Energy Metabolism and Body Temperature

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Part I  Energy metabolism

- **Definition**
  - The metabolic processes by which energy is made available for the use of the body
    - The main sources of chemical energy are carbohydrates, fats, and protein.
    - The breakdown of organic molecules liberates the energy and ATP synthesis.
    - The breakdown of ATP serves as the immediate energy source for biological work.
      - Growth, repair, and physical activity......
Energy sources

- Carbohydrates - mainly glucose
  - Major source: >70% of the total energy
  - ATP is synthesized and stored
    - By glycolysis
    - By citric acid cycle (Krebs cycle)
  - 1g of carbohydrate contains 4 kcal

Energy sources

- Fat – fatty acids
  - Major form of energy storage
    - The storage of fat in the body is much greater than that of glucose
  - Alternative energy source
    - 1g of fat contains 9 kcal
Energy sources

- **Proteins**
  - The amount of energy provided by proteins is relatively small in human beings
    - 1g of protein contains 4 kcal
  - Protein will become the major energy source to maintain the essential vital activities in special conditions

ATP: “Energy Currency”

- ATP is generated by combustion of carbohydrates, fats and proteins
- Energy from ATP can be used by the cells for:
  - Synthesis and growth
  - Muscular contraction
  - Glandular secretion
  - Nerve conduction
  - Active absorption
Phosphocreatine: an ATP “buffer”

- Phosphocreatine (PCr or creatine phosphate)
  - is synthesized in the liver
  - serves as a rapidly mobilizable reserve of high-energy phosphates in skeletal muscle and brain.
  - Phosphocreatine can anaerobically donate a phosphate group to ADP to form ATP during an intense muscular or neuronal effort.

Energy transfer

- Heat is the end product of almost all the energy released in the body
- About 60% of the energy released from organic molecules appears immediately as heat.
- The rest is used for work.
How do we measure energy metabolic rate or energy expenditure?

- Metabolic rate
  - Total energy expenditure per unit time
  - Normally expressed in terms of the rate of heat liberation during the chemical reactions
  - Unit of energy is calorie or joule.

- Measurement of energy metabolism
  - Direct calorimetry
  - Indirect calorimetry

Measurement of energy metabolism

- Direct calorimetry
Indirect calorimetry

- Energy metabolic rate
  \[ \text{energy metabolic rate} = \text{energy equivalent of oxygen} \times \text{oxygen consumption} \]

- Energy equivalent of oxygen
  Heat production by consuming one litre of oxygen to oxidize a specific type of food

- Methods of measuring O₂ consumption
  - Open circuit method
  - Closed circuit method

Closed circuit method
Factors that affect energy metabolic rate

Physical activity: the factor that most increase MR

<table>
<thead>
<tr>
<th>Form of Activity</th>
<th>Heat Output (Kj/m²/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Awake lying still</td>
<td>2.616</td>
</tr>
<tr>
<td>Sitting at rest</td>
<td>3.399</td>
</tr>
<tr>
<td>Cleaning the window</td>
<td>8.301</td>
</tr>
<tr>
<td>Washing clothes</td>
<td>9.887</td>
</tr>
<tr>
<td>Cleaning the floor</td>
<td>11.369</td>
</tr>
<tr>
<td>Playing volleyball</td>
<td>17.045</td>
</tr>
<tr>
<td>Playing basketball</td>
<td>24.216</td>
</tr>
<tr>
<td>Playing football</td>
<td>24.969</td>
</tr>
</tbody>
</table>

Psychic activity

- Emotional stress $\rightarrow$ MR↑
  - Sympathetic nerve activation
  - E, NE
Factors that affect energy metabolic rate

- Specific dynamic action of foods (Diet induced thermogenesis)
  - The ingestion of food rapidly increases the metabolic rate by 10~20% for a few hours after eating.
  - Most of the increased heat production is caused by the processing of the absorbed nutrients by the liver.
  - Ingested protein produces the greatest effect.

Factors that affect energy metabolic rate

- Environmental temperature
  - 20-30 °C, energy metabolism stably
  - T < 20 °C or T >30 °C, energy metabolism ↑
  - Shivering thermogenesis, EM
  - Sweating, FM

![Specific dynamic action of foods](image)
Basal metabolism

- Basal metabolic rate (BMR)
  - MR in the basal condition
  - The minimum energy expenditure for the body to exist
  - 50-70% of the daily energy expenditure
  - BMR is usually expressed as calories per hour per square meter of body surface area

Method for determining BMR

- To measure the rate of O₂ utilization under the basal conditions
  - At mental and physical rest
  - Room temperature: 20 to 25°C
  - Keep fast at least for 12 hours
Factors that influence the BMR

- Sex: women less than men at any given age

![Graph showing BMR by age and gender]

Factors that influence the BMR

- Thyroid hormone, male sex hormone, growth hormone and fever
  \[\uparrow\text{BMR}\]
- Sleep and malnutrition
  \[\downarrow\text{BMR}\]
How to maintain a stable body weight

- **Energy balance** is the difference between the number of kilocalories that you eat (energy intake) and the number of kilocalories that you burn (energy expenditure).

![Energy Balance Diagram]

**Energy intake**

- Nutrient metabolism in the absorptive state

**Postprandial period (immediately after eating)**

- Insulin secretion increases (dominant effect)
- Glucagon and GH may increase in response to dietary amino acids
- Little secretory activity of the adrenal medulla and cortex at this time

- Dietary carbohydrates and lipids are transferred to storage depots in liver, adipose tissue, and muscle
- Amino acids are converted to proteins in various tissues
- Extrahepatic tissues use dietary glucose and fail to meet their needs instead of glucose derived from hepatic glycogen or fatty acids mobilized from adipose tissue
- Hepatic glycogen increases
- Fatty acids mobilization is inhibited
TABLE 16–1 Summary of Nutrient Metabolism during the Absorptive Period

1. Energy is provided primarily by absorbed carbohydrate in a typical meal.
2. There is net uptake of glucose by the liver.
3. Some carbohydrate is stored as glycogen in liver and muscle, but most carbohydrate and fat in excess of that used for energy are stored mainly as fat in adipose tissue.
4. There is some synthesis of body proteins, but some of the amino acids in dietary protein are used for energy or converted to fat.

Energy intake

- Nutrient metabolism in the postabsorptive state

**Postabsorptive period (several hours after eating)**

- Body begins to draw on fuels
- 75% of the glucose secreted by the liver derives from glycogen and the remainder comes from gluconeogenesis
- 75% of the glucose is taken by brain, blood cells and other tissues whose consumption of fuel is independent of insulin
- 25% of the glucose is taken by muscle and adipose tissue
- Blood FFA gradually increases
- Blood glucose remains constant, but glucose metabolism in muscle decreases
**TABLE 16-2** Summary of Nutrient Metabolism during the Postabsorptive Period

1. Glycogen, fat, and protein syntheses are curtailed, and net breakdown occurs.
2. Glucose is formed in the liver both from the glycogen stored there and by gluconeogenesis from blood-borne lactate, pyruvate, glycerol, and amino acids. The kidneys also perform gluconeogenesis during a prolonged fast.
3. The glucose produced in the liver (and kidneys) is released into the blood, but its utilization for energy is greatly reduced in muscle and other nonneural tissues.
4. Lipolysis releases adipose tissue fatty acids into the blood, and the oxidation of these fatty acids by most cells and of ketones produced from them by the liver provides most of the body’s energy supply.
5. The brain continues to use glucose but also starts using ketones as they build up in the blood.

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**Energy intake**

**Fasting (> 24 hours after the last meal)**

- Insulin decreases further
- Glucose, glucagon, catecholamine, and GH increase
- Cortisol values remain unchanged until late in starvation.
  - It plays a permissive role in allowing gluconeogenesis and lipolysis to proceed and is an essential component of the survival mechanism.

- Glucose metabolism in muscle and adipose tissue is inhibited
- FFA mobilization is accelerated
- Muscle proteins break down providing amino acids for gluconeogenesis

> 24 hrs

- FFA mobilization is further increased
- Ketogenesis becomes significant

> 3 days

Terminal starvation

- Protein may become the only remaining substrate and are rapidly broken down to amino acids
Energy output

- Humans oxidize carbohydrate, protein, fat to produce energy. The energy is needed:
  - **To maintain body functions**---to breathe, to keep the heart beating, to keep the body warm and all the other functions that keep the body alive
  - **For physical activity**---for active movement--- muscle contraction
  - **For growth and repair** which require new tissues to be made

Regulation of energy balance

<table>
<thead>
<tr>
<th>Energy balance</th>
<th>Body fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>(e) Intake = expenditure</td>
<td>Normal</td>
</tr>
<tr>
<td>(b) Intake &gt; expenditure</td>
<td>Obesity</td>
</tr>
<tr>
<td>(c) Intake &lt; expenditure</td>
<td>Starvation</td>
</tr>
</tbody>
</table>
Control of energy balance

- Leptin
  - synthesized by adipose tissue cells
  - functions in a negative feedback system to maintain a constant body weight

- Stress

- Ghrelin
  - is released from endocrine cells in the fundus of stomach
  - increase hunger
  - decreases the burning of fat and increases gastric motility and acid production

Treatment of obesity

- **↓ Energy input**
  - Reducing diets
    - Bulk-- non-nutritive cellulose substances
  - Drugs for decreasing the degree of hunger
    - Amphetamines
      - (-) feeding centers
    - Sibutramine
      - A sympathomimetic
      - ↓ food intake and ↑ energy expenditure
  - Drugs for altering lipid metabolism
    - Lipase inhibitor—-orlistat
Treatment of obesity

- ↑Energy expenditure
  - An effective means
  - ↑physical activity

Part 2 Body Temperature and Temperature Regulation
Body temperature

- **Skin temperature**
  - Changing with the temperature of the surroundings

- **Core temperature**
  - Maintaining constant (when $T=12$~$54^\circ C$)

### Normal core temperature

<table>
<thead>
<tr>
<th>Site</th>
<th>Mean value of temperature</th>
<th>Standard deviation</th>
<th>Range of variation of temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axilla</td>
<td>36.79°C</td>
<td>0.357</td>
<td>36.0-37.4°C</td>
</tr>
<tr>
<td>Oral cavity</td>
<td>37.19°C</td>
<td>0.249</td>
<td>36.7-37.7°C</td>
</tr>
<tr>
<td>Rectum</td>
<td>37.47°C</td>
<td>0.251</td>
<td>36.9-37.9°C</td>
</tr>
</tbody>
</table>
Physiological fluctuations of the body temperature

- Circadian rhythm
  - Diurnal rhythmic changes with a variation of 1 °C
  - These rhythms originate in the hypothalamus
- Sex difference in body temperature

Physiological fluctuations of the body temperature

- Age
- Emotional stress
- Muscle activity
- Food, drugs
Temperature regulation

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

Major organs of heat production in the body:

<table>
<thead>
<tr>
<th>Organ</th>
<th>Percentage in body weight</th>
<th>Percentage in heat-production At rest</th>
<th>Percentage in heat-production During labor</th>
</tr>
</thead>
<tbody>
<tr>
<td>The brain</td>
<td>2.5</td>
<td>16</td>
<td>1</td>
</tr>
<tr>
<td>The internal organs (i.e. liver and spleen, etc.)</td>
<td>34</td>
<td>56</td>
<td>8</td>
</tr>
<tr>
<td>The muscle &amp; skin</td>
<td>56</td>
<td>18</td>
<td>90</td>
</tr>
<tr>
<td>The Others</td>
<td>7.5</td>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>

Body temperature is constant when heat gain and heat loss are balanced.
Temperature regulation

- Modes of heat-production
  - Shivering thermogenesis
  - Non-shivering thermogenesis
- Control of thermogenesis
  - Thyroxine, catecholamines, androgens and GH
  - Sympathetic nervous system

Shivering thermogenesis

- Reflex change (shivering thermogenesis)
  - consists of rhythmic, oscillating skeletal muscle contractions
  - primary controlled by hypothalamus
Nonshivering thermogenesis

- occurs in brown adipose tissue (brown fat) that is present in human infants and hibernating mammals
- is mediated by sympathetic stimulation and thyroid hormone

Temperature regulation

- Heat loss
  - By the skin
  - By expiration, urination, and defecation
  - By panting
Heat is mainly lost from the skin

How is heat lost from the skin surface?

- **Radiation: 60%**
  - The emission of heat energy from the surface of a warm body in the form of electromagnetic waves, or heat waves (infrared heat rays)
  - The human body both emits and absorbs radiant energy
How is heat lost from the skin surface?

- **Conduction**
  - is the transfer of heat between objects of differing temperatures that are in direct contact with each other
  - The rate of heat transfer by conduction depends on the temperature difference between the touching objects and the thermal conductivity of the substances involved

How is heat lost from the skin surface?

- **Convection**
  - transfer of heat energy by air currents
  - The combined conduction-convection process of dissipating heat from the body is enhanced by forced movement of air across the body surface
How is heat lost from the skin surface?

- **Evaporation**
  - When water evaporates from the skin surface, the heat required to transform water from a liquid to a gaseous state
  - A necessary cooling mechanism at very high air temperature
  - 0.58 calorie of heat is lost for 1 g water that evaporates

- **Evaporation**
  - two forms of evaporation
    - Insensible evaporation
      - 1000 ml H₂O/day
    - Evaporation of sweat
      - Sweating is an active evaporative heat loss process
      - Sweat is actively extruded to the surface of the skin by sweat glands
      - The sweat glands are innervated by cholinergic nerve fibers
Temperature regulation

- **Control of heat loss**
  - By regulation of skin blood flow
  - By regulation of sweat glands

Regulation of body temperature

- The temperature of the body is regulated almost entirely by nervous feedback mechanisms
- Behavioral control of body temperature
Regulation of body temperature

- Temperature receptors (thermoreceptor)
  - Temperature receptors in the skin
    - Warmth receptors
    - Cold receptors: more
  - Deep body temperature receptors
    - Spinal cord, abdominal viscera, great veins

Regulation of body temperature

- Preoptic and anterior hypothalamic (PO/AH) region
  - Cold-sensitive neurons
  - Heat-sensitive neurons
  - To serve as a thermostatic body temperature control center
Regulation of body temperature

- Temperature-regulating centers
  - In the hypothalamus
  - Preoptic and anterior hypothalamic (PO/AH) region

Set point
- is the level at which the body attempts to maintain its temperature
- A critical body temperature value: 37.1°C
- PO/AH
Temperature-decreasing mechanisms when the body is too hot

- Vasodilatation
- Sweating
- Decrease in heat production
Temperature-increasing mechanisms when the body is too cold

- Skin vasoconstriction
- Increase in heat production
  - Shivering
  - Sympathetic excitation
  - Thyroxine (Eskimos--higher incidence of toxic thyroid goitres)

Regulation of body temperature
Abnormalities of body temperature regulation

- Fever
  - Pyrogens: Shift the set point
Abnormalities of body temperature regulation

- **Heat stroke**
  - An acute condition of hyperthermia that is caused by prolonged exposure to excessive heat or heat and humidity
  - BT: 40-42 °C
  - Cool water immersion
  - Sponge or spray cooling of the skin

*The End.*