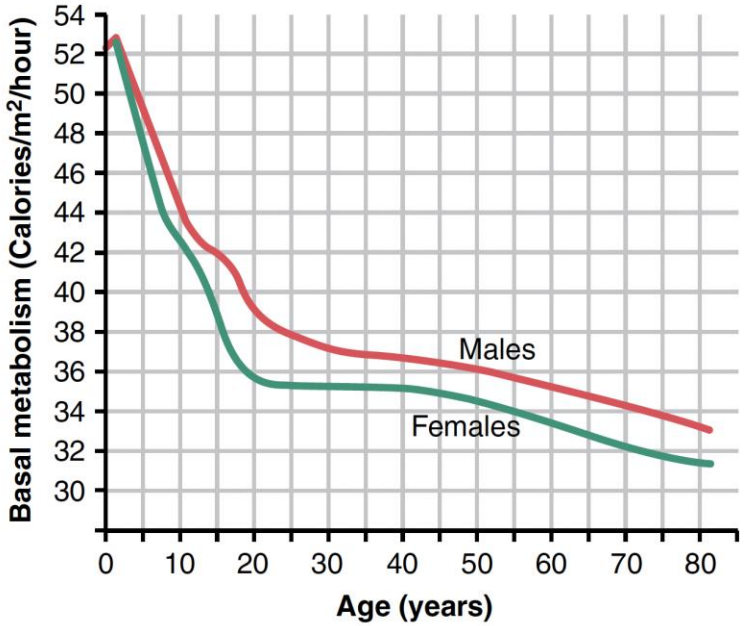
Normal range: **36° - 37.5 °C**

Average: **37 °C**

Factors affecting body temperature

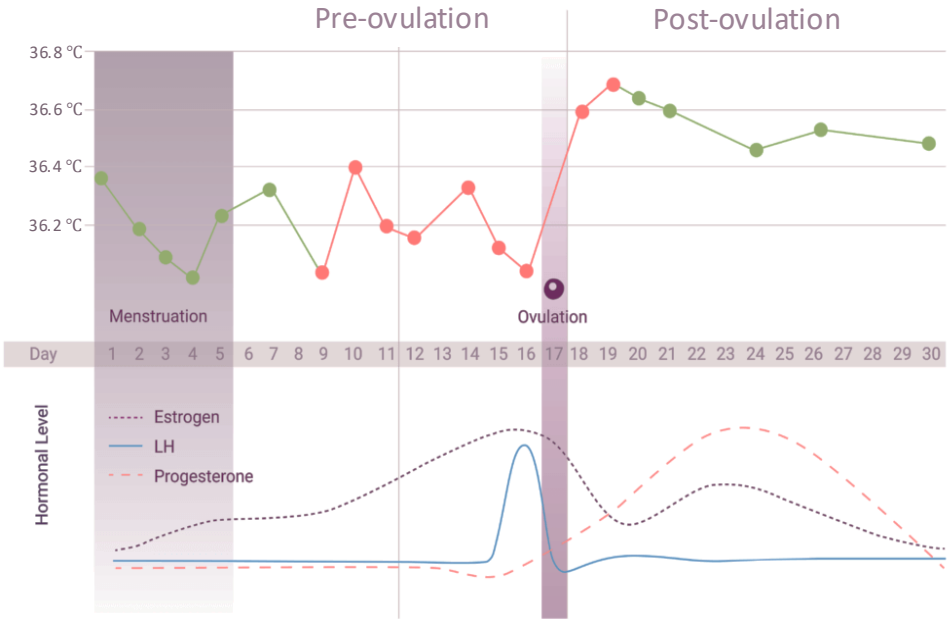
- ***Circadian rhythmicity***
  - ***Linked to sleep-wake cycle***
  - ***Highest*** *in the late afternoon* ***/ Lowest*** *in the early morning*
- ***Ages***
  - ***Linked to metabolic rate/fat accumulation/muscle mass***
  - ***Younger > Elderly***
- ***Sex***
  - ***Male > Female***



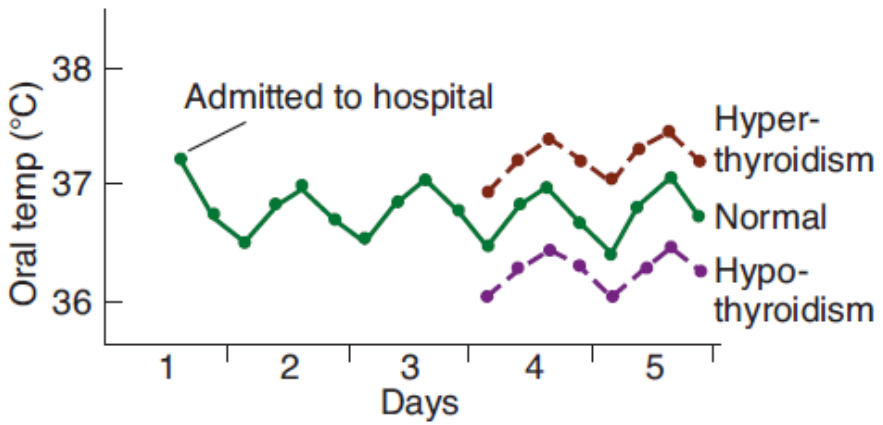


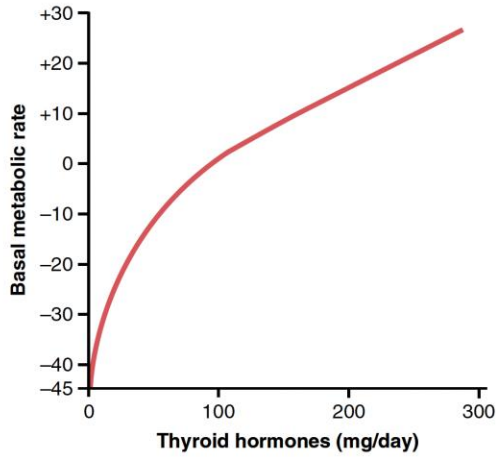
Factors affecting body temperature

- ***Menstrual cycle***
  - ***Progesterone drives BBT to increase***



- ***Hormones***
  - ***Thyroxine***
  - ***Growth hormone***
  - ***Male sex hormone***





Factors affecting body temperature

- ***Activities***
  - ***Linked to muscular activity or emotional excitement***

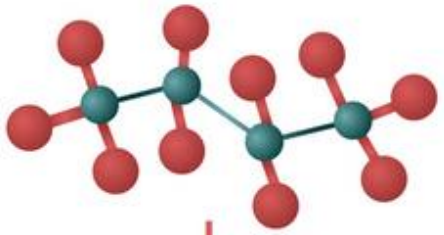
Form of Activity	Calories per Hour
Sleeping	65
Awake lying still	77
Sitting at rest	100
Standing relaxed	105
Dressing and undressing	118
Typewriting rapidly	140
Walking slowly (2.6 miles per hour)	200
Carpentry, metalworking, industrial painting	240
Sawing wood	480
Swimming	500
Running (5.3 miles per hour)	570
Walking up stairs rapidly	1100

- ***Metabolism***
  - ***Extra metabolism linked to hormones and sympathetic stimulation***
  - ***Thermogenic effect of food***

Metabolism *" The chemical processes in the body "*

Catabolism

- *The metabolic processes that **breaks down** molecules into smaller units*
- *Amounts of **energy (mostly ATP) are released***



Breakdown
Large molecule

release

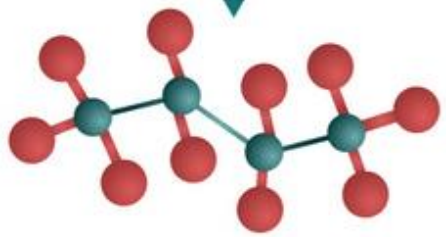
ENERGY + HEAT

Anabolism

ENERGY

uptake

Synthesize
Large molecule



+ HEAT

- *The **synthesis** of complex molecules from smaller units*
- ***Utilization of the energy** released by catabolism*

Body temperature measurement

Core temperature

36.0 - 37.5°C

Esophageal and tympanic temperature

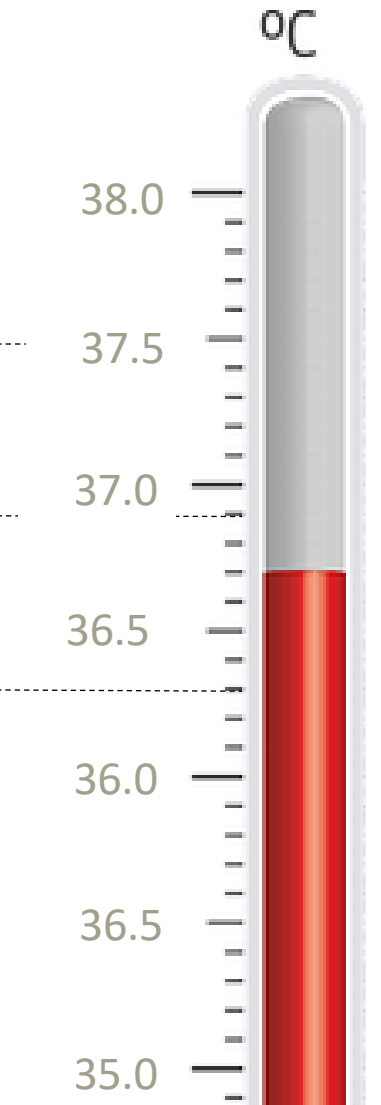
Rectal temperature

Oral temperature

< Rectal temp ≈ 0.6 °C

Axillary temperature

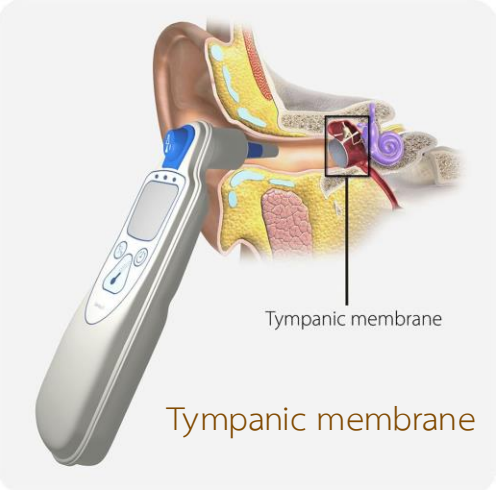
< Oral temp ≈ 0.6 °C



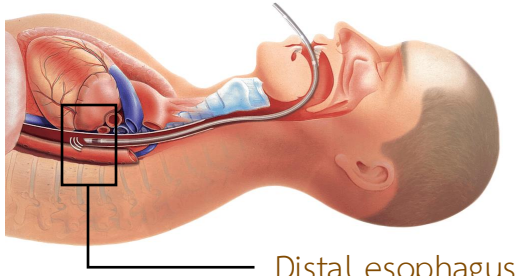
Body temperature measurement

Clinically accessible sites for core temperature measurement :

Tympanic membrane	The most central site, but danger of damaging tympanic membrane
External auditory meatus	Close to tympanic membrane. Needs to be insulated from atmosphere
Nasopharyngeal	Central site. Easy to use in anaesthetized patients
Esophageal	Close to heart. Suitable for anaesthetized patients. May be affected by inflow of tracheal gases during artificial ventilation
Rectal	Slow to respond to changes in central temperature. Higher temperature than tympanic. Tolerated for long periods by conscious individual
Axillary/sublingual	Sites of high blood flow. Lower than tympanic measurement
Bladder	Similar to rectal



Tympanic membrane


Distal esophagus


Rectal temperature

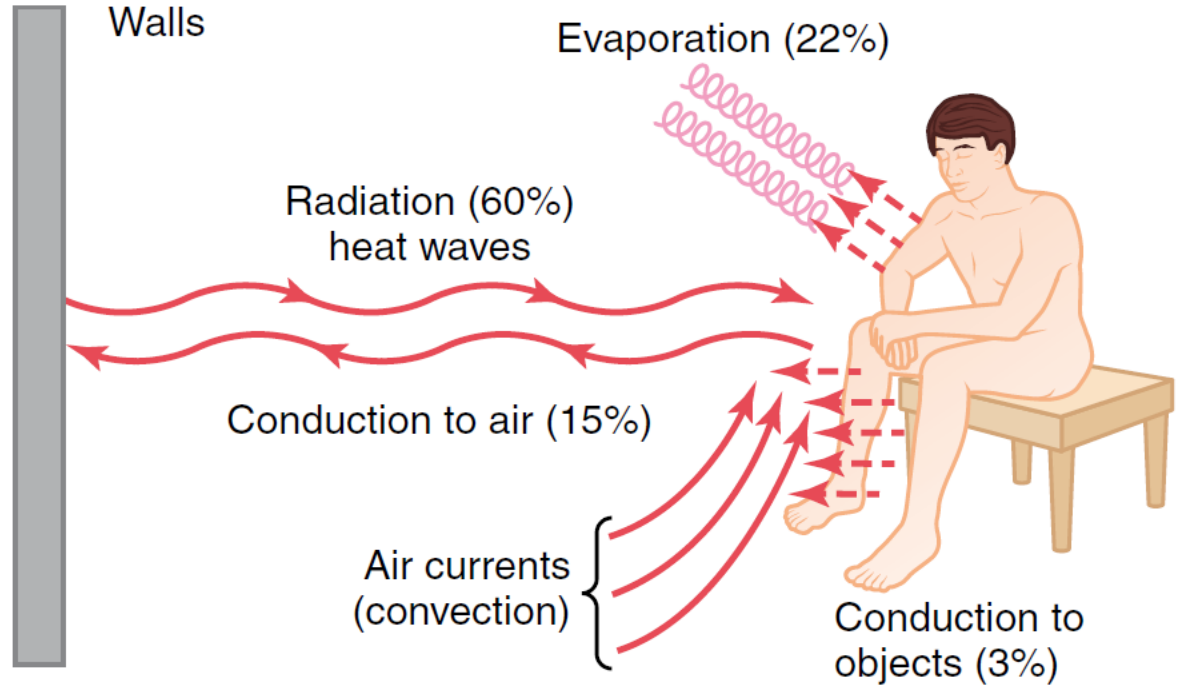
Body temperature is controlled by

body heat loss and heat production balance

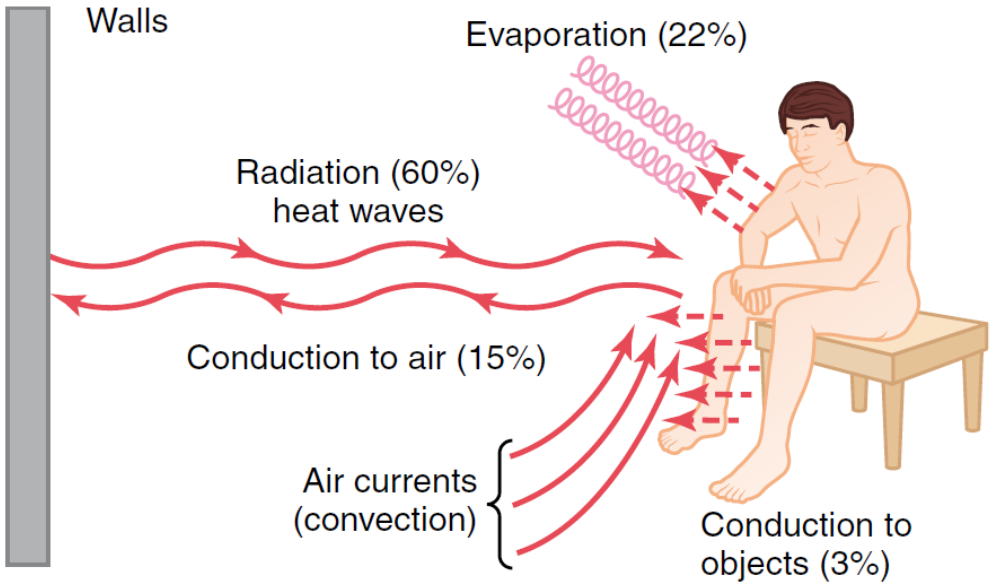
Heat production

- Basal metabolic processes
- Extra metabolism (sympathetic & hormone)
- Dietary thermogenesis
- Voluntary muscular activity
- Involuntary muscle activity (shivering)
- Non- shivering thermogenesis

Heat loss



Heat loss mechanism



Evaporation

Evaporative heat loss occurs primarily through the skin and the respiratory system

Radiation

Loss of heat in the form of infrared heat rays

Convection

The transfer of heat to moving molecules such as air or liquids

Conduction

Heat transfer between two surfaces in direct contact

Insulator system of the body

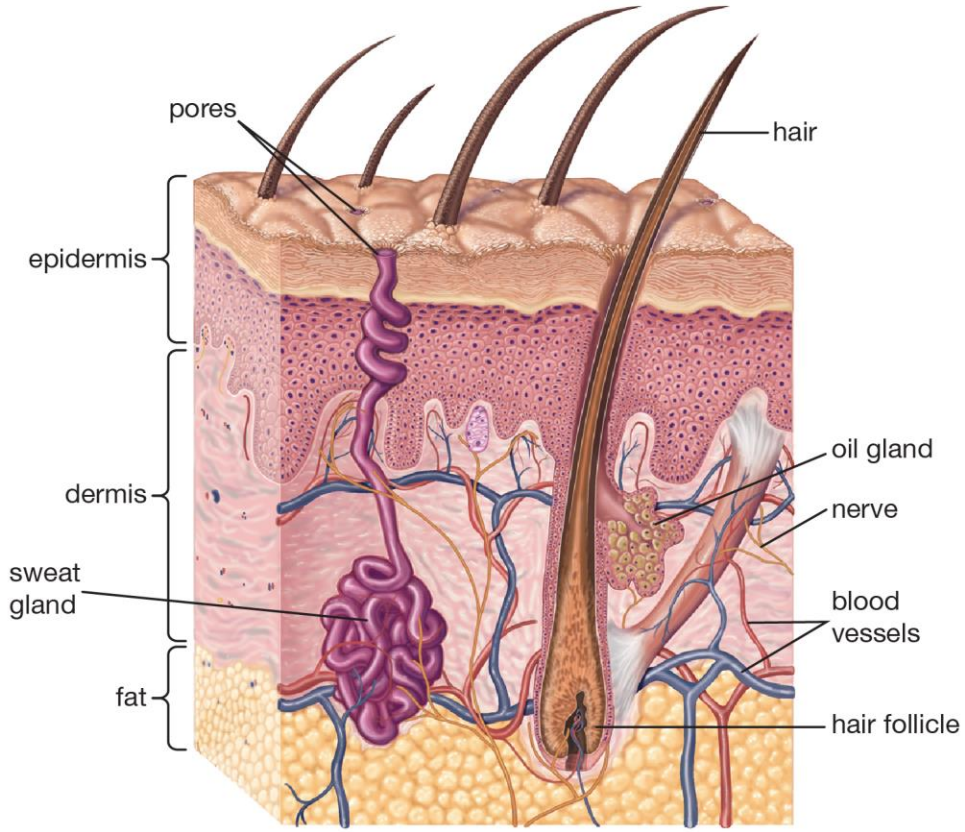
Maintaining system for normal internal core temperature

Heat insulator for the body: *The skin, the subcutaneous tissues, and especially the fat*

Insulator properties: *female* > ***male***

Function of insulator system

- Prevent body heat loss
- Allows the temperature of the skin to approach the surroundings temperature



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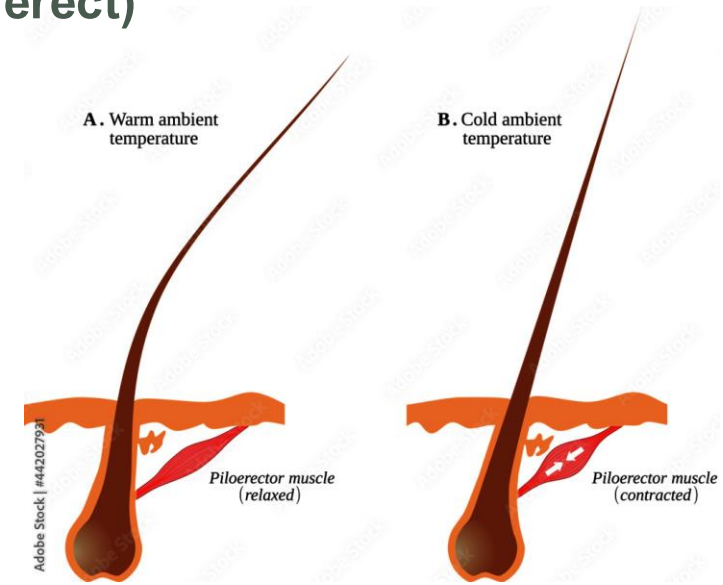
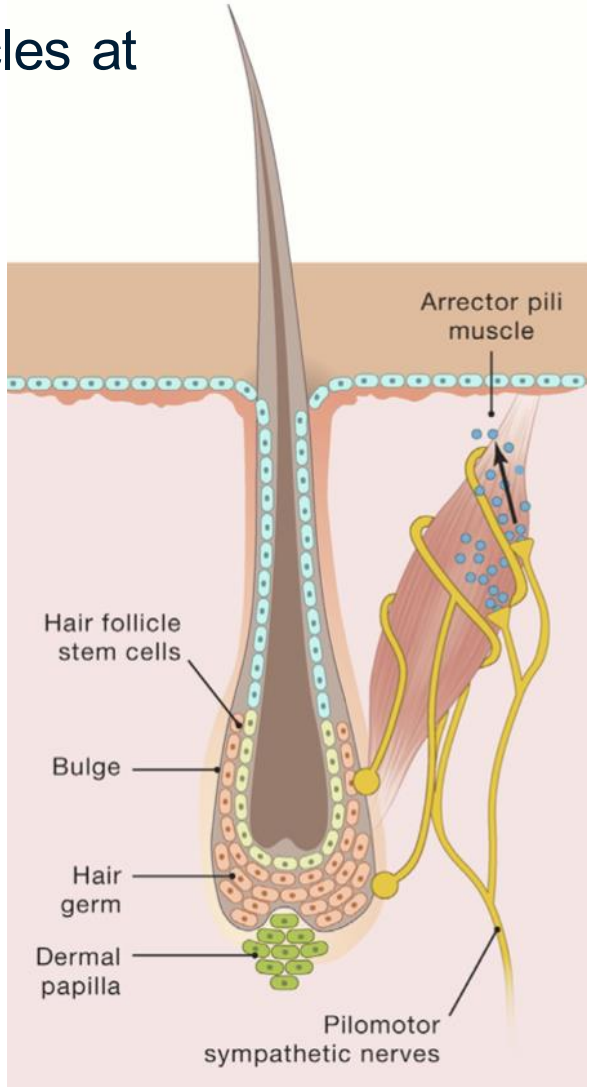
Piloerection *helping to insulate the body and retain heat*

Piloerection is a physiological response involving the contraction of muscles at the base of hair follicles, causing hairs to stand erect.

The sympathetic pilomotor nerves, which release the norepinephrine (NE) to trigger arrector pili muscles contraction and cause piloerection (hairs to become erect)

in response to cold



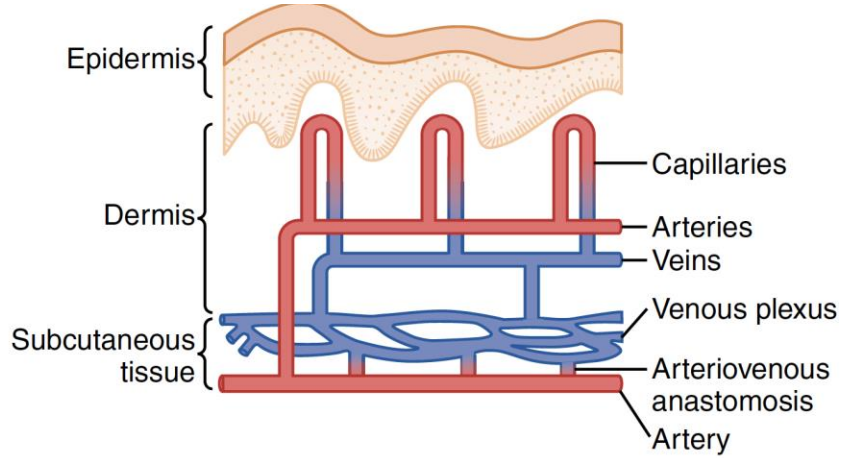


Pascalau R, Kuruvilla R. A Hairy End to a Chilling Event. Cell. 2020 Aug 6;182(3):539-541. doi: 10.1016/j.cell.2020.07.004. PMID: 32763185.

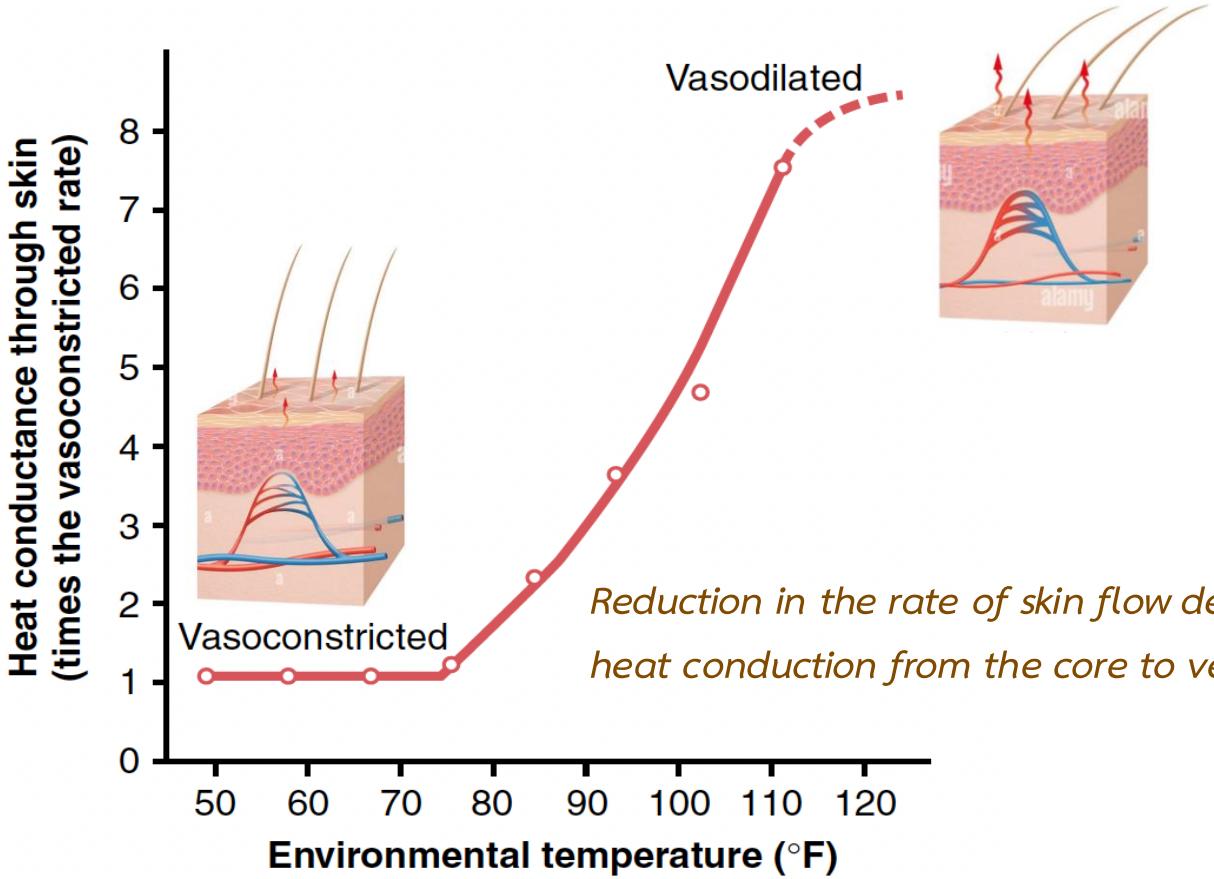
Blood flow and heat transfer

Heat is transferred from the deeper organs and tissues to the skin, where it is lost to the air and other surroundings

Blood flow from the body core to the skin provides **heat transfer**



A high rate of skin flow causes heat to be conducted from the body core to the skin with great efficiency



Reduction in the rate of skin flow decrease the heat conduction from the core to very little

Arteriovenous anastomosis

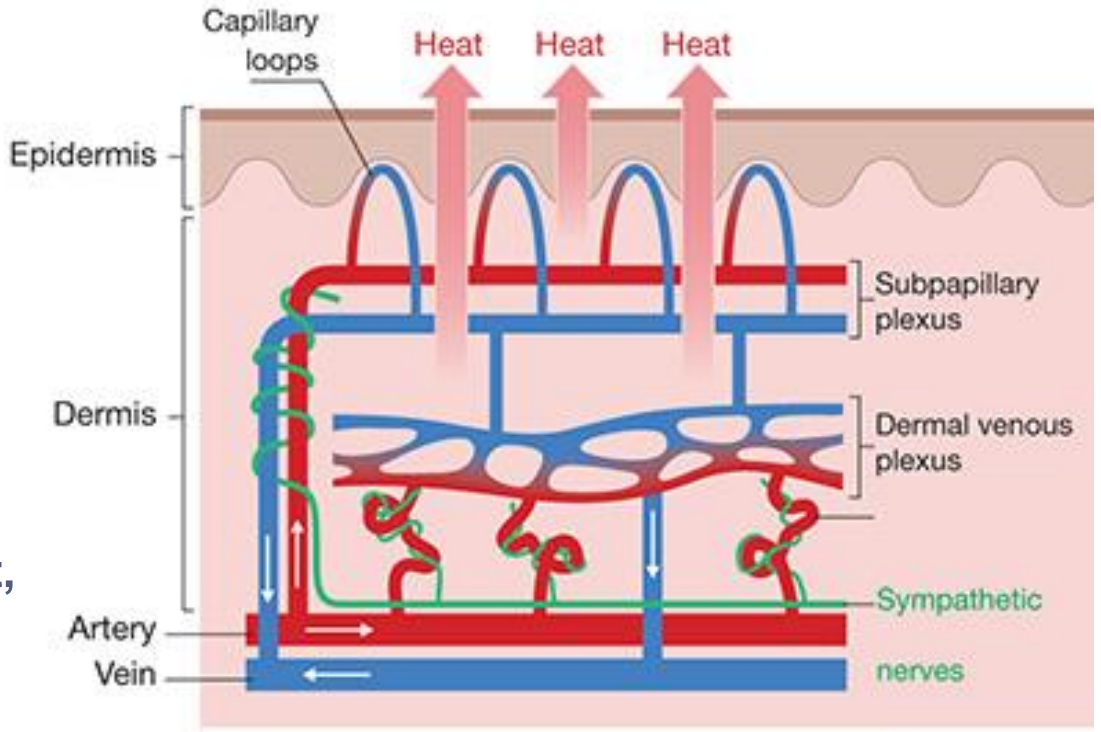
An arteriovenous anastomosis (AVA) is a direct connection between an artery and a vein, bypassing the capillary network

The intermediate segments of the AVAs are richly innervated with **sympathetic nerves**

AVAs play a key role in regulating body temperature

- When the body needs to cool down, **AVAs open,** allowing warm blood to flow closer to the skin surface where heat can be more dissipated

- When the body needs to conserve heat, **AVAs constrict,** diverting blood away from the skin's surface



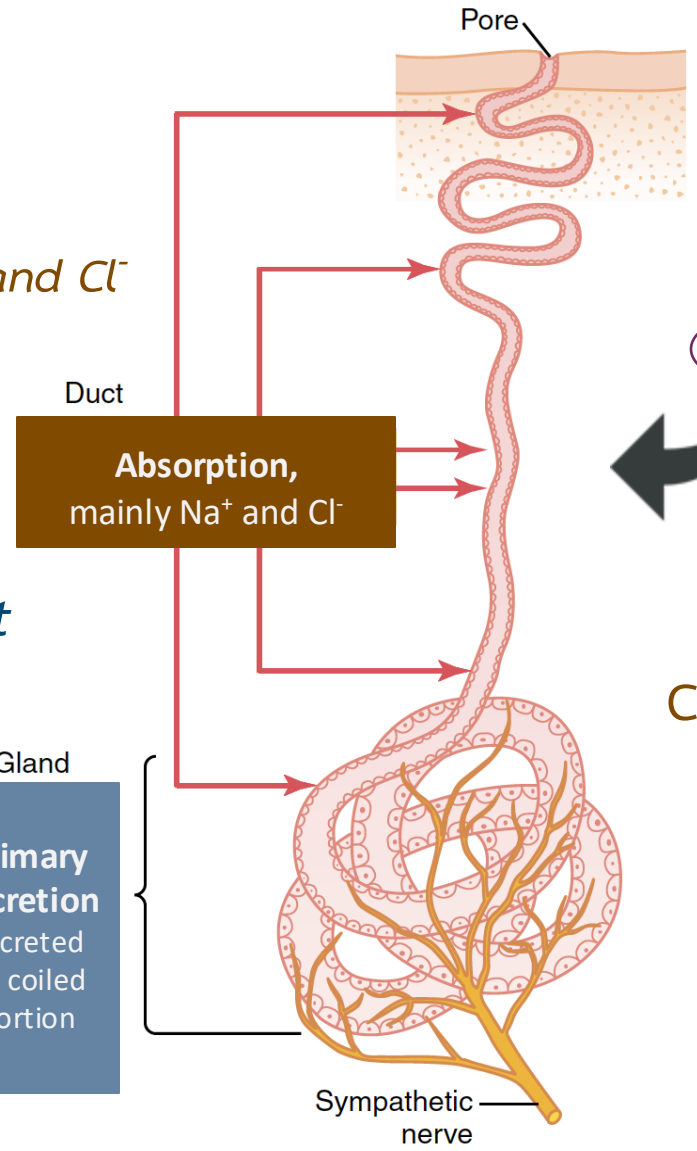
Sweat gland: *A tubular structure consisting 2 portions*

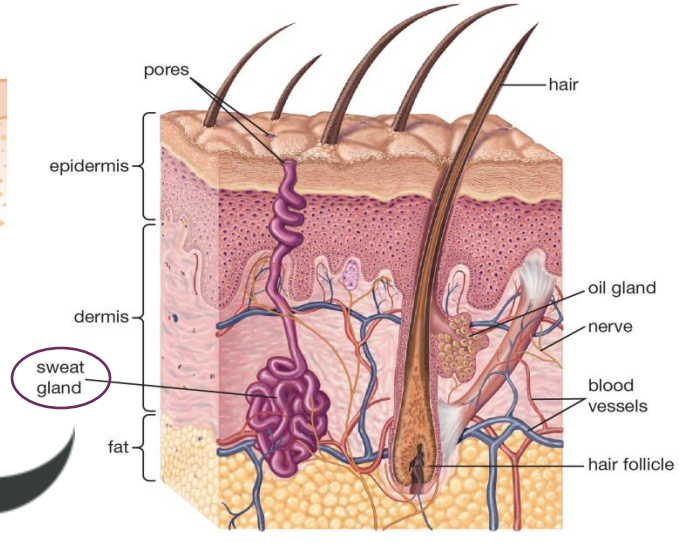
❖ *A duct portion*

>>> modifies primary secretion

by reabsorption of most of the Na^+ and Cl^-

The degree of this reabsorption depends on **the rate of sweating**





❖ *A coiled portion >> secretes the sweat*

- A fluid called the primary secretion or precursor secretion
- The composition is similar to plasma
  - Na^+ ~ 142 mEq/L
  - Cl^- ~ 104 mEq/L
  - Free protein

Innervated by

Cholinergic sympathetic nerve;

secrets acetylcholine (Ach)

These glands can also be stimulated by epinephrine or norepinephrine circulating in the blood

Sweating secretion

Binding of Ach to muscarinic receptors

↓

↑ Intracellular Ca^{2+}

↓

Efflux of K^+ and Cl^-

↓

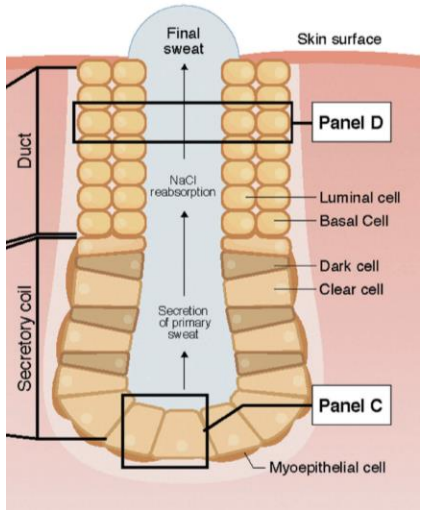
Triggers an influx of Na^+, K^+, and Cl^- via Na-K-2Cl cotransporters

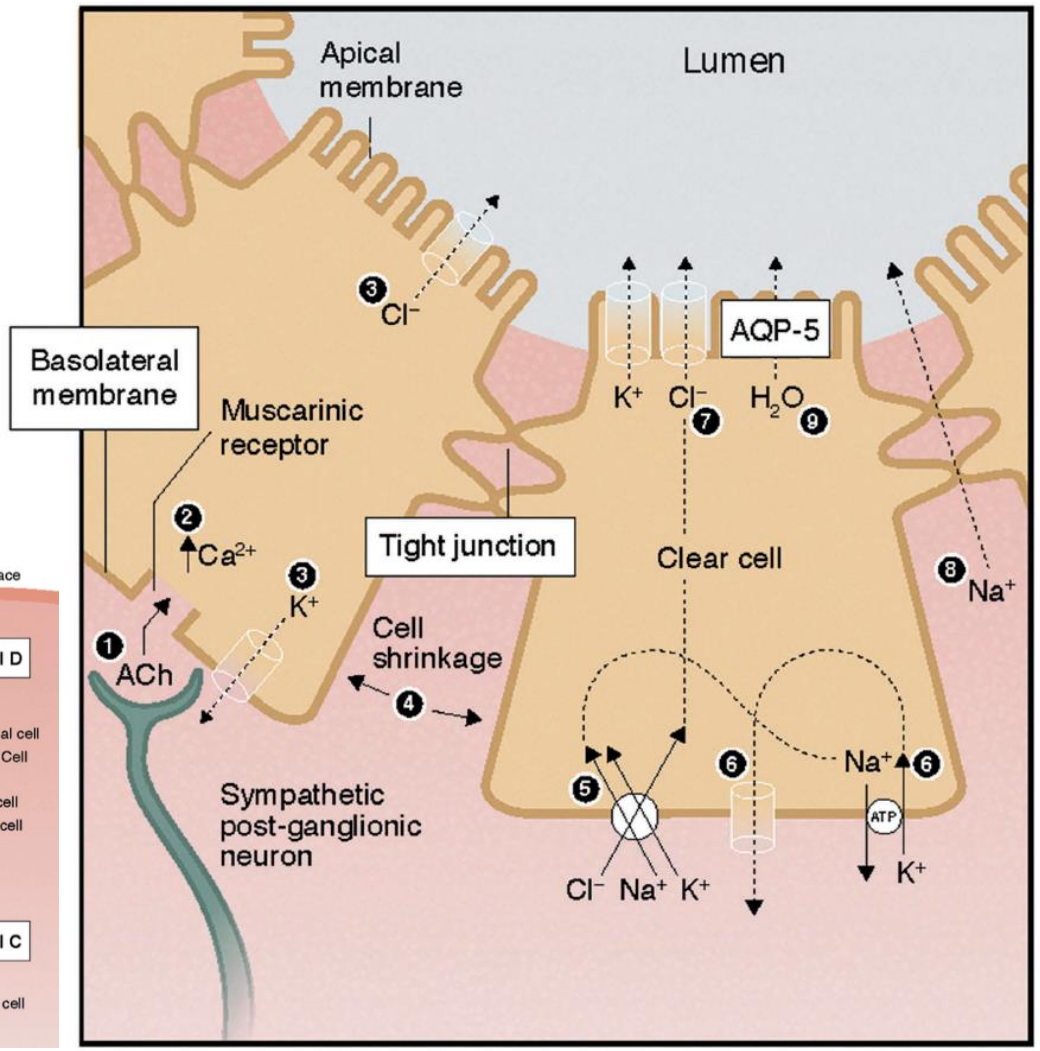
↓

Cl^- efflux creates an electrochemical gradient for Na^+ movement across the cell junction

↓

Net KCl efflux from the cell creates an osmotic gradient for water movement into the lumen





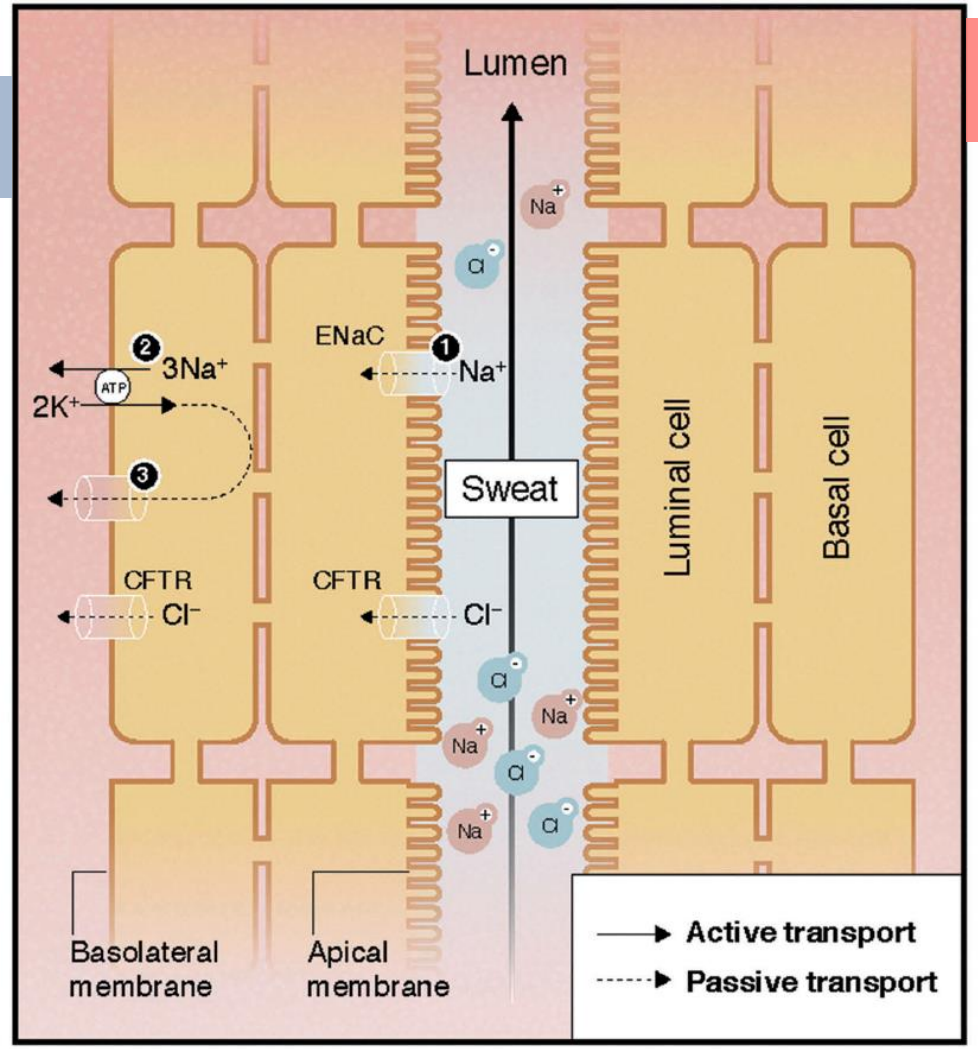
Baker LB. Physiology of sweat gland function: The roles of sweating and sweat composition in human health. *Temperature (Austin).* 2019;6(3):211-259

Reabsorption process depends on the rate of sweating

Slow rate

(rest, cool temperature)

Na^+ & Cl^- reabsorption



High rate

(exercise, hot temperature)

Na^+ & Cl^- reabsorption

Loss electrolytes

(Max ~ 50-60 mEq/L)

" an unacclimatized person "

Role of "Aldosterone"
In acclimatized person

↓ ↓ **Loss electrolytes**

~ 3-5 grams of salt each day

Baker LB. Physiology of sweat gland function: The roles of sweating and sweat composition in human health. *Temperature (Austin)*. 2019;6(3):211-259

Body temperature regulation

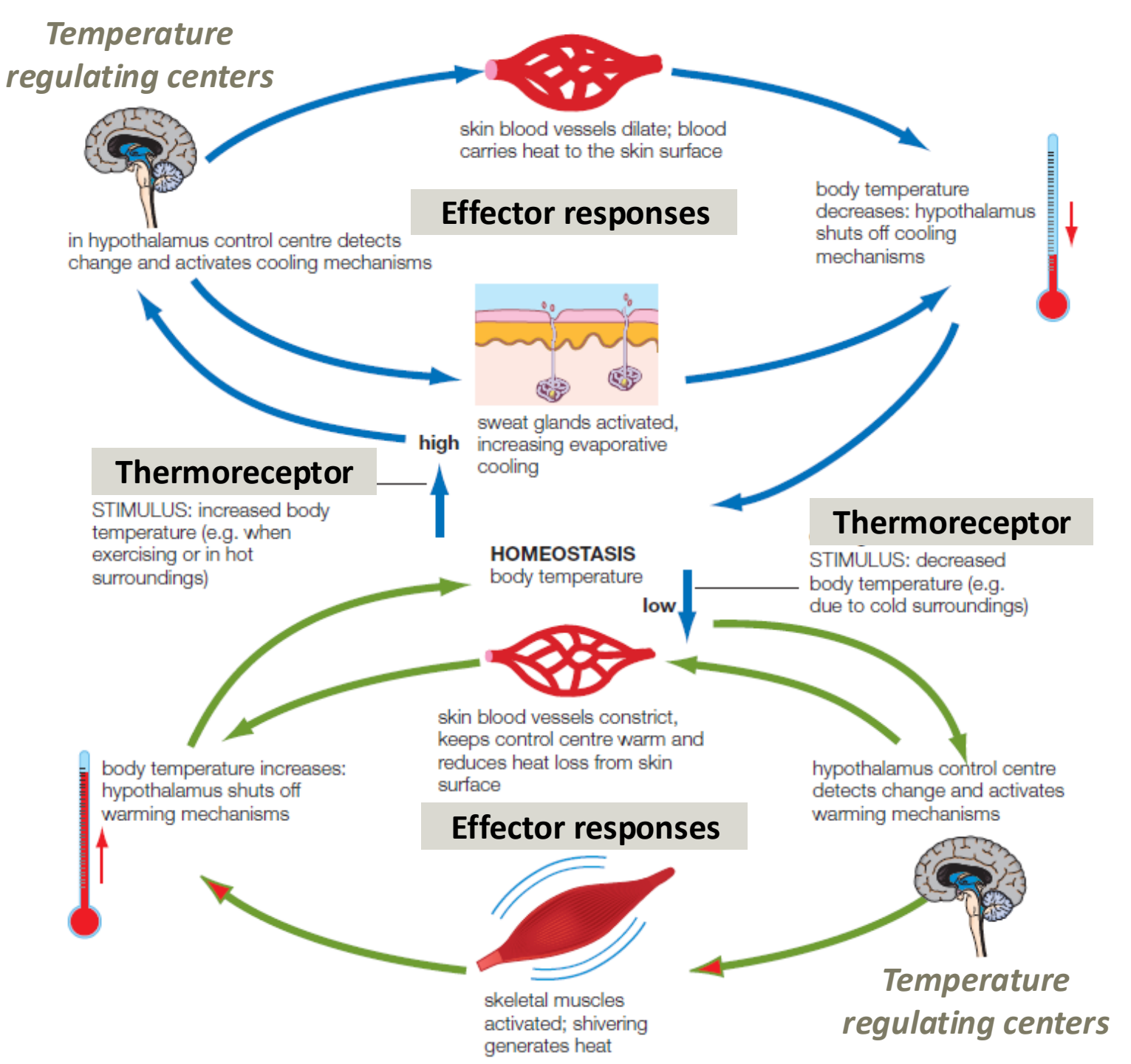
Thermoreceptor

↓

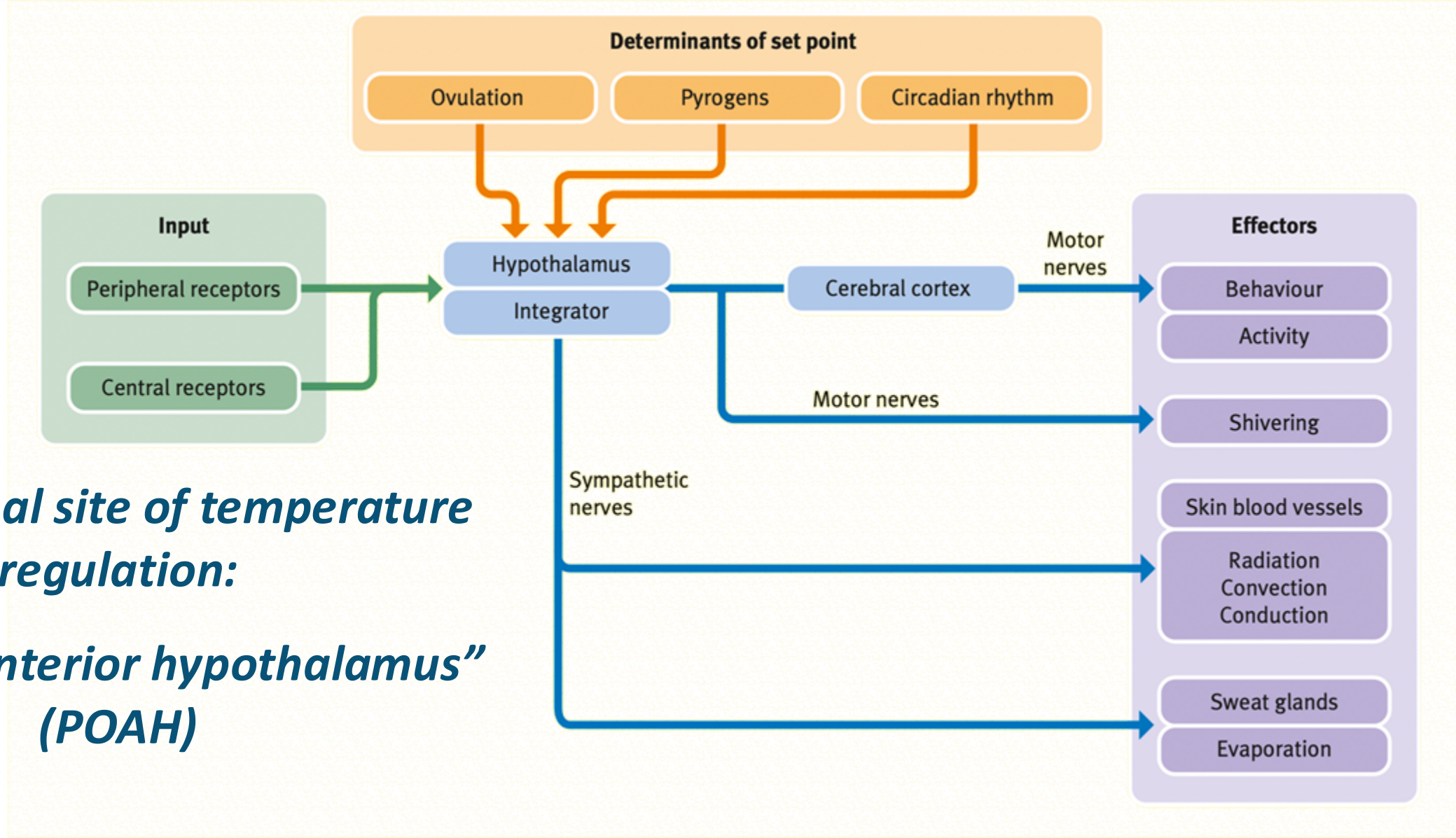
Temperature regulating center

↓

Effector responses



Thermoregulatory mechanism



The principal site of temperature regulation:

"Preoptic anterior hypothalamus" (POAH)

Thermoreceptors

1 **Central thermoreceptor:** *Preoptic anterior hypothalamus*

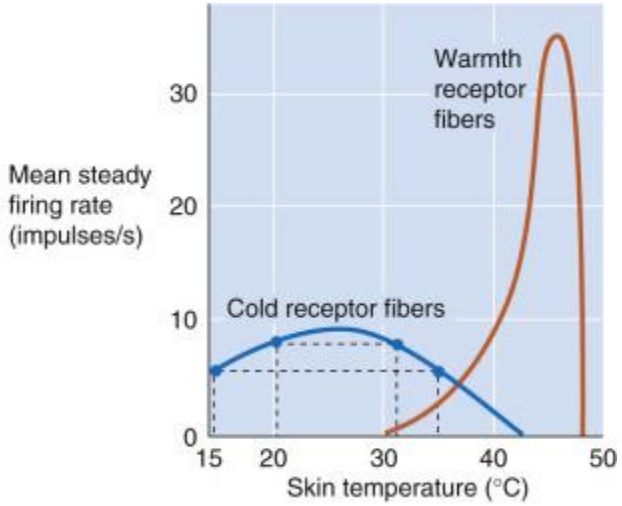
Sensitive neuron: Warmth > Cold

"Prevent brain hyperthermia"

2 **Peripheral thermoreceptor:** *Receptor: Cold > Warmth*

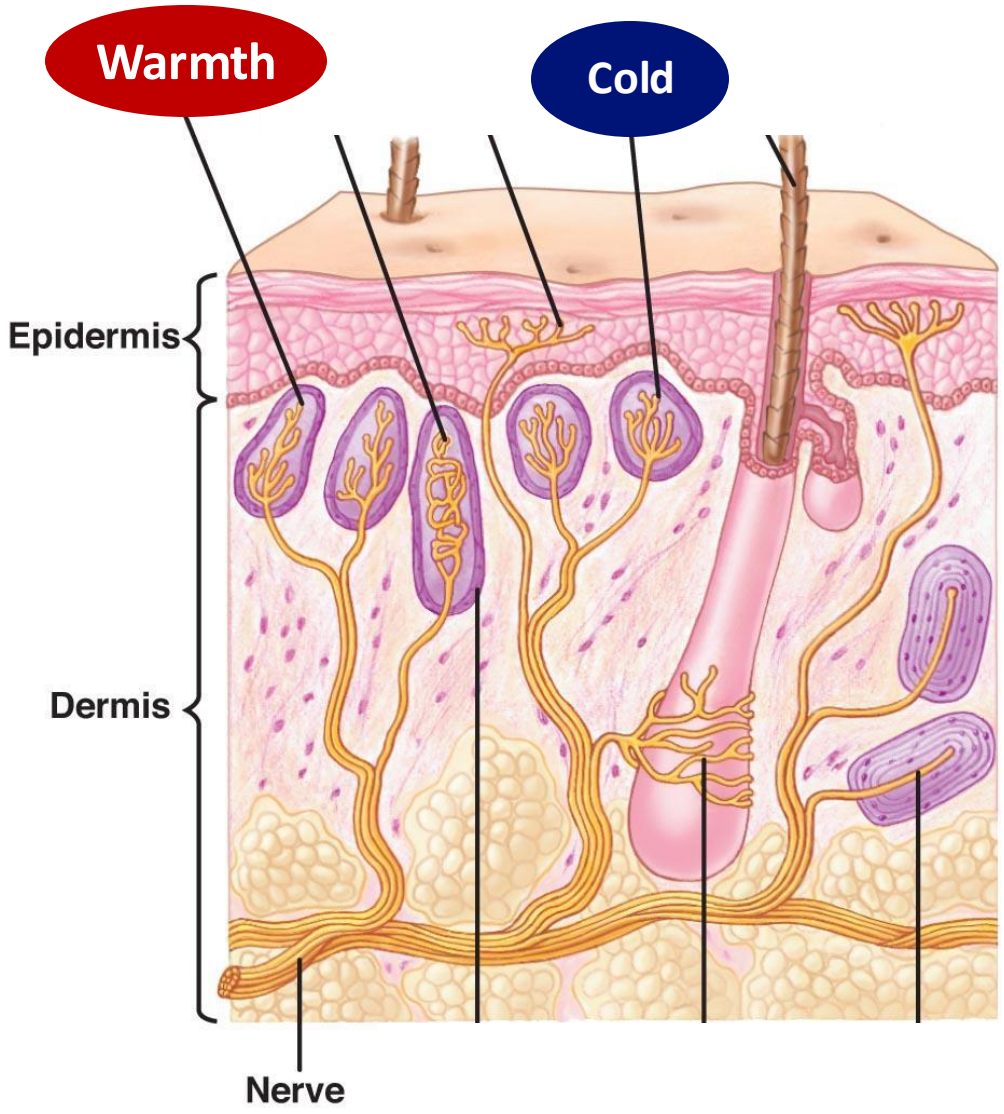
"Prevent hypothermia"

- ***Skin thermoreceptor***
- ***Deep tissue thermoreceptor***
  - *Spinal cord*
  - *Abdomen viscera*
  - *In or around great vein*
  - *Upper abdomen & thorax*

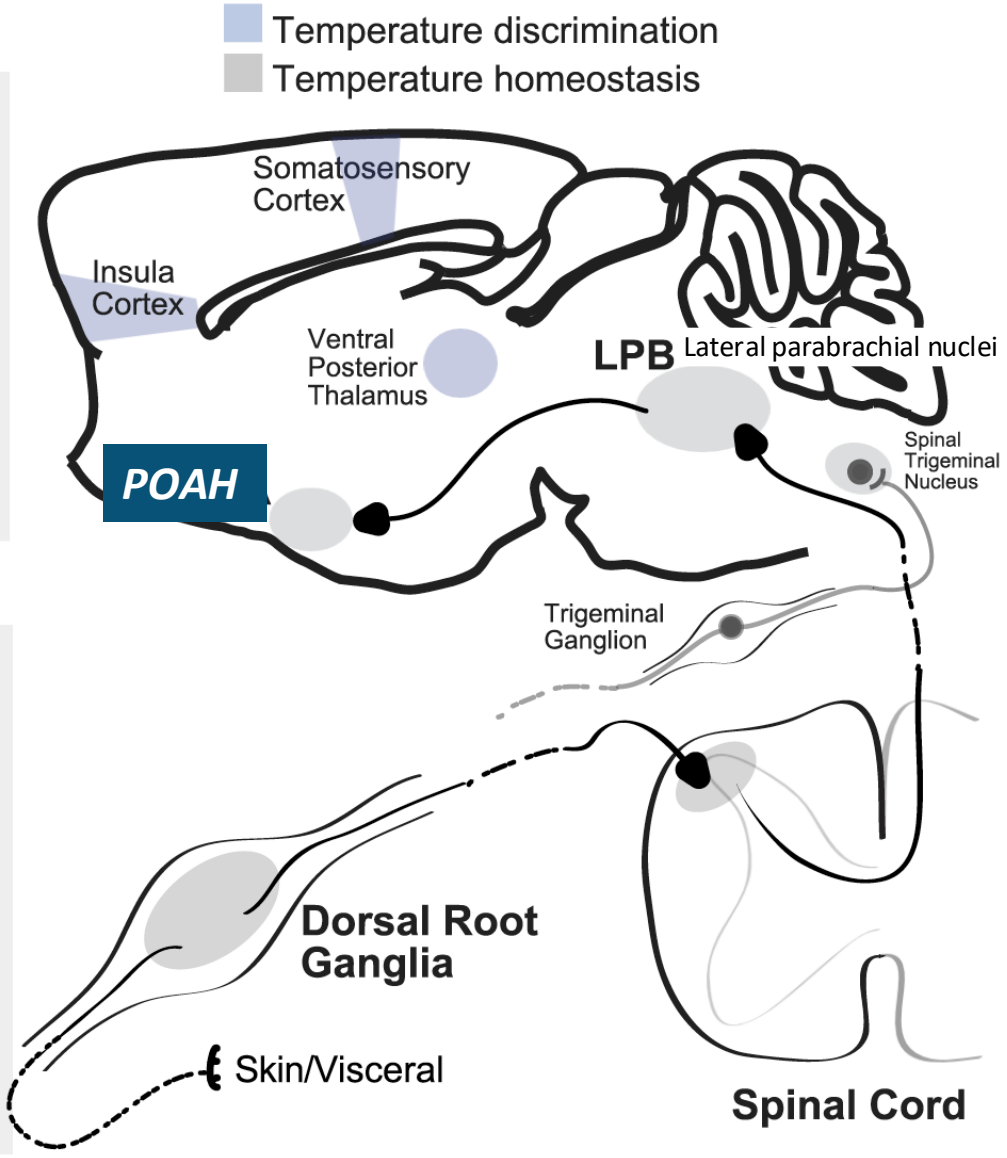


Skin thermoreceptors

Peripheral thermoreceptors play a minor role in the homeostatic control of core body temperature, which is ***dominated by hypothalamic thermoreceptors***



Ascending neural pathways

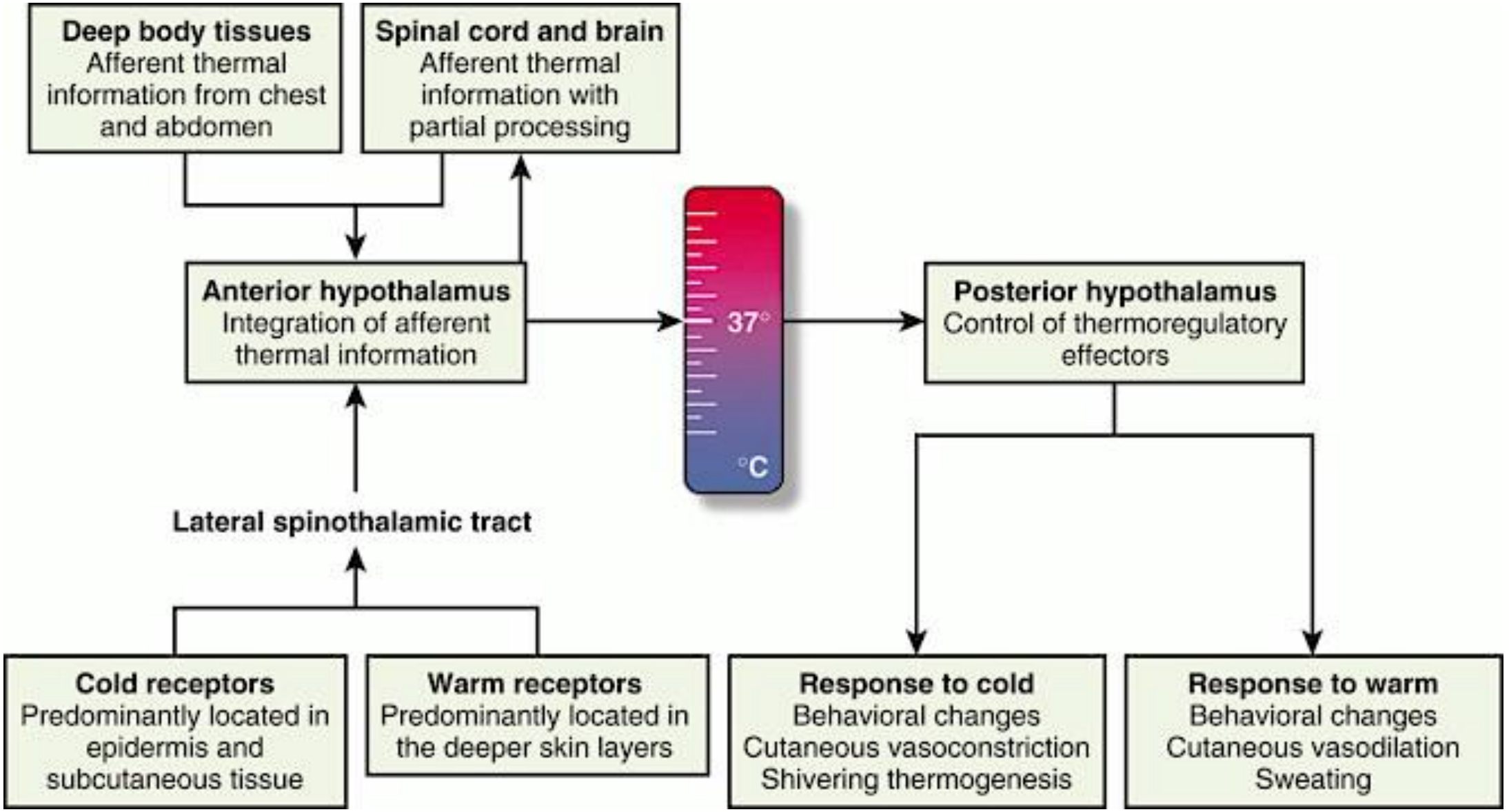


Processing of afferent thermal information takes place in the preoptic anterior hypothalamus (POAH), whereas the posterior hypothalamus controls the efferent pathways to the effectors

Integrated in the POAH and compared to the threshold temperatures

Tan CL, Knight ZA. Regulation of Body Temperature by the Nervous System. Neuron. 2018;98(1):31-48.

Body temperature regulation



Mechanism of responses

When the body is too hot

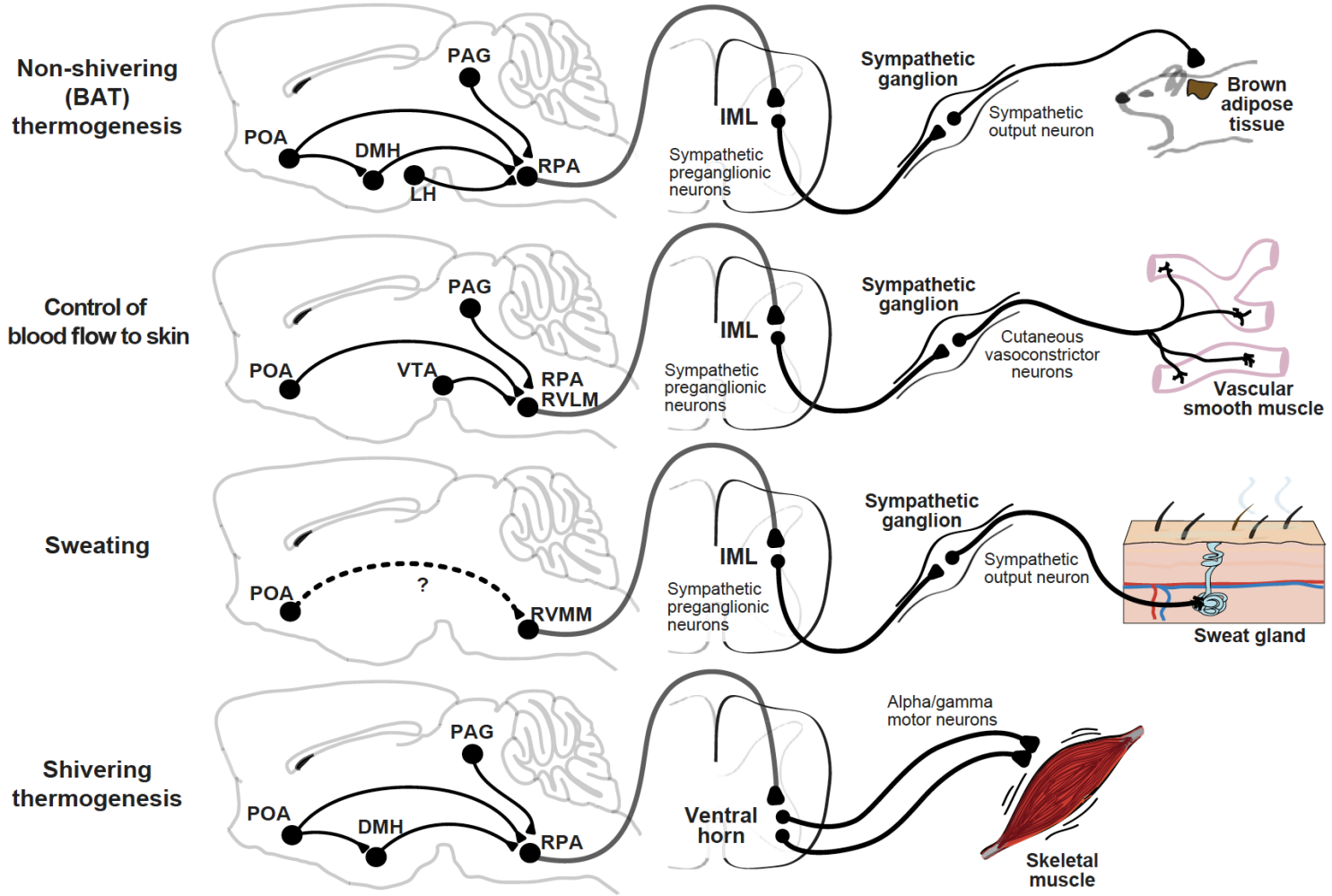
- Vasodilation
  - Increase rate of heat transfer to skin
- Sweating
- Increased respiration rate
- Decreased heat production
- Behavioral responses

When the body is too cold

- Vasoconstriction
  - Decrease rate of heat transfer to skin
- Piloerection
- Increased heat production
  - Sympathetic excitation
  - Shivering
  - Thyroxine secretion
- Behavioral responses

Descending Circuits Controlling Thermoregulatory Effectors

The threshold is 37°C for sweating and vasodilation, 36.8°C for vasoconstriction, 36°C for non-shivering thermogenesis, and 35.5°C for shivering



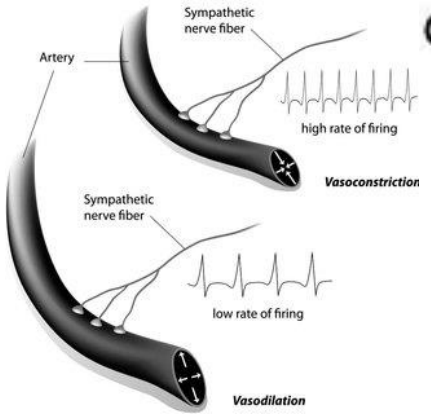
Tan CL, Knight ZA. Regulation of Body Temperature by the Nervous System. Neuron. 2018;98(1):31-48.

Skin circulation and heat transfer

Local alpha-adrenergic sympathetic nerves (release NE)

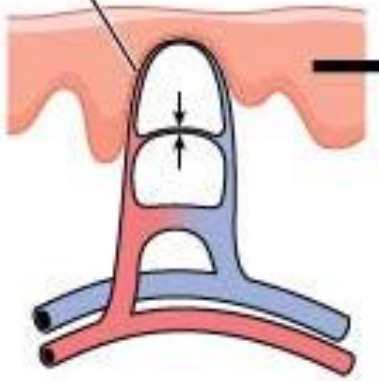
mediate constriction in the thermoregulation

↑ SNS (NE) >>> Degree of vasoconstriction



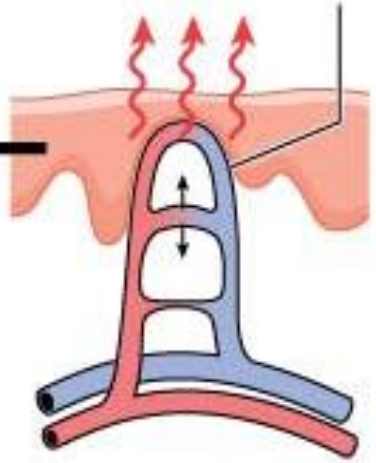
Cold condition

Capillaries vasoconstrict near skin surface to conserve heat



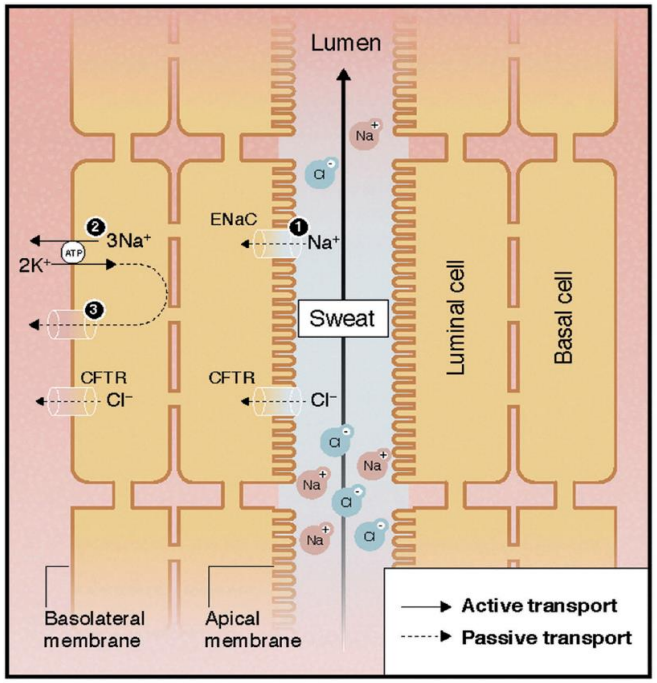
Blood temperature approaches hypothalamic set-point and heat loss/retention mechanisms return to baseline state

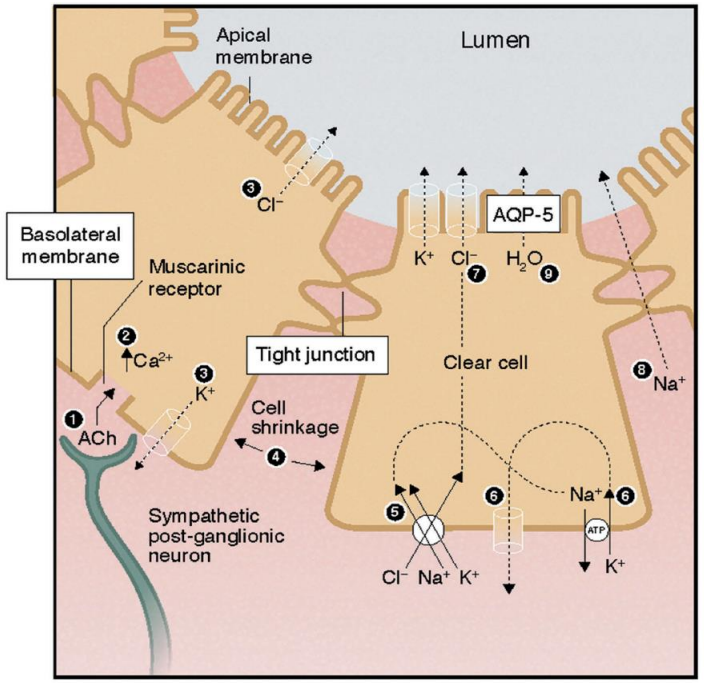
Capillaries dilate near skin surface to lose heat to the environment

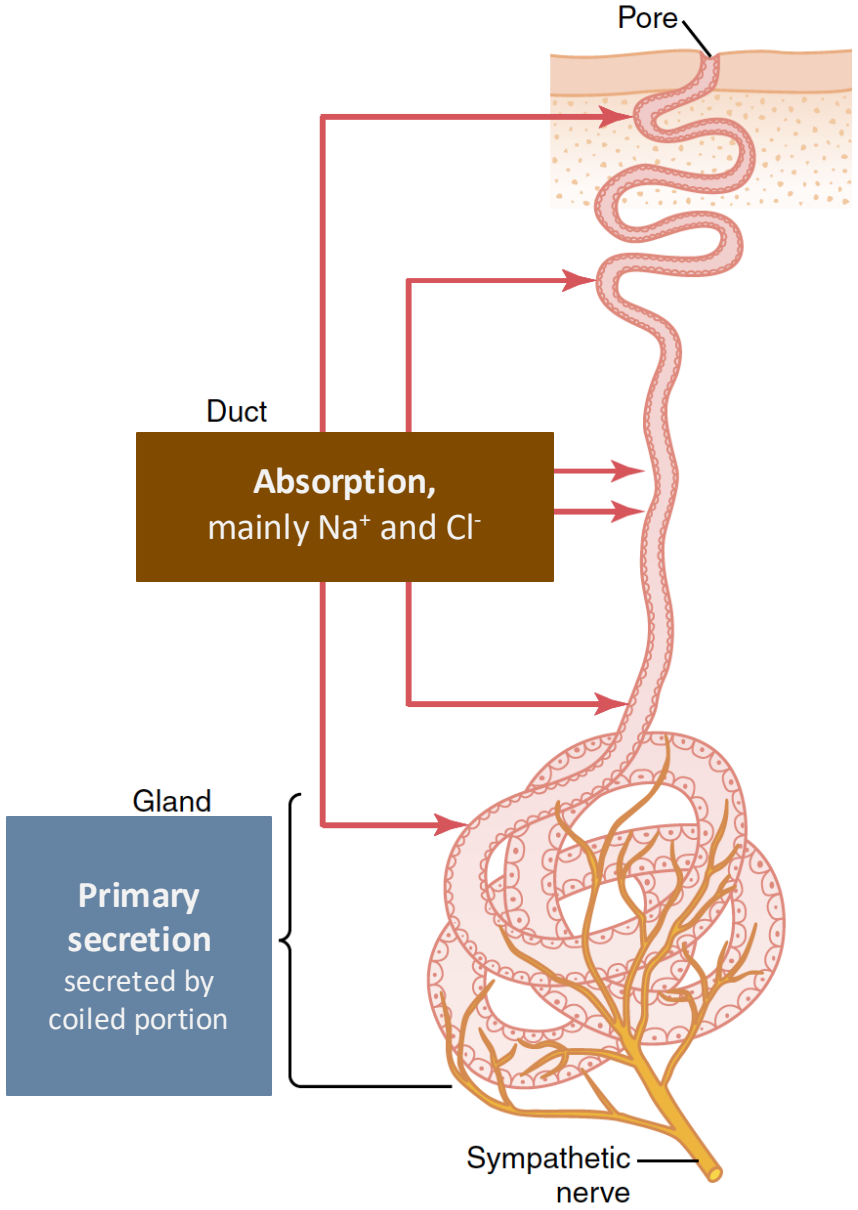


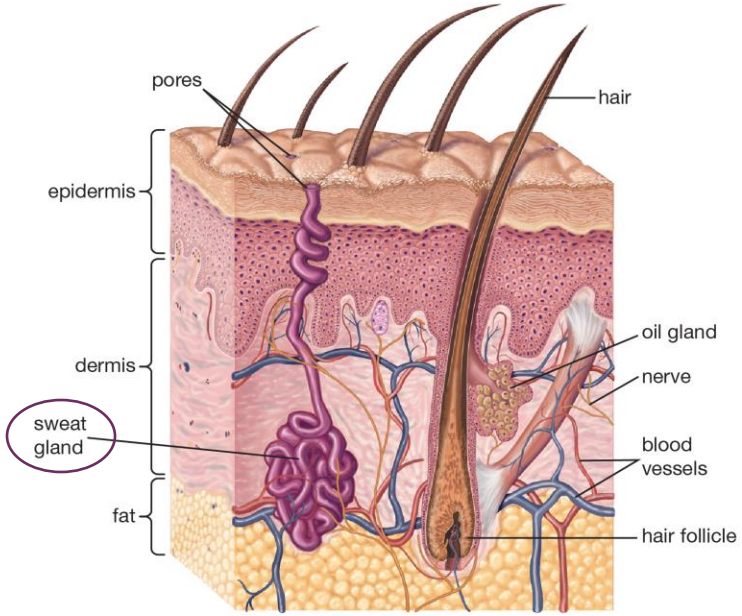
Warm condition

Evaporative heat loss by sweating







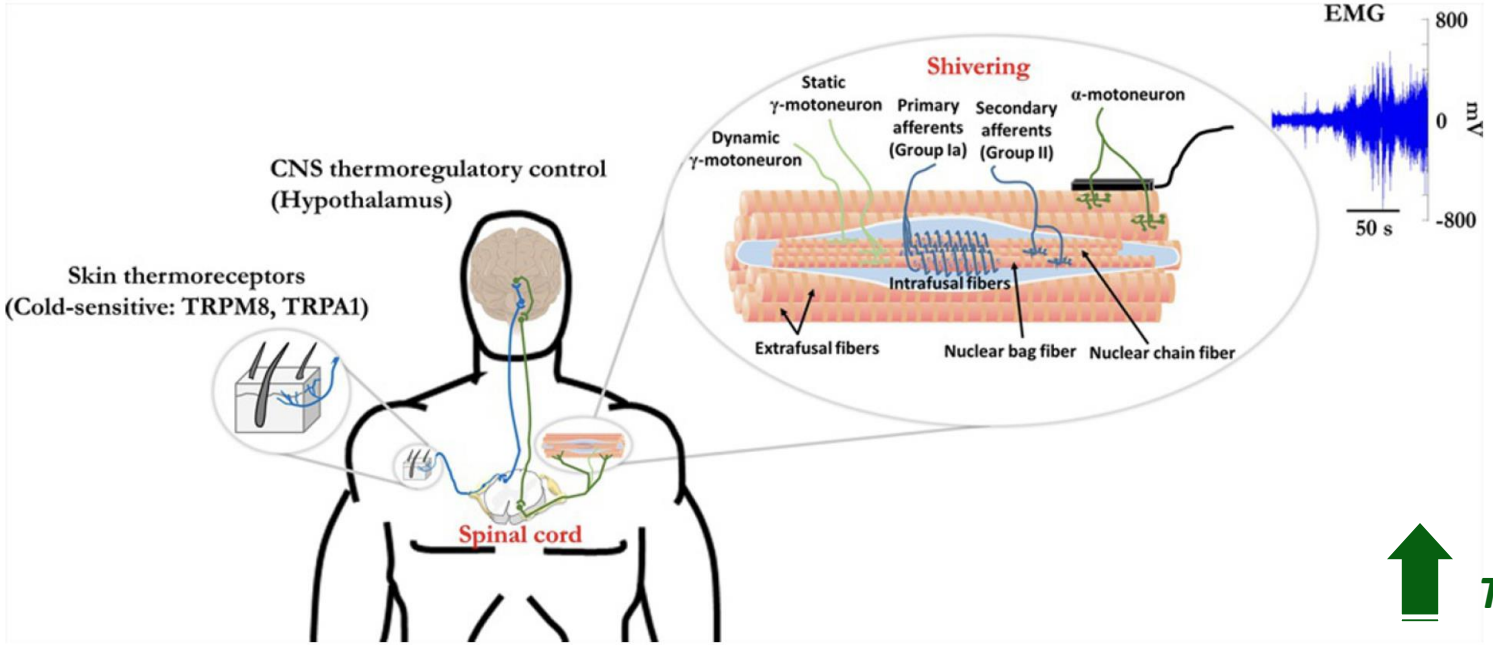


Shivering: a mechanism for heat production

A repetitive contraction of skeletal muscle to generate heat that is triggered by cold exposure or fever (chills)

Primary motor center for shivering: *the dorsomedial portion of the posterior hypothalamus*

- ***Normally inhibited*** *by signals from the heat center in the preoptic anterior hypothalamus (POAH)*
- ***Excited*** *by cold signals from the skin and spinal cord*



Cold signals

↓

Primary motor center for shivering

↓

Anterior motor neurons

↓

Shivering

↑

Tone of the skeletal muscles throughout the body

Non-shivering Thermogenesis

Occurs mainly through metabolism in brown fat tissue (BAT) which has highly vascularized and has rich sympathetic innervation

Cold stress

↓

Increased sympathetic activity
with the release of norepinephrine

↓

Increased BAT metabolism & UCP1 activity

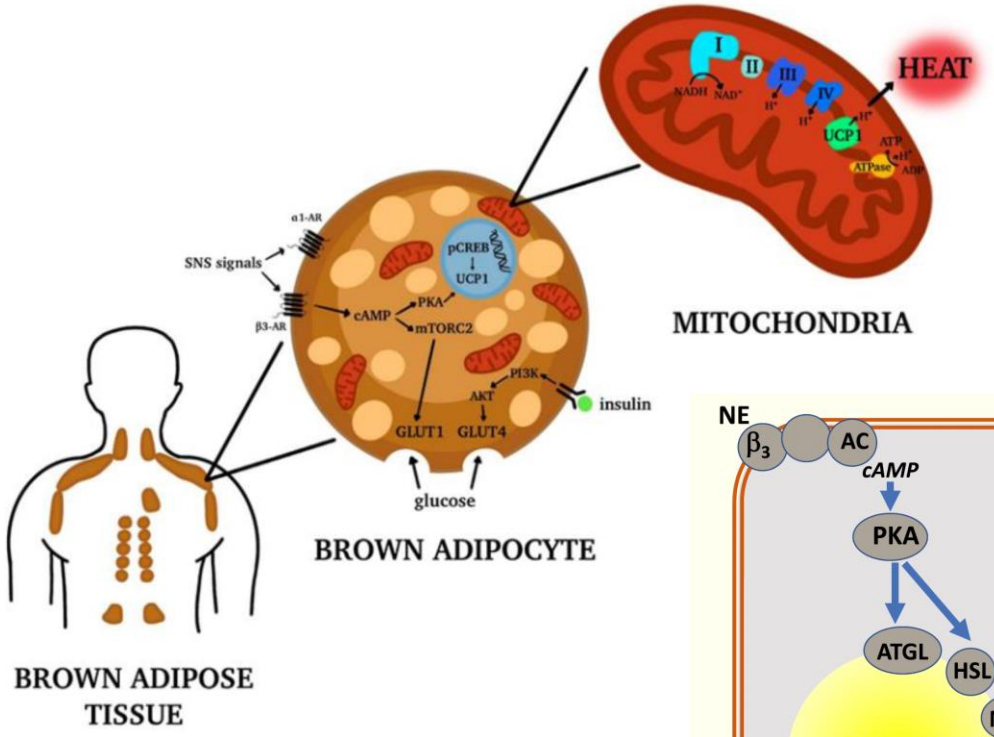
↓

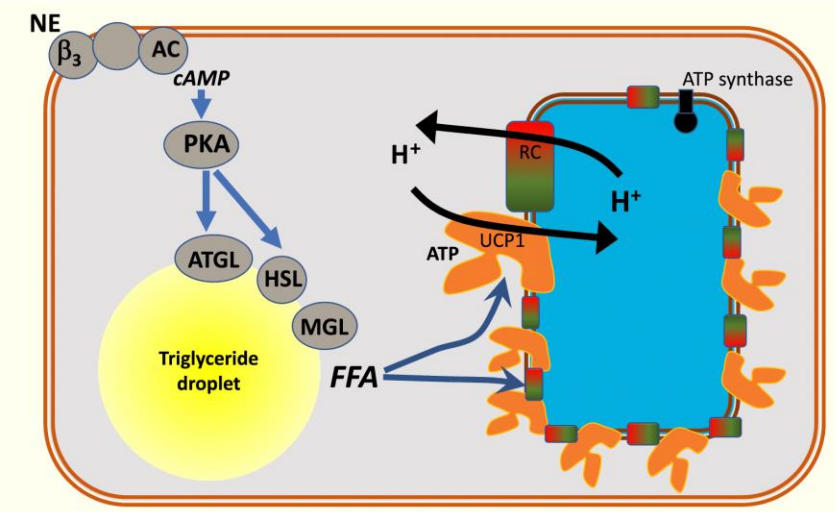
Increased uncouple oxidative phosphorylation

↓

Increased heat production

Uncouple protein 1 (UCP1) *is responsible for the energy releasing in the form of heat*

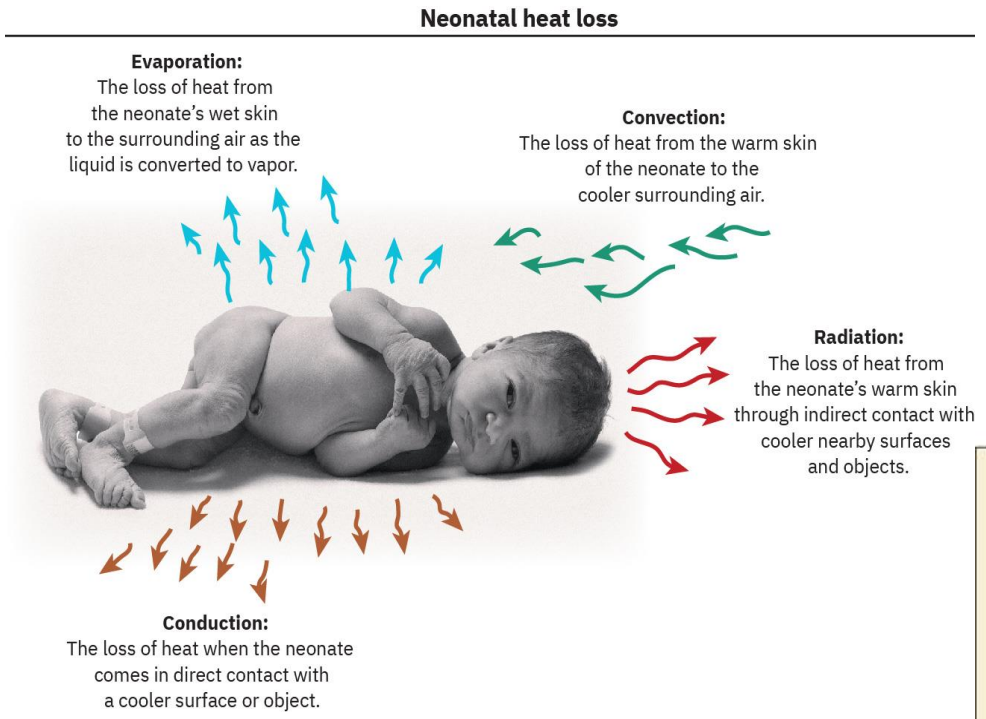


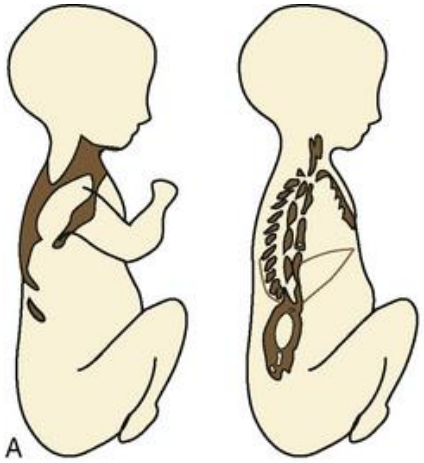


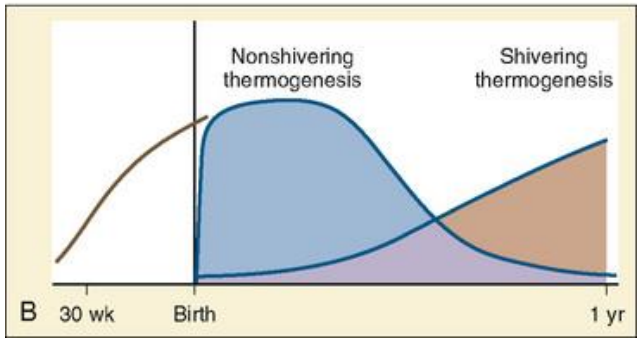
Verduci E et al. Brown Adipose Tissue: New Challenges for Prevention of Childhood Obesity. A Narrative Review. *Nutrients* **2021**, *13*, 1450.

Non-shivering Thermogenesis in newborn

- Newborns has a large skin surface area compared with their body mass and low subcutaneous insulation tissue
- When compared with adults, neonates lose proportionately more heat through their skin
- Infants at **high risk for hypothermia**





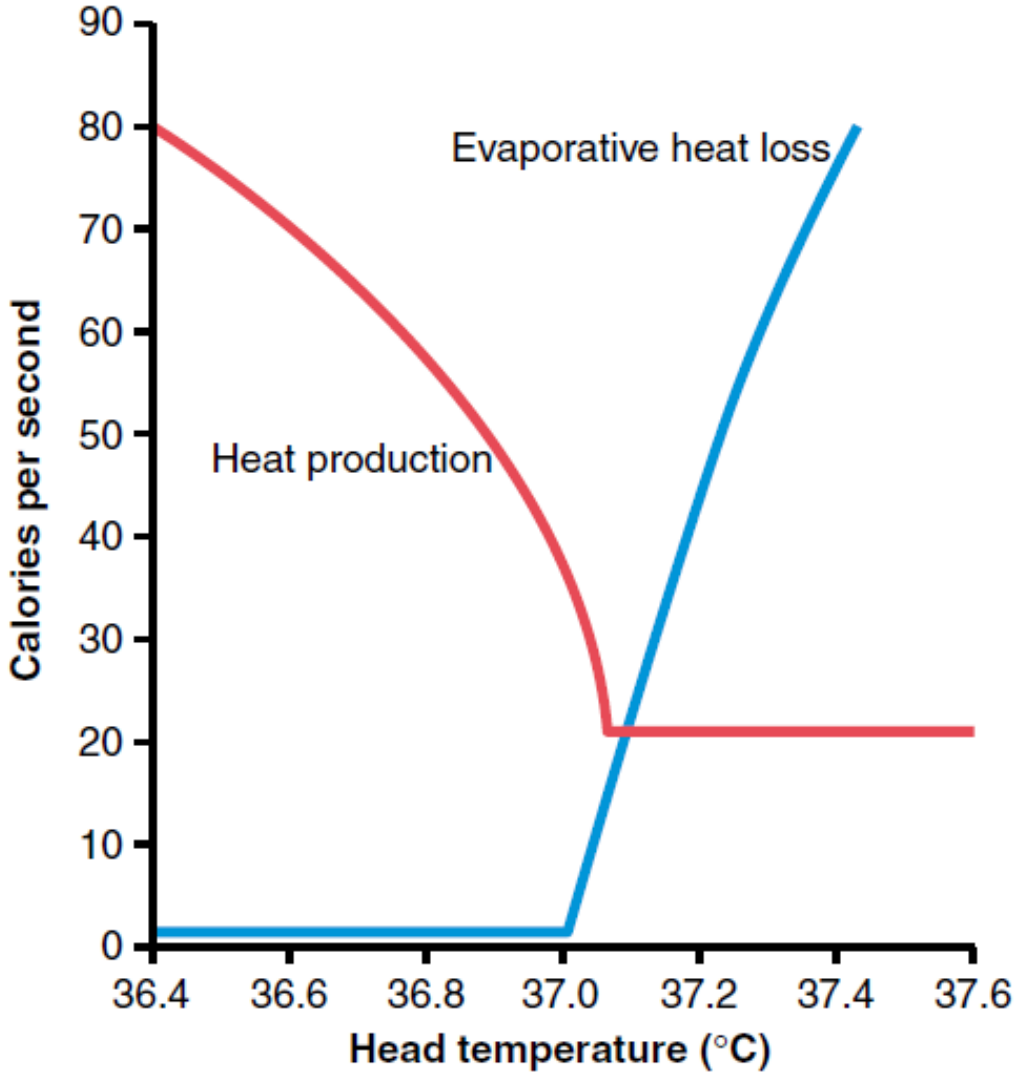


Brown fat comprises only 2% - 6% of the infant's total body weight and is found in

- *The scapula*
- *Blood vessels of the neck and internal mammary the axillae*
- *The mediastinum*
- *The adrenal glands or kidneys*

Non-shivering thermogenesis is important during the first year of life

The "set-point" of the temperature control mechanism



A critical body core temperature: Set point

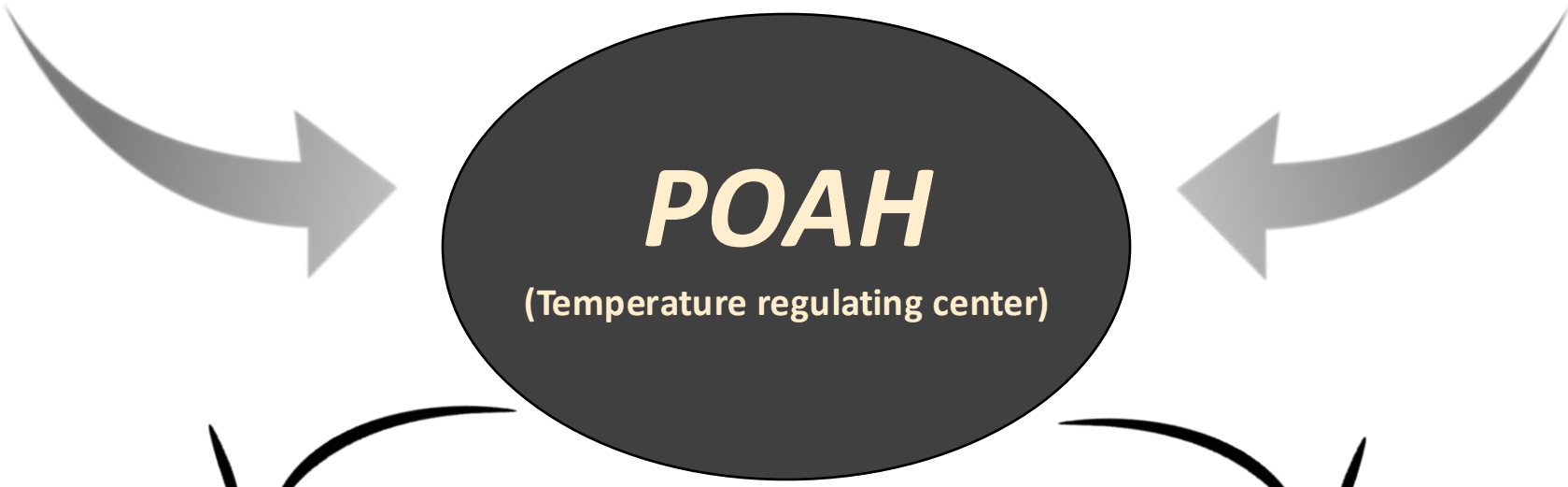
37.1°C (98.8°F)

All the temperature control mechanisms continually attempt to bring the body temperature ***back to this set-point level***

Body temperature regulation

Central thermoreceptor

Peripheral thermoreceptors



Too hot

↑↑ เพิ่มการสูญเสียความร้อน

↓↓ลดการสร้างความร้อน

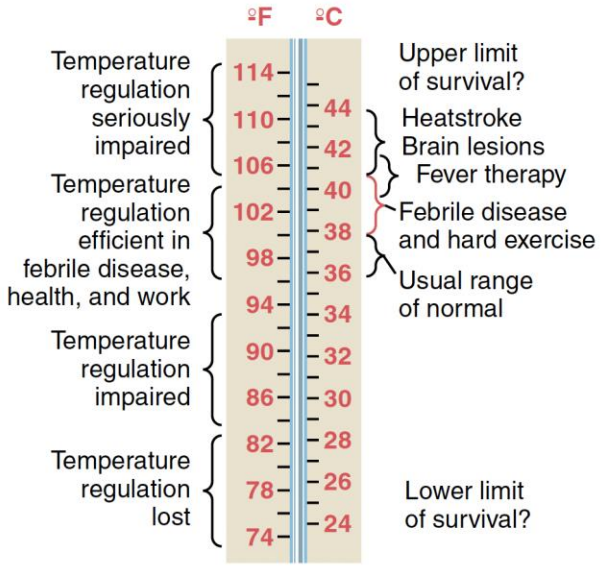
Too cold

↓↓ลดการสูญเสียความร้อน

↑↑เพิ่มการสร้างความร้อน

Abnormalities of body temperature regulation

" FEVER or PYREXIA "



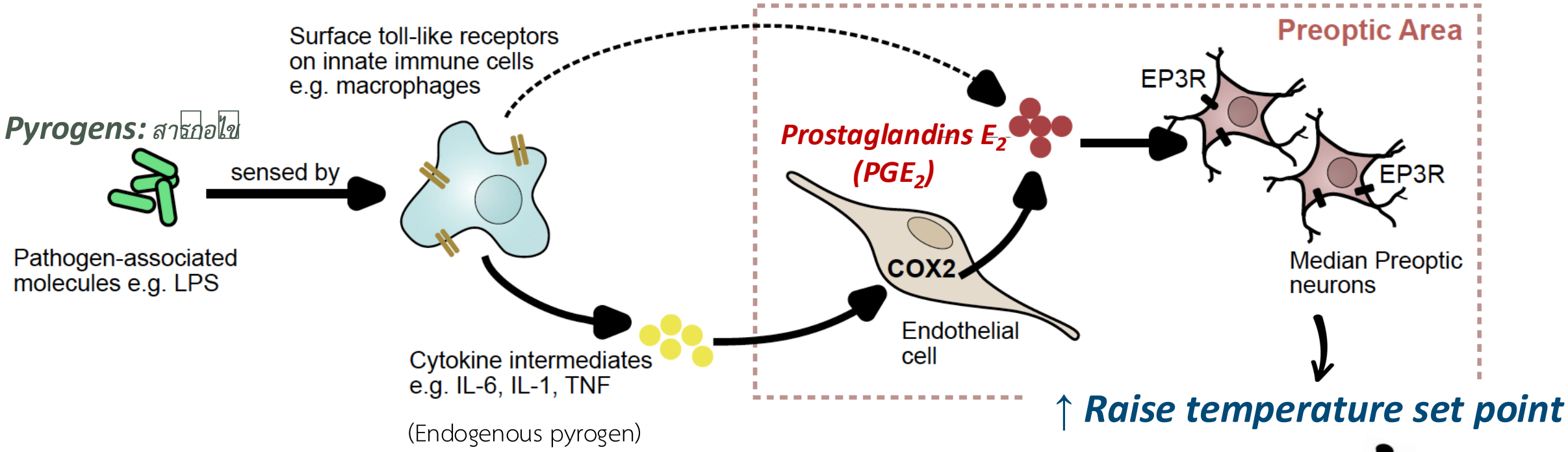
- ***A body core temperature above the normal range (> 37.8 °C)***
- ***Raising the set point of body temperature***

Caused by

- *Abnormalities in the brain/ Brain lesions*
- *Toxic substances that affect the temperature regulating centers (Pyrogen)*
- *Infection*
- *Tissue injury and inflammation*
- *Malignancy*
- *Endocrine disorders*
- *Environmental conditions*
- *Drug*

Pathogenesis of fever: Mechanism of Action of Pyrogens in Causing Fever

Resetting the Hypothalamic Temperature- Regulating Center in Febrile Diseases



All the mechanisms for raising the body temperature are activated

Fever

Pathogenesis of fever: Effect of Pyrogens

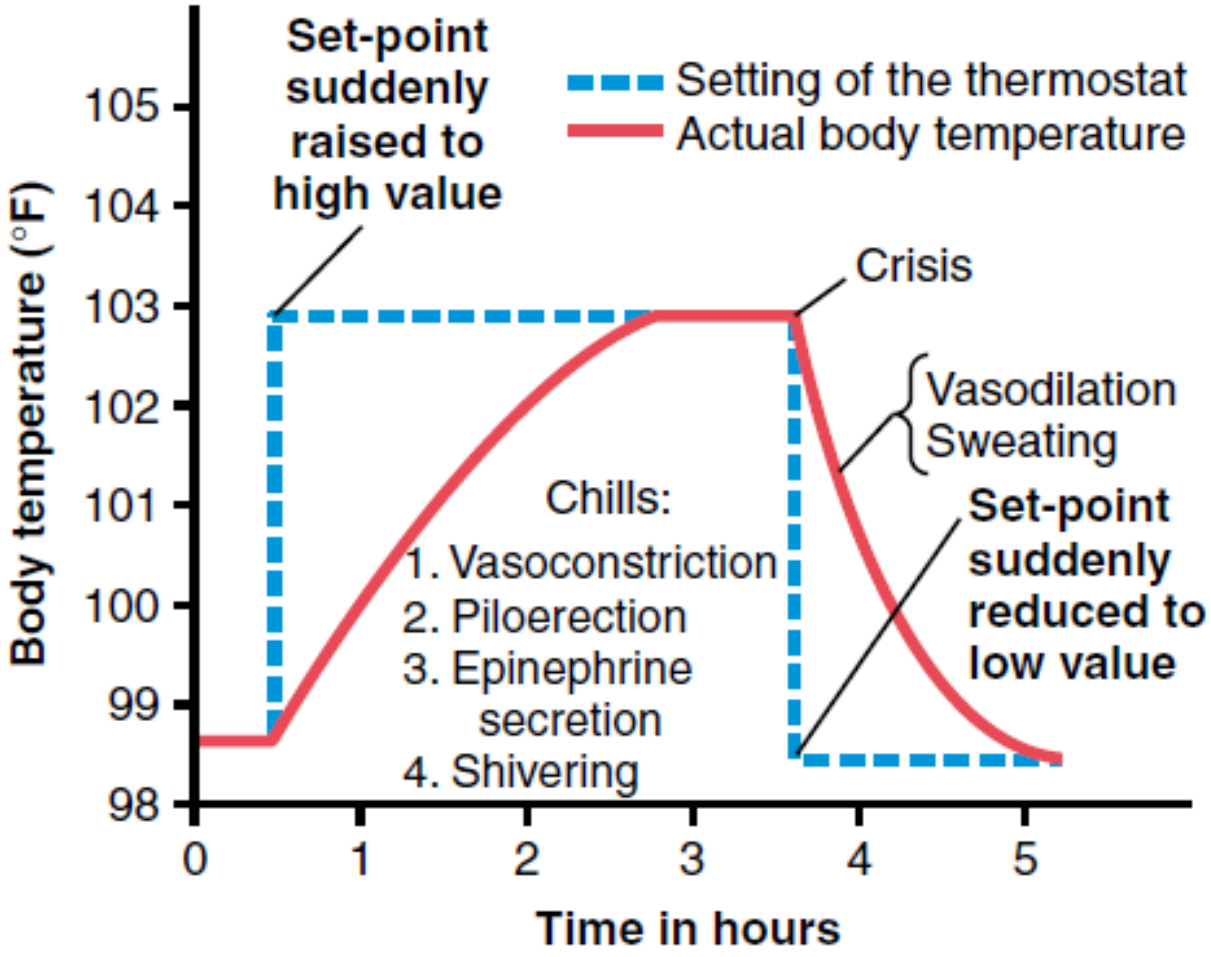
When the hypothalamic temperature

set-point is suddenly increased

The body temperature usually takes several hours

to ***reach the new temperature setpoint***

Effects of changing the set point



Abnormalities of body temperature regulation

Hyperthermia: *Rising body* core temperature >38 °C

- Causes:
  - Exercise in higher surrounding heat and/or humidity
  - Fever, resetting the hypothalamic set point
  - Excess thyroid hormone and epinephrine production
  - Malfunction of hypothalamic control center
- Can progress to heatstroke (40-44 °C)

Dehydration induced an increased body temperature

Dehydration or hypohydration can caused increases heat storage by

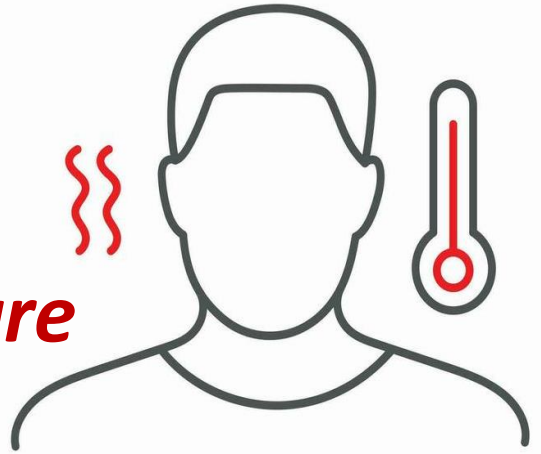
- **Impaired sweating:**

  When dehydrated, the body has less fluid available to produce sweat, a crucial mechanism for cooling down through evaporation

- **Reduced blood volume:**

  Dehydration decreases blood volume, leads to low blood perfusion to skin and other organs

Increased body temperature



Heatstroke

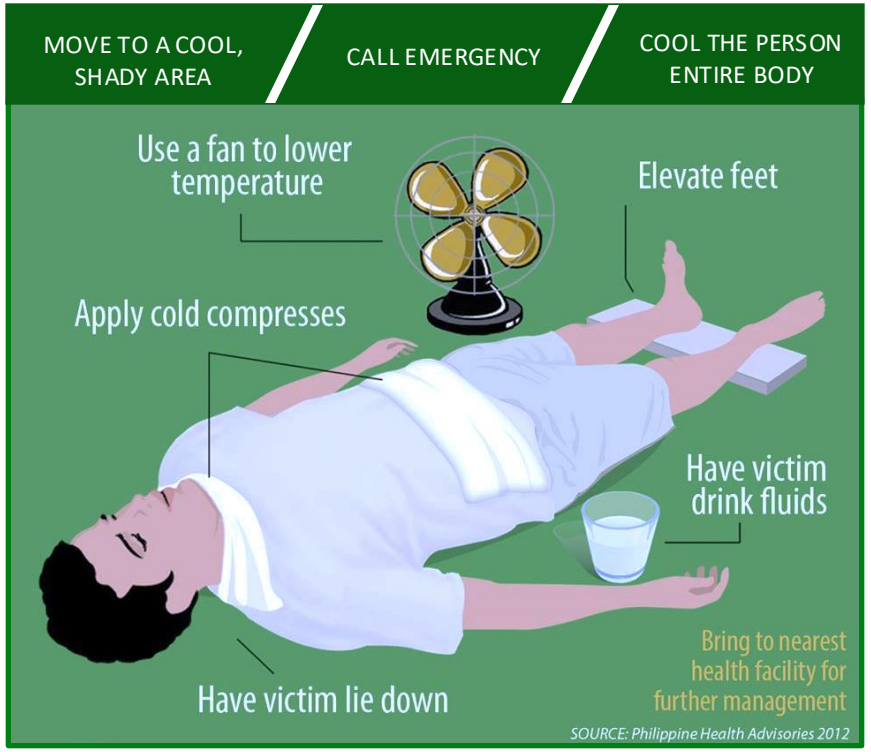
- ***A life-threatening illness characterized by a core body temperature > 40°C and CNS dysfunction***
- *Thermoregulatory responses is insufficient the sweating mechanism fails, and the body is unable to cool down*

Sign & Symptoms:

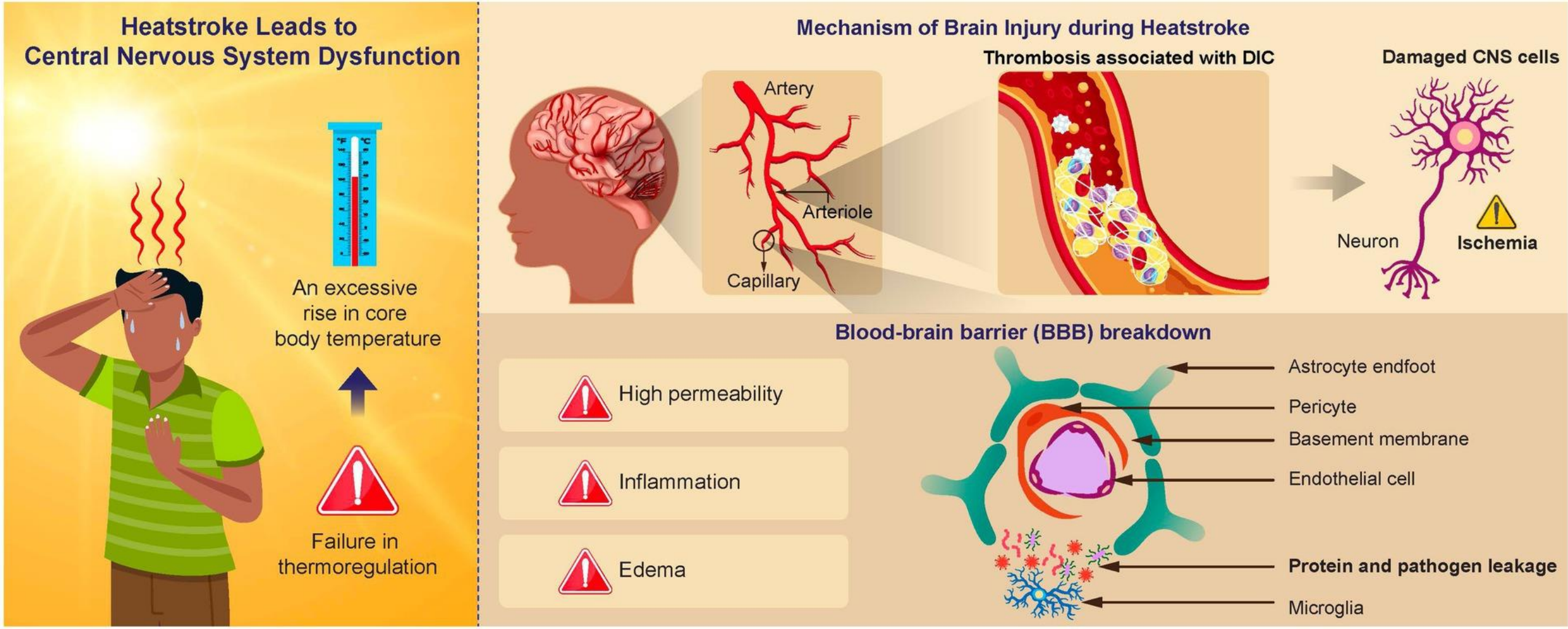
- Dizziness
- Delirium
- Vomiting
- Abdominal distress
- Loss of consciousness

→

- Damage to organs
- Death



Mechanism of brain injury in heatstroke



Abnormalities of body temperature regulation

Hypothermia: *Decreasing body* core temperature < 35°C

The compensatory physiologic mechanisms that conserve heat begin to fail

Causes:

- Direct prolonged exposure to the cold
- A complication of a serious systemic disorder or injury
  - Endocrine dysfunction
  - Acute spinal cord injury
  - Etc.

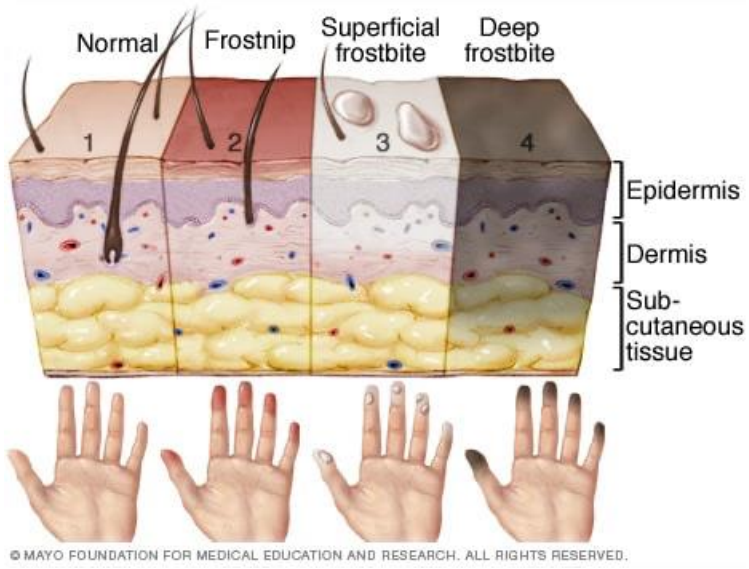
TABLE 454-2 Physiologic Changes Associated with Accidental Hypothermia

SEVERITY	BODY TEMPERATURE	CENTRAL NERVOUS SYSTEM	CARDIOVASCULAR	RESPIRATORY	RENAL AND ENDOCRINE	NEUROMUSCULAR
Mild	35°C (95°F)– 32.2°C (90°F)	Linear depression of cerebral metabolism; amnesia; apathy; dysarthria; impaired judgment; maladaptive behavior	Tachycardia, then progressive bradycardia; cardiac cycle prolongation; vasoconstriction; increase in cardiac output and blood pressure	Tachypnea, then progressive decrease in respiratory minute volume; declining oxygen consumption; bronchorrhea; bronchospasm	Diuresis; increase in catecholamines, adrenal steroids, triiodothyronine, and thyroxine; increase in metabolism with shivering	Increased preshivering muscle tone, then fatiguing
Moderate	<32.2°C (90°F)–28°C (82.4°F)	EEG abnormalities; progressive depression of level of consciousness; pupillary dilation; paradoxical undressing; hallucinations	Progressive decrease in pulse and cardiac output; increased atrial and ventricular arrhythmias; suggestive (J-wave) ECG changes	Hypoventilation; 50% decrease in carbon dioxide production per 8°C (17.6°F) drop in temperature; absence of protective airway reflexes	50% increase in renal blood flow; renal autoregulation intact; impaired insulin action	Hyporeflexia; diminishing shivering-induced thermogenesis; rigidity
Severe	<28°C (<82.4°F)	Loss of cerebrovascular autoregulation; decline in cerebral blood flow; coma; loss of ocular reflexes; progressive decrease in EEG abnormalities	Progressive decrease in blood pressure, heart rate, and cardiac output; reentrant dysrhythmias; maximal risk of ventricular fibrillation; asystole	Pulmonic congestion and edema; 75% decrease in oxygen consumption; apnea	Decrease in renal blood flow that parallels decrease in cardiac output; extreme oliguria; poikilothermia; 80% decrease in basal metabolism	No motion; decreased nerve-conduction velocity; peripheral areflexia; no corneal or oculocephalic reflexes

Frostnip: *Nonfreezing cold injury resulting from intense vasoconstriction of exposed acral skin, damage is reversible*

Frostbite: *Tissue freezing due to exposed to extremely low temperatures (tissue temp drops below 0°C)*

- *Ice crystal formation*
- *A sensation of numbness with accompanying sensory loss*
- *Permanent circulatory impairment >>> Gangrene*



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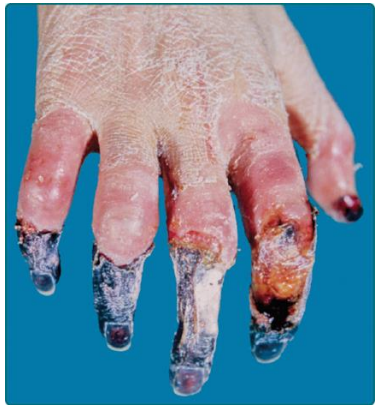
Frostbite with vesiculation

Deep Frostbite



Dry gangrene

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End.

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