Section VII

Energy Metabolism and Body Temperature

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2012-4-20
Purpose and requirement

• To understand the processes of energy metabolism, the principles of measurement of energy metabolism.

• To master the concept of basic metabolic rate and factors affecting metabolic rate.

• To master normal changes in body temperature and measurement of body temperature, and the mechanisms of thermoregulation.
CHAPTER 27
Energy Metabolism

• What’s the concept of metabolic rate?
• How to measure energy metabolism?
• What’s the factors affect metabolic rate?
What is metabolism?

It is a process using several chemical reactions. These reactions take place in our body’s cells.
Energy metabolism

Anabolism:
The chemical reactions that cause different molecules to combine to larger, more complex ones. The result of anabolism is the creation of new cellular material.

Catabolism:
A complex, slow, stepwise process that breaks down complex molecules into simpler ones for energy production.

— to store energy
— to release energy
Anabolism: \[ A + B = AB \]

Catabolism: \[ AB = A + B + \text{Energy} \]

Triglyceride $\rightarrow$ glycerol + fatty acids

Anabolism = building substances for growth and repair.

Catabolism = breaking substances down and liberating energy

The whole process of metabolism is a balancing act between anabolism and catabolism that happen at the same time.
Energy intake (energy input)

- **Energy sources**

1. **Carbohydrate**, a major energy source:
   - The principal product of carbohydrate digestion and the principal circulating sugar is glucose.
   - The production of energy-rich phosphate compounds during the metabolism of glucose depends on whether metabolism occurs via the aerobic oxidation or glycolysis pathway (anaerobic).
   - Glucose (1 mol) aerobic oxidation yields 38 mol ATP; anaerobic glycolysis yields 2 mol ATP

2. **Fat**

3. **Proteins**
Energy intake

- Energy sources
  1. Carbohydrate
  2. Fat:
     • Major form of energy storage
     • The energy liberated by oxidation of 1g of fat is 2 times that produced by the same amount of glucose.
     • 1 mol 6C fatty acid yield 44 mol ATP.
  3. Proteins
Energy intake

■ Energy sources

1. Carbohydrate
2. Fat
3. Proteins:
   • rarely used as energy donator.
   • plays an important role in growth and development during childhood, adolescence, and pregnancy.
   • Protein will become the major energy source to maintain the essential vital activities in special conditions.
Energy intake

- Energy sources
  1. Carbohydrate
  2. Fat
  3. Proteins:
ATP: “Energy Currency” (guyton hal 815)

Energy is stored by forming high-energy phosphate compounds of adenosine triphosphate (ATP).

The two terminal P-O bonds of ATP each contains about 12 kcal of potential energy per mole under physiological conditions.
ATP: “Energy Currency”

- Direct donator of energy.
- Generated by combustion of carbohydrates, fats and proteins.
- Energy from ATP can be used by the cells
  - Synthesis and growth
  - Muscular contraction
  - Glandular secretion
  - Nerve conduction
  - Active absorption
ATP is produced mainly during the oxidation of energy-rich compounds processed in the respiratory chain and in photosynthesis.

- **Heat is the end product of almost all the energy released in the body.**
27.1 Metabolic Rate

Maintaining physiological functions:
- muscle contraction; glandular secretion; nerve impulse conduction; food digestion and metabolism; thermoregulation

The amount of energy released by catabolism of food in the body is the same as the amount released when food is burned outside the body.

Energy output = External work + Energy storage + Heat
Metabolic rate:
the amount of energy released per unit of time.

• Isotonic muscle contractions perform work at a perk efficiency approximating 50% of total energy expended.
• Essentially all of the energy of isometric contractions appears as heat, because little or no external work is done.

Energy output = \textit{External work} + \textit{Energy storage} + \textit{Heat}

\[
\begin{align*}
\text{“0”} \quad & \quad \text{“0”} \\
\end{align*}
\]

• In an adult individual who has not eaten recently and who is not moving, all of the energy output appears as heat.
calorie:

• The standard unit of heat energy.
• Defined as the amount of heat energy necessary to raise the temperature of 1 g of water 1 degree, from 15 °C to 16 °C.
• Also called the gram calorie, small calorie, or standard calorie.
• Calorie (kilocalorie; kcal), which equals 1000 cal.
Measurement of Energy Metabolism

Direct calorimetry:
The calorie value of energy released by combustion of foodstuffs outside the body can be measured directly by oxidizing the compounds in a special apparatus such as a bomb calorimeter.

Indirect calorimetry
Measurement of Energy Metabolism
Measurement of Energy Metabolism

Direct calorimetry

Indirect calorimetry:
• Energy production can also be calculated by measuring the products of the energy-producing biologic oxidation, such as CO₂, H₂O, and the end products of protein catabolism produced, or by measuring the oxygen consumed.
Measurement of Energy Metabolism

Indirect calorimetry:
• $O_2$ is not stored.
• The amount of $O_2$ consumption per unit of time is proportionate to the energy liberated by metabolism.
  → measurement of $O_2$ consumption is used to determine the metabolic rate.

• The amount of energy released per mole of oxygen consumed varies slightly with the type of compound being oxidized.
• More accurate measurements require data on the foods being oxidized.
  → an analysis of respiratory quotient and nitrogen excretion.
27.2 Respiratory Quotient (RQ)

--the ratio in the steady state of the volume of CO₂ produced and the volume of O₂ consumed per unit of time.

\[
RQ = \frac{\text{CO}_2 \text{ production (mol)}}{\text{O}_2 \text{ consumption (mol)}} = \frac{\text{CO}_2 \text{ production (ml)}}{\text{O}_2 \text{ consumption (ml)}}
\]
Carbohydrate:  \( C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \) (glucose)
\[ \text{RQ} = \frac{6}{6} = 1.00 \]

Fat:  \( 2C_{51}H_{98}O_6 + 145O_2 \rightarrow 102CO_2 + 98H_2O \) (tripalmitin)
\[ \text{RQ} = \frac{102}{145} = 0.703 \]

Table 27-a Respiratory Quotient of carbohydrates, fats and proteins

<table>
<thead>
<tr>
<th>Foods</th>
<th>( O_2 ) consumption (L/g)</th>
<th>( CO_2 ) production (L/g)</th>
<th>Respiratory Quotient (RQ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbohydrates</td>
<td>0.83</td>
<td>0.83</td>
<td>1.00</td>
</tr>
<tr>
<td>fats</td>
<td>2.03</td>
<td>1.43</td>
<td>0.71</td>
</tr>
<tr>
<td>proteins</td>
<td>0.95</td>
<td>0.76</td>
<td>0.80</td>
</tr>
</tbody>
</table>

• The approximate amounts of carbohydrate, protein, and fat being oxidized in the body at any given time can be calculated from the RQ and the urinary nitrogen excretion.
Non-protein respiratory quotient (NPRQ)

-- The ratio of the CO₂ volume produced to the O₂ volume consumed per unit of time by the compounds oxidized with carbohydrate and fat.

Table 27-b Non-protein respiratory quotient (NPRQ)

<table>
<thead>
<tr>
<th>Respiratory quotient</th>
<th>Carbohydrates (%)</th>
<th>Fats (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.707</td>
<td>0.00</td>
<td>100.00</td>
</tr>
<tr>
<td>0.71</td>
<td>1.10</td>
<td>98.90</td>
</tr>
<tr>
<td>0.72</td>
<td>4.75</td>
<td>95.20</td>
</tr>
<tr>
<td>0.73</td>
<td>8.40</td>
<td>91.60</td>
</tr>
<tr>
<td>0.74</td>
<td>12.00</td>
<td>88.00</td>
</tr>
<tr>
<td>0.75</td>
<td>15.60</td>
<td>84.40</td>
</tr>
<tr>
<td>0.76</td>
<td>19.20</td>
<td>80.80</td>
</tr>
<tr>
<td>0.77</td>
<td>22.80</td>
<td>77.20</td>
</tr>
<tr>
<td>0.78</td>
<td>26.30</td>
<td>73.70</td>
</tr>
<tr>
<td>0.79</td>
<td>29.00</td>
<td>70.10</td>
</tr>
<tr>
<td>0.80</td>
<td>33.40</td>
<td>66.60</td>
</tr>
</tbody>
</table>
Table 27-b Non-protein respiratory quotient (NPRQ)

<table>
<thead>
<tr>
<th>Respiratory quotient</th>
<th>Carbohydrates (%)</th>
<th>Fats (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.81</td>
<td>36.90</td>
<td>63.10</td>
</tr>
<tr>
<td>0.82</td>
<td>40.30</td>
<td>59.70</td>
</tr>
<tr>
<td>0.83</td>
<td>43.80</td>
<td>56.20</td>
</tr>
<tr>
<td>0.84</td>
<td>47.20</td>
<td>52.80</td>
</tr>
<tr>
<td>0.85</td>
<td>50.70</td>
<td>49.30</td>
</tr>
<tr>
<td>0.86</td>
<td>54.10</td>
<td>45.90</td>
</tr>
<tr>
<td>0.87</td>
<td>57.50</td>
<td>42.50</td>
</tr>
<tr>
<td>0.88</td>
<td>60.80</td>
<td>39.20</td>
</tr>
<tr>
<td>0.89</td>
<td>64.20</td>
<td>35.80</td>
</tr>
<tr>
<td>0.90</td>
<td>67.50</td>
<td>32.50</td>
</tr>
<tr>
<td>:</td>
<td>:</td>
<td>:</td>
</tr>
<tr>
<td>:</td>
<td>:</td>
<td>:</td>
</tr>
<tr>
<td>1.00</td>
<td>100.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

In general, the foods contain carbohydrates, fats and proteins, the RQ is about **0.85**.
• **Indirect calorimetry**

For an individual, we can determine the metabolic rate by measuring O\(_2\) consumption, CO\(_2\) production, and urine nitrogen output.

1. Urine nitrogen output → oxidation of protein, the **energy liberated by protein**
2. Total O\(_2\) consumption and CO\(_2\) production – proportion of protein → proportion of carbohydrate and fat
3. Searching NPRQ → the **energy liberated by carbohydrate and fat**
4. Together → the total energy
### 27.3 Factors affecting the metabolic rate

Table 27-1 Factors affecting the metabolic rate.

<table>
<thead>
<tr>
<th>Muscular exertion during or just before measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent ingestion of food</td>
</tr>
<tr>
<td>High or low environmental temperature</td>
</tr>
<tr>
<td>Height, weight, and surface area</td>
</tr>
<tr>
<td>Sex</td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>Growth</td>
</tr>
<tr>
<td>Reproduction</td>
</tr>
<tr>
<td>Lactation</td>
</tr>
<tr>
<td>Emotional state</td>
</tr>
<tr>
<td>Body temperature</td>
</tr>
<tr>
<td>Circulating levels of thyroid hormones</td>
</tr>
<tr>
<td>Circulating epinephrine and norepinephrine levels</td>
</tr>
</tbody>
</table>
1. Muscular exertion / penggunaan

--The most important factor

$O_2$ consumption is elevated not only during exertion but also for as long afterward as is necessary to repay the $O_2$ debt.

Table 27-c Metabolic rate under different state

<table>
<thead>
<tr>
<th>State</th>
<th>Heat production (kJ/(m²·min))</th>
</tr>
</thead>
<tbody>
<tr>
<td>At rest</td>
<td>2.73</td>
</tr>
<tr>
<td>Meeting</td>
<td>3.40</td>
</tr>
<tr>
<td>Cleaning windows</td>
<td>8.30</td>
</tr>
<tr>
<td>Washing clothes</td>
<td>9.89</td>
</tr>
<tr>
<td>Sweeping the floor</td>
<td>11.37</td>
</tr>
<tr>
<td>Playing volleyball</td>
<td>17.50</td>
</tr>
<tr>
<td>Playing basketball</td>
<td>24.22</td>
</tr>
<tr>
<td>Playing football</td>
<td>24.98</td>
</tr>
</tbody>
</table>
2. Specific dynamic action (SDA)

The SDA of a food is the obligatory energy expenditure that occurs during its assimilation into the body.

It takes 30 kcal to assimilate the amount of protein sufficient to raise the metabolic rate 100 kcal;
Carbohydrate ............ 6 kcal
Fat------------------------ 5 kcal

Most of the increased heat production is secondary to processing of the absorbed nutrients by the liver, not the energy expended by the gastrointestinal tract in digestion and absorption.
3. Environmental temperature

The curve relating the metabolic rate to the environmental temperature is **U-shaped**.
BMR

• The metabolic rate determined at rest in a room at a comfortable temperature in the thermoneutral zone 12~14 hours after the last meal is called the basal metabolic rate (BMR).

• In the basal condition, the subject is at mental and physical rest.

• In a room at a comfortable temperature.

• And has not eaten for at least twelve hours, that is, he or she is in a post absorptive state.

• These conditions are arbitrarily designated basal.
One variable that correlates well with the metabolic rate in different species is the body surface area.

\[ BMR = 3.52W^{0.67} / BMR = 3.52W^{0.75} \]

Figure 27-1 Correlation between metabolic rate and body weight, plotted on logarithmic scales. The slope of the colored line is 0.75. The black line represents the way surface area increases with weight for geometrically similar shapes and has a slope of 0.67.
BMR

In the adult human, BMR amounts to an average daily expenditure of 20 to 25 kcal / kg body weight (or 1.0 to 1.2 kcal/min), and it requires the use of approximately 200 to 250 ml oxygen/min.
• For clinical use, the BMR is usually expressed as a percentage increase or decrease above or below a set of generally used standard normal values.
• +65 ---- 65% above the standard for that age and sex.
• **Thyroid hormones** (TH), hyperthyroidism and hypothyroidism
• **Epinephrine**
Thyroid Hormones

The thyroid hormones are the single most important determinant of BMR regardless of size, age, or sex.

Patient with exophthalmic hyperthyroidism.

Patient with hypothyroid.
Epinephrine

• Epinephrine is another hormone that exerts a calorigenic effect.

• This effect may be related to its stimulation of glycogen and triglyceride catabolism, since ATP splitting and energy liberation occur in both the breakdown and subsequent resynthesis of these molecules.

• This accounts for part of the greater heat production associated with emotional stress.
Factors affecting the metabolic rate

• Muscular exertion
• Specific dynamic action, SDA
• Environmental temperature
• Basal metabolic rate, BMR
Overview of energy balance. In a steady state, input as caloric equivalents of food equals output as caloric equivalents of various forms of mechanical and chemical work and heat.
How to maintain a stable body weight

- Energy intake – Energy output

Body weight in adults is usually regulated around a relatively constant set point.

Dietary factors have been associated with the cause or prevention of many diseases, including coronary heart disease, hypertension, cancer, osteoporosis, and so on.
What is fat?

Your “body mass index” or BMI is a measure of body fat based on height and weight. A BMI of:

• Under 20 = underweight
• 20-25 = normal
• 25-30 = overweight
• 30+ = obese
BMI = \frac{\text{Weight}}{(\text{Height})^2} \quad \text{(Kg/m}^2\text{)}

For example:

A 70kg person with a height of 180 cm

\[
\text{BMI} = \frac{70}{1.8^2} = 21.6 \quad \text{(Kg/m}^2\text{)}
\]
OBESITY (guyton hal 807 – 808)

• Energy intake > energy expenditure
• Abnormal feeding regulation
• Psychogenic factors
  During or after stressful situations
• Neurogenic abnormalities
  Hypothalamus
• Genetic factors
• Childhood overnutrition
• Basal metabolic rate (BMR)
• BMR means the basal metabolic rate is measured in certain standardized conditions.
• The metabolic rate determined at rest in a room at a comfortable temperature in the thermoneutral zone 12~14 hours after the last meal is called the basal metabolic rate.
• Specific dynamic action (SDA)
• Respiratory Quotient (RQ)
Summary

Basic Concepts of Energy Expenditure and Stores

I. The energy liberated during a chemical reaction appears either as heat or work.

II. Total energy expenditure = heat produced + external work done + energy stored.

III. Energy metabolism can be measured by direct or indirect calorimetry.

IV. Metabolic rate is influenced by the many factors, such as muscular exertion, specific dynamic action, environmental temperature, and so on.
Summary

Basic Concepts of Energy Expenditure and Stores

V. BMR means the basal metabolic rate is measured in certain standardized conditions.

VI. Metabolic rate is increased by the thyroid hormones and epinephrine.

VII. Being overweight or obese, the result of an imbalance between food intake and metabolic rate, increases the risk of many diseases.
CHAPTER 28

Body temperature

The traditional normal value for the oral temperature is 37°C.
• (buku bsr hal 654)
• Normal body function depends on a relatively constant body temperature.
• The enzyme systems of the body have narrow temperature ranges in which their function is optimal.
• The balance between heat production and heat loss determines the body temperature.
Important to maintain a stable body temperature

<table>
<thead>
<tr>
<th>Core temperature(℃)</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>Muscle failure</td>
</tr>
<tr>
<td>30</td>
<td>Loss of body temperature control</td>
</tr>
<tr>
<td>33</td>
<td>Loss of consciousness</td>
</tr>
<tr>
<td>37</td>
<td>Normal</td>
</tr>
<tr>
<td>42</td>
<td>Central nervous system breakdown</td>
</tr>
<tr>
<td>44</td>
<td>Death</td>
</tr>
</tbody>
</table>
2012 European cold wave was a deadly cold wave that started on 27 January 2012 and brought snow and freezing temperatures to much of the European continent. There were 824+ deaths reported.

Freezing temperatures, combined with snow have been responsible for the death of people.
August 17, 2011

Tokyo's maximum surface temperature exceeded 50 degrees. As the national power shortage, so some people turn off air conditioning, resulting in higher heat stroke.

The NHK television alone, a survey conducted said that in the past week, the country's 12 prefectures have 35 hot dead, more than 7,000 people sent to hospital for treatment for heat stroke.
28.1 Normal body temperature

The traditional normal value for the oral temperature is 37°C. In normal young adults, the morning oral temperature averaged 36.7°C.

The actual temperature varies from species to species and from individual to individual.

Various parts of the body are at different temperatures.

The magnitude of the temperature difference between the parts varies with the environmental temperature.

The normal human core temperature undergoes a regular circadian fluctuation of 0.5~0.7°C.

The body temperature rises during exercise.
1. **Various parts** of the body are at different temperatures.

- The extremities are generally cooler than the rest of the body.
- The **rectal temperature** is representative of the temperature at the core of the body. It varies least with changes in environmental temperature.
- The **oral temperature** is normally 0.5°C lower than the rectal temperature.
- The oral temperature is affected by many factors, including ingestion of hot or cold fluids, gum-chewing, smoking, and mouth breathing.
- The **temperature of the scrotum** is carefully regulated at 32°C.
# Normal core temperature

<table>
<thead>
<tr>
<th>Site</th>
<th>Range of variation of temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axilla</td>
<td>36.0~37.4°C</td>
</tr>
<tr>
<td>Oral Cavity</td>
<td>36.7~37.7°C</td>
</tr>
<tr>
<td>Rectum</td>
<td>36.9~37.9°C</td>
</tr>
</tbody>
</table>
2. Various parts of the body are at different temperatures, and the magnitude of the temperature difference between the parts varies with the environmental temperature.

Skin controls temperature in protecting the body’s internal organs from extremes in outside temperatures and allowing them to stay within a normal homeostatic temperature range.
3. The normal human core temperature undergoes a regular circadian fluctuation of 0.5~0.7°C.

Fig 28-1 Typical temperature chart of a hospitalized patient who does not have a febrile disease. Note the slight rise in temperature, due to excitement and apprehension, at the time of admission to hospital and the regular circadian temperature cycle.
The normal human core temperature undergoes a regular circadian fluctuation of 0.5~0.7°C.

It is lowest at about 6 am and highest in the evenings.
4. In women, an additional monthly cycle of temperature variation is characterized by a rise in basal temperature at the time of ovulation.

Elevation in body temperature shortly after ovulation.

- Temperature regulation is less precise in young children, and they may normally have a temperature that is 0.5°C or so above the established norm for adults.
5. During exercise, the heat produced by muscular contraction accumulates in the body, and the rectal temperature normally rises as high as 40°C.

Body temperature also rises slightly during emotional excitement, probably owing to unconscious tensing of the muscles.
6. Body temperature is chronically elevated by as much as 0.5°C when the metabolic rate is high, as in hyperthyroidism, and lowered when the metabolic rate is low, as in hypothyroidism.

Fig28-1 Typical temperature chart of a hospitalized patient who does not have a febrile disease. Note the slight rise in temperature, due to excitement and apprehension, at the time of admission to hospital, and the regular circadian temperature cycle.
28.1 Normal body temperature

The traditional normal value for the oral temperature is 37°C. In normal young adults, the morning oral temperature averaged 36.7°C.

Various parts
The environmental temperature
A regular circadian fluctuation
Gender
Age
Exercise and emotional excitement
Metabolic rate

Room temperature
28.2 Heat production and heat loss

Body temperature is controlled by balancing heat production against heat loss.

Heat production:
Mainly in Liver ----- at rest
Mainly in Muscle --- during exercise
Main organs of heat production in the body

<table>
<thead>
<tr>
<th>Percentage in body weight</th>
<th>Heat production(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>at rest</td>
</tr>
<tr>
<td>Brain</td>
<td>2.5</td>
</tr>
<tr>
<td>Viscera (especially liver)</td>
<td>34</td>
</tr>
<tr>
<td>Skeletal muscle</td>
<td>56</td>
</tr>
<tr>
<td>Others</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Liver ------- at rest
Muscle ----- during exercise
28.2 Heat production and heat loss

Heat production can be varied by endocrine mechanisms in the absence of food intake or muscular exertion.

- Epinephrine and norepinephrine
  ---- rapid but short-lived increase

- Thyroid hormones (TH)
  ---- slowly developing but prolonged increase
28.2 Heat production and heat loss

Body temperature is controlled by balancing heat production against heat loss.

**Conduction** ---- heat exchange between objects or substances that are in contact with one another.

**Convection** ---- is the process where by conductive heat loss or gain is aided by movement of the air or water next to the body.
28.2 Heat production and heat loss

Body temperature is controlled by balancing heat production against heat loss.

**Radiation** ---- is the transfer of heat by from one object to another at a different temperature with which it is not in contact

**Evaporation** ----

- sweat secretion
- insensible water loss

Other than sweat secretion, the other major processing transferring heat from the body in human is vaporization of water on the skin and mucous membrane of mouth and respiratory passages.

Vaporization of 1g of water removes about 0.6kcal. A certain amount of water is vaporized at all times. This insensible water loss amounts to 50 ml / h in humans.
28.2 Heat production and heat loss

Conduction, convection, radiation

Evaporation ----

Vaporization of 1 g of water removes about 0.6 kcal of heat.

• sweat secretion

  During muscular exertion (penggunaan) in a hot environment, sweat secretion reaches values as high as 1600 mL/h, and in dry atmosphere, most of this sweat is vaporized. Heat loss by vaporization of water therefore varies from 30 to over 900 kcal/h.

• insensible water loss
  This insensible water loss amounts to 50 mL/h, 1000 mL/d.

  Vaporized at all times.
Body heat is produced by:

- Basic metabolic processes
- Food intake (specific dynamic action)
- Muscular activity

Body heat is lost by:

<table>
<thead>
<tr>
<th>Percentage of heat lost at 21 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation and conduction</td>
</tr>
<tr>
<td>Vaporization of sweat</td>
</tr>
<tr>
<td>Respiration</td>
</tr>
<tr>
<td>Urination and defecation</td>
</tr>
</tbody>
</table>

The relative contribution of each of the processes that transfer heat away from the body varies with the environmental temperature. At 21 °C, vaporization is a minor component in humans at rest.
28.3 Regulation of body temperature

28.3.1 Thermoregulatory responses

Cold

Sweating
Increased respiration
Anorexia

or

hot?

Shivering
Hunger
Curling up
28.3.1 Thermoregulatory responses

- Curling up “in a ball” is a common reaction to cold in animals.
- It decreases the body surface exposed to the environment.
- Shivering is an involuntary response of the skeletal muscles.
- Cold also causes a semiconscious general increase in motor activity.
28.3.1 Thermoregulatory responses (guyton hal 826)

• Endocrine response:
  Increased catecholamine secretion is an important endocrine response to cold.
• Thyroid-stimulating hormone, TSH?
Heat-conserving responses

Local responses:

Cutaneous blood vessels are cooled

→ more sensitive to catecholamines

→ the arterioles and venules constrict

→ direct blood away from the skin
Heat-conserving responses

Countercurrent exchange:
Another heat-conserving mechanism that is important in animals living in cold water is heat transfer from arterial to venous blood in the limbs.

• Deep veins run alongside the arteries
• Heat is transferred from the warm arterial blood going to the limbs to the cold venous blood coming from the extremities → keeps the tips of the extremities cold but conserves body heat.
28.3.1 Thermoregulatory responses

- Thermoregulatory responses include autonomic, somatic, endocrine, and behavioral changes.
- One group of responses increases heat loss and decreases heat production; the other decreases heat loss and increases heat production.
- When exposure to heat stimulates the former group of responses and inhibits the latter, whereas exposure to cold does the opposite.
28.3.2 Thermoregulatory centers

• The reflex responses activated by cold are controlled from the posterior hypothalamus.

• Those activated by warmth are controlled primarily from the anterior hypothalamus.

The hypothalamus is thought to integrate body temperature information from sensory receptors (primarily cold receptors) in the skin, deep tissues, spinal cord, extrahypothalamic portions of the brain, and the hypothalamus itself.
28.3.2 Thermoregulatory centers

• In the posterior hypothalamus.
• Preoptic and anterior hypothalamic (PO/AH) region.
• Cold-sensitive neurons
• Heat-sensitive neurons

• Thermostat: set point
Set point — a critical temperature threshold

• It is clear that at a critical body core temperature, at a level of almost exactly 37.0 °C, drastic changes occur in the rates of both heat loss and heat production.
• At temperatures above this level, the rate of heat loss is greater than that of heat production, so that the body temperature falls and reapproaches the 37.0 °C level.
Set-point: a critical temperature threshold for each response.
28.4 Fever

--hallmark of disease
Infection

Macrophages

\[ \downarrow \]

Secrete endogenous pyrogens (IL-1, IL-6, ? others)

\[ \downarrow \]

↑ Firing of neural receptors

Shivering

Curl up, put on clothes and blankets

↑ Heat production

Vasoconstriction

↑ Plasma IL-1, IL-6, ? others

Heat production > heat loss

Heat retention

↑ Body temperature
28.4 Fever

• An elevation of body temperature due to a “resetting of the thermostat” in the hypothalamus.

• A person with a fever still regulates body temperature in response to heat or cold but at a higher set point.

• The most common cause of fever is infection, but physical trauma and stress can also induce fever.
28.5 Hypothermia

• Humans tolerate body temperatures of 21~24 °C (70~75 °F) without permanent ill effects, and induced hypothermia has been used in surgery.

• Accidental hypothermia due to prolonged exposure to cold air or cold water is a serious condition and requires careful monitoring and prompt rewarming.
Summary

Regulation of Body Temperature

I. Core body temperature shows a circadian rhythm, being highest during the day and lowest at night.

II. The body exchanges heat with the external environment by radiation, conduction, convection, and evaporation of water from the body surface.

III. The hypothalamus and other brain areas contain the integrating centers for temperature-regulating reflexes, and both peripheral and central thermoreceptors participate in these reflexes.
Regulation of Body Temperature

IV. Body temperature is regulated by altering heat production and/or heat loss so as to change total body heat content.

Additional Clinical Examples

I. Fever is due to a resetting of the temperature set point so that heat production is increased and heat loss is decreased in order to raise body temperature to the new set point and keep it there. The stimulus is endogenous pyrogen, which is interleukin 1 and other peptides as well.
II. The hyperthermia of exercise is due to the increased heat produced by the muscles, and it is partially offset by skin vasodilation.

III. Extreme increases in body temperature can result in heat exhaustion or heat stroke. In heat exhaustion, blood pressure decreases due to vasodilation. In heat stroke, the normal thermoregulatory mechanisms fail, and thus heat stroke can be fatal.