Temperature Regulation
Normal Core Temperature

- Orally measured temperature
  - Generally: 97°F(36°C)~99.5°F(37.5°C)
  - Average normal: 98°F(36.7°C)~98.6°F(37°C)
- Rectally measured: 1°F higher than orally
- Change on extreme exercise and surroundings
  - Temperature regulation can not be perfect
  - (101~104°F(40°C)) ~ 96°F(35.5°C)
Normal Person Range

**Oral**
- **96°F (36°C)**: Early morning, cold weather, etc.
- **98°F (37°C)**: Usual range of normal
- **100°F (38°C)**: A few normal adults, many active children
- **102°F (39°C)**: Emotion or moderate exercise
- **104°F (40°C)**: Hard exercise

**Rectal**
- **96°C (36°C)**: Early morning, cold weather, etc.
- **98°C (37°C)**: Usual range of normal
- **100°C (38°C)**: A few normal adults, many active children
- **102°C (39°C)**: Emotion or moderate exercise
- **104°C (40°C)**: Hard exercise
Heat Production Factors

• Affecting metabolic rate of body
  – Basal rate of metabolism
  – Extra rate of metabolism
    • by muscle activity, shivering
  – Extra metabolism by the effect of thyroxine
    • Also other hormones; growth hormone, testosterone
  – Extra metabolism by sympathetic stimulation
    • epinephrine, norepinephrine
  – Extra metabolism by increased temperature
    • Increased chemical process
Insulator System of Body

• Heat insulator
  – Skin, subcutaneous tissues, and fat
  – **Fat**: conductance is 1/3 of other tissues
  – When no blood is flowing
    • $\frac{3}{4}$ of usual suit of clothes for man
    • >3/4 for woman

• Maintain normal internal temperature
  – Even skin temperature approaches surrounding temperature
Blood Flow to Skin

• Venous plexus
  – In most exposed areas: hands, feet, ears
  – Directly supplied highly muscular arteriovenous anastomoses
    • Minimum: 0%
    • Maximum: 30% Of cardiac output
Effect of Vasodilation

• Increase up to **8 fold** than fully vasoconstricted
  – Blood flow to the skin is most effective mechanism for heat transfer
  – Controlled by sympathetic nervous system
Heat Loss from Body

- Nude person in minimal metabolism

Diagram:
- Walls
- Radiation (60%)
- Heat waves
- Conduction to air (15%)
- Air currents (convection)
- Evaporation (22%)
- Conduction to objects (3%)
Effect of Clothing

• Entrap airs & increase thickness of private zone, decrease convection airflow
  – Usual suit: Decrease heat loss to $\frac{1}{2}$ of nude body
  – Arctic type suit: decrease to 1/6

• Mostly radiation to clothes
  – Reflecting gold layer inside the clothes increase insulating and reduces weight in half

• Effect of clothing is lost if wet
  – Heat loss increase 20~25 times
  – Need caution not to be wet and not to sweat
Sweating

• Regulated by ANS
  – When anterior hypothalamus-preoptic area is stimulated
  – By electrically or thermally

• Primary secretion includes sodium and chlorides
  – Reabsorbed in ducts
    • Depend on sweating rate
Sweat Reabsorption

- In unacclimatized person

<table>
<thead>
<tr>
<th></th>
<th>Slightly stimulated</th>
<th>Strongly stimulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount of precursor secretion</td>
<td>Small</td>
<td>Large</td>
</tr>
<tr>
<td>Flow in duct</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Na, Cl reabsorption</td>
<td>Most of them</td>
<td>Half of them</td>
</tr>
<tr>
<td>Osmotic pressure</td>
<td>Reduced</td>
<td>Not reduced</td>
</tr>
<tr>
<td>Water reabsorption</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>Urea, lactic acid, ...</td>
<td>Very concentrated</td>
<td>Moderately increased</td>
</tr>
<tr>
<td>Loss of NaCl</td>
<td>None</td>
<td>Much</td>
</tr>
</tbody>
</table>
Acclimatization

• When exposed to hot weather for 1~6 weeks
  – Sweat production: 1L/hr → 2~3L/hr
  – Can remove 10 times of normal basal rate heat by evaporation

• By change internal sweat cell themselves
  – Increase sweating capability
  – Decrease NaCl concentration to conserve body salt
    • 15~30g/day (1st week) → 3~5g/day (4~6 weeks)
  – By increase secretion of aldosterone
Hypothalamus

• Temperature regulating center
  – Maintain 97~100°F in 55~130°F range when ambient temperature increases from 30°F ~150°F

• Also need temperature detectors
Temperature Regulating Center

• Anterior Hypothalamic-Preoptic Area
  – Found by thermode stimulation experiments

• Many heat sensitive neurons
  – Central thermoreceptors
  – Increase firing rate 2~10 folds by 10°C increase
  – Immediately breaks out sweat & vasodilate

• Less(33%) cold sensitive neurons
  – Increase firing rate when temperature falls
Central Thermoreceptors

Warm True receptors

Cold True receptors

Warm Interneurons

Cold Interneurons
Temperature Receptors

- Other parts of the body
  - Additional role in temperature regulation
- Warm and cold (10x) receptors in skin
  - Mainly detect cool and cold temperature
  - Stimulation to shiver, stop sweating, vasoconstriction
- Deep body temperature sensors
  - Spinal cord, abdominal viscera, great veins
  - Exposed to body core temperature
  - Mainly detect cold to prevent hypothermia
Thermoreceptor Responses

- Peripheral thermoreceptors

Static response

Dynamic response

\[ \text{Impulses/s} \]

- Warmth Receptor
- Cold Receptor

\[ \text{Receptor temperature} \]

\[ \text{Temperature} \]

\[ T_1, T_2, T_3 \]

\[ \text{Time} \]
Summating Area

• Posterior Hypothalamus
  – Receives signals from Anterior Hypothalamic-Preoptic Area
  – Receives signals from skin receptors
  – Receives signals from deep body receptors

• Combined to control heat production and conserving reaction
When body too hot

• Temperature decreasing mechanism
  1. Vasodilation
     – Skin blood vessels intensely dilated
     – By inhibition of sympathetic tone causing vasoconstriction
  2. Sweating
     – Sharp increase in heat loss
  3. Decrease heat production
     – Strongly inhibit shivering, chemical thermogenesis
When body too hot

- **Increase in temperature**
  - Skin warmth receptors
  - Hypothalamic thermostat 37°C
  - voluntary responses
  - cooling
  - loose clothing
  - cool drink

- **Cholinergic sympathetic nervous system**
  - Ach
  - sweating

- **Adrenergic sympathetic nervous system**
  - BMR
dec
  - skin vasodilation
  - rest
  - lethargy
Critical Temperature

• Heat production reaches minimum level
• Heat loss begins to increase sharply
  – Additional 1°C increase generates sweat to remove 10 times of basal heat rate
When body too cold

• Temperature increasing mechanism
  1. Skin vasoconstriction
     – By stimulating posterior hypothalamus center
  2. Piloerection: hairs on standing end
     – Entrap thick air layer for insulation
     – Sympathetic stimulation to hair erection muscles
     – Important in lower animals than man
  3. Increase heat production
     – Increase shivering, sympathetic excitation, thyroxine secretion
When body too cold
Shivering Stimulation

• Primary motor center for shivering
  – Dorsomedial portion of hypothalamus
  – Normally inhibited by heat center
  – Excited by cold signal from skin and spinal cord
    • If body temperature fall below critical temperature even a fraction of degree
  – Signals → Brain stem → Spinal cord → Motor neurons
  – Shivering with muscle spindle feedback
Chemical Thermogenesis

- Cellular metabolism increase by
  - Sympathetic stimulation, epinephrine, norepinephrine
  - Partly caused by uncoupled oxidation
    • Oxidization of extra food releasing heat w/o ATP formation
- Proportional to **brown fat**
  - Contains many special mitochondria for uncoupled oxidization
- Affected by acclimatization
  - Rat: 33% → 100~500% increase in heat production
- Adults(15%, no BF), infants(100%, small BF)
Increased Thyroxine

- Long-term cause of heat production increase
- Require several weeks of exposure to cold
  - Thyroid gland hypertrophy
    - 20~40% in animal
  - Man in Arctic region, Eskimos
    - Increased toxic thyroid goiters

\[
\begin{align*}
\downarrow & \text{Temperature regulating center} \\
\uparrow & \text{thyrotropin-releasing hormone (hypothalamus)} \\
\uparrow & \text{thyroid stimulating hormone (pituitary gland)} \\
\uparrow & \text{thyroxine (thyroid)} \\
\uparrow & \text{Cellular mechanism (entire body)}
\end{align*}
\]
Other Endocrine Glands

• Adrenomedullary Gland
  – By epinephrine and norepinephrine
  – Sympathetic enhancement for cold regulation
  – Thermogenesis in brown fat

• Adrenocortical Gland
  – Secretion rise to cold, ascorbic acid variation

• Pituitary Gland
  – Produce stimulating hormones: TSH, ACTH

• Posterior Pituitary
  – By controlling antidiuretic hormone production
Set-Point

- Lower than set-point
  - Increase heat production
  - Increase temperature back to set-point
- Higher than set-point
  - Increase evaporation
  - Decrease temperature back to set-point temp.
- High feedback gain: 27
  - Very high compared to 2 of arterial pressure control
Set-Point Determination

- By the receptors in heat regulation center
- Partly by receptors from skin and deep body
  - By altering set point of temperature control center
Behavioral Control

• Psychic sensation of heat, feeling of discomfort by the cold
• Appropriate adjustment to re-establish comfort
  – Moving into heated(cooled) room, wearing clothing
• Powerful than physiological control effect
• Only method in severely cold environments
Local Skin Temperature Reflex

• Foot under a hot lamp
  – Local vasodilation, mild local sweating
• Foot in cold water
  – Local vasoconstriction, local cessation of sweating
• By local effect of temperature, and spinal cord reflexes
  – Small but, added to CNS controlled effect
• After cutting the spinal cord
  – Extremely poor temperature regulation
  – Need behavioral regulation
Thermal Neutrality

- Thermoregulation: behavioral → physiological
- Thermal steady state without active regulation
  - Basic metabolic rate = heat loss to environment
    - $H_m = 50\text{W/m}^2$
    - Core Temp.$=37^\circ\text{C}$
    - Skin$=33.5^\circ\text{C}$
    - Ambient$=28-30^\circ\text{C}$
  - Also in manikin
    - producing $50\text{W/m}^2$
Regulation against Cold Stress

A. Neutral condition
B. Without regulation
C. With regulation
Heat Stress Regulation

Slight Heat Stress

A. Neutral condition
B. Without regulation
C. With regulation

Moderate Heat Stress
Heat Stress Regulation

High External Heat Stress

A. Neutral condition
B. Without regulation
C. With regulation

High Internal Heat Stress
Responses to Cold

• Vasoconstriction
  – Decreasing blood supply in extremities
  – Increasing frostbite possibility
  – Digestive problems
  – Angina pectoris

• Increased metabolic heat production
Responses to Heat

- Perspiration, dehydration
  - Loss of water, electrolytes, NaCl
- Cardiac problems
  - Increased coronary artery diseases
  - Increased cardiac failure
- Dependent on
  - Level of acclimatization
  - Temperature variation rather mean temperature
  - Age
Thermoregulation Abnormality

<table>
<thead>
<tr>
<th></th>
<th>Passive Abnormality</th>
<th>Active Impairment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulatory Mechanism</td>
<td>Normal</td>
<td>Abnormal</td>
</tr>
<tr>
<td>Process</td>
<td>Cannot counterbalance at their maximum</td>
<td>Failure in response for thermal balance</td>
</tr>
<tr>
<td>Results</td>
<td>Accidental hypothermia, hyperthermia</td>
<td>Fever</td>
</tr>
</tbody>
</table>
Accidental Hypothermia

- Progressive internal temperature decrease
  - Men in artic region and in mountains
  - During water immersion

  - 25 time greater in convective power
  - Immersion in 15°C still water can be lethal
Progressive Failures

Reference to rectal temperature
- 37°C : Cold sensation
  Cutaneous vasoconstriction
  Increased muscle tension
- 36°C : Sporadic shivering
  Gross shivering
  Uncontrollable shivering
- 35°C : Mental confusion
  Drowning possible
  Decreasing will to struggle
- 34°C : Amnesia; poor articulation
  sensory & motor degradation
- 33°C : Hallucination
  Clouding consciousness
  50% lethality
- 32°C : Cardiac irregularity
  Motor function impaired
- 31°C : Failure to recognize family
- 30°C : No response to pain
- 29°C : Loss of consciousness
- 28°C : Tendon, skin, pupillary
  reflex lost
- 27°C : Ventricular fibrillation
  Death
Accidental Hyperthermia

• Heat loss cannot compensate heat gain
  – Normal regulation but in hot environment
• Too much production of heat
  – Ex: marathon runners, racing cyclists
• Impaired heat loss mechanism
  – Not enough sweating owing to dehydration
  – Decreased environment evaporative power
    • Warm and humid
• Loss of electrolytes
  – Other symptom of thermal distress
Clinical Results of Hyperthermia

• Heat fatigue(syncope)
  – In moderate hyperthermia
  – Blood distribution shift to skin by vasodilation

• Heat exhaustion
  – Cannot replace water and electrolytes lost
  – Thirsty followed by hallucination and delirium

• Heat stroke
  – Heat storage increase not compensated by evaporation
Heat Stroke

• When body temperature above 41°C
  – Dizziness, abdominal distress, vomiting, delirium, loss of consciousness
  – By circulatory shock, excessive loss of fluid and electrolytes in sweat
  – Damages body tissues, in brain
  – Death caused by cardiac failure in 42~43°C

• A few minutes of heat stroke is fatal
  – Place person in cold water bath
    • May cause uncontrollable shivering
  – Sponge or spray of cooling of skin: efficient
Active Impairment

• Abnormal functioning of thermal control
• Combined with environmental condition
• Alcohol:
  – Depress vasomotor tone, increase heat loss
  – In lower temperature easily lead to hypothermia
• Malignant hyperthermia
  – Increase in central temperature during anesthesia
  – By triggering hypothermia effector responses
Fever

• Body temperature above normal range
  – By brain itself
  – By toxic substances
  – Bacterial diseases
  – Brain tumors
  – Environmental conditions
**Pyrogens**

- Some proteins, breakdown product of proteins, lipopolysaccharide toxins from bacterial cell membrane
- Cause set point to rise
  - All the mechanisms to raise body temperature are in action
  - Body temperature approaches to raised set-point
Effect of Hyperpyrexia

• Local hemorrhages
• Parenchymatous degeneration
  – Especially in brain
• Once neuronal cell destroyed, never be replaced
• Damage to liver & kidney can cause death
Acclimatization to Heat

- Soldiers in tropical duty, miners in 2-mile deep (36°C, 100% humidity)
- 1~3 weeks when exposed several hours per day with reasonably heavy load
- Twofold increase of sweat rate, plasma volume, reduced loss of salt via sweat and urine almost none
- Increased secretion of aldosterone
  - cause the conservation of sodium, secretion of potassium, increased water retention, and increased blood pressure
Exposure to Extreme Cold

• Exposed to ice water for 20~30 minutes
  – Decrease body temperature to 25°C
  – Die due to heart standstill or fibrillation
• Lost regulation below 29.5°C
• Regulation greatly impaired below 34.5°C
• Twofold decrease in chemical heat production mechanism for each 10°F
• Sleepiness at first, coma at last
  – Depress thermoregulation activity in brain
Frostbite

• Surface area can freeze
  – Ears, digits of hands and feet
• Extensive formation of ice crystal in the cell → permanent damage
  – Circulatory impairment and local tissue damage
• Gangrene follows after thawing
  – Must surgically be removed
• Cold induced vasodilation
  – Final protection against frostbite
Artificial Hypothermia

- Depress temperature control center by strong sedative
- Cool the person with ice with cooling blanket
- Maintain temperature below 32°C for a week
- During heart surgery to stop heart for many minutes
  - Slow the heart and depress cell metabolism
- No damaging physiological results