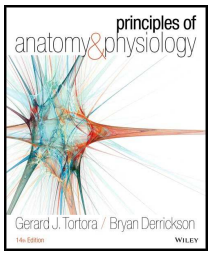


Principles of Anatomy and Physiology

14th Edition

CHAPTER 25
Metabolism and Nutrition

Metabolic Reactions

- **Metabolism** refers to all of the chemical reactions taking place in the body.
- Reactions that break down complex molecules into simpler ones are **catabolic (decomposition)**.
- Reactions that combine simple molecules to make complex molecules are **anabolic (synthesis)**.

Metabolic Reactions

Interactions Animation:

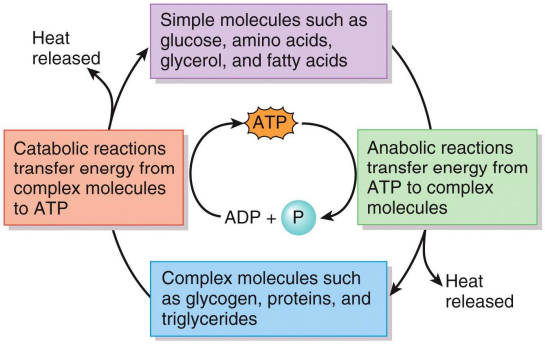
- Introduction to Metabolism

You must be connected to the Internet and in Slideshow Mode to run this animation.

Metabolic Reactions

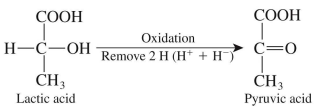
Metabolism results from the balance of anabolic and catabolic reactions. **ATP (adenosine triphosphate)** is the energy molecule that couples the two types of reactions.

Metabolic Reactions



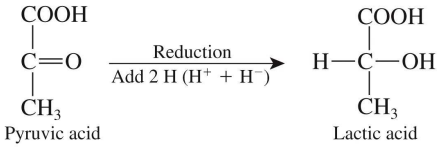
Energy Transfer

- **Oxidation-Reduction reactions** are one category of reactions important in energy transfer.
- **Oxidation** involves the **removal of electrons** from an atom or molecule. An example is the conversion of lactic acid to pyruvic acid.



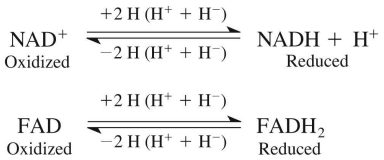
Energy Transfer

Reduction involves the **addition of electrons** to a molecule. An example is the conversion of pyruvic acid to lactic acid.



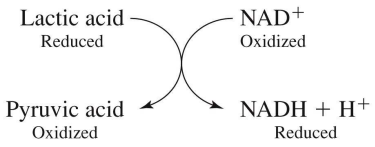
Energy Transfer

When a substance is oxidized, the liberated hydrogen atoms are transferred by **2 coenzymes** to another compound. These are **nicotinamide adenine dinucleotide (NAD)** and **flavin adenine dinucleotide (FAD)**.



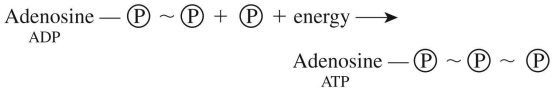
Energy Transfer

Oxidation and reduction are always coupled. That is why the two reactions together are called **oxidation-reduction** or **redox reactions**. The oxidation of lactic acid to pyruvic acid and the associated reduction of NAD^+ may be written as:



Energy Transfer

Some of the energy released during oxidation reactions is captured when ATP is formed. A **phosphate group** is added to **ADP (phosphorylation)** along with **energy** to form **ATP**. A **high-energy bond** is indicated by a "**squiggle.**"



Carbohydrate Metabolism

Carbohydrate metabolism is, in reality, mostly **glucose metabolism**. The body's use of glucose depends on the needs of cells. These needs include:

- ATP production
- Amino acid synthesis
- Glycogen synthesis
- Triglyceride synthesis

Carbohydrate Metabolism

Interactions Animation:

- Carbohydrate Metabolism

You must be connected to the Internet and in Slideshow Mode to run this animation.

Carbohydrate Metabolism

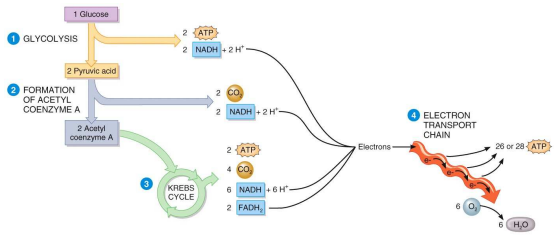
- Glucose must pass through the plasma membrane to be used by the cell. **Facilitated diffusion** makes this happen. In most body cells, **GluT molecules (transporters)** perform this.
- **Insulin** increases the insertion of **GluT4 transporters** into the plasma membrane increasing the rate of facilitated diffusion.

Carbohydrate Metabolism

The oxidation of glucose to produce ATP is **cellular respiration**. Four sets of reactions are involved:

1. Glycolysis
2. Formation of acetyl coenzyme A
3. Krebs cycle reactions
4. Electron transport chain reactions

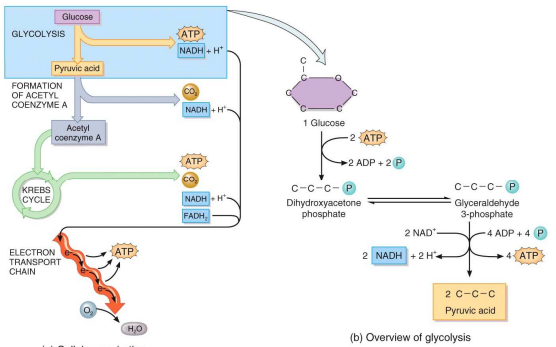
Carbohydrate Metabolism



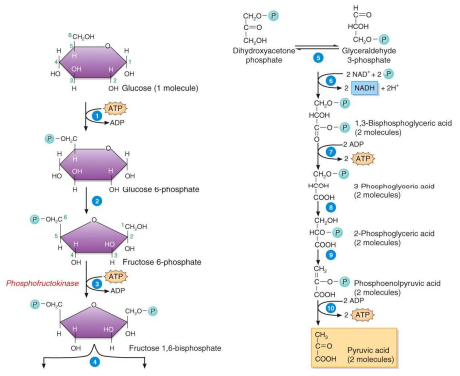
Carbohydrate Metabolism

- **Glycolysis** is the process whereby a 6-carbon glucose molecule is split into two 3-carbon molecules of **pyruvic acid**.
- Glycolysis involves **10 reactions**.

Carbohydrate Metabolism



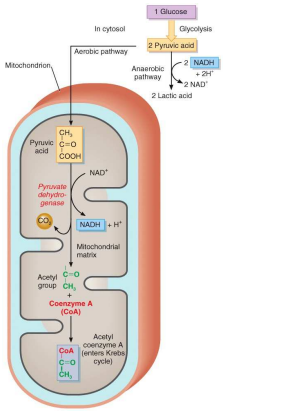
Carbohydrate Metabolism



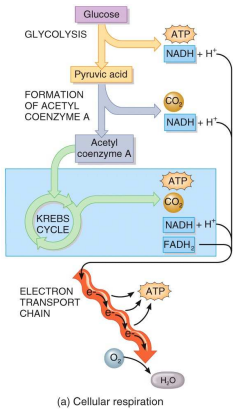
Carbohydrate Metabolism

- What happens to the **pyruvic acid** depends on the **availability of oxygen**.
- If oxygen is scarce (**anaerobic conditions**), pyruvic acid is reduced by the addition of 2 hydrogen atoms to form **lactic acid**.
- If oxygen is plentiful (**aerobic conditions**), most cells convert pyruvic acid to **acetyl coenzyme A**.

Carbohydrate Metabolism



Carbohydrate Metabolism

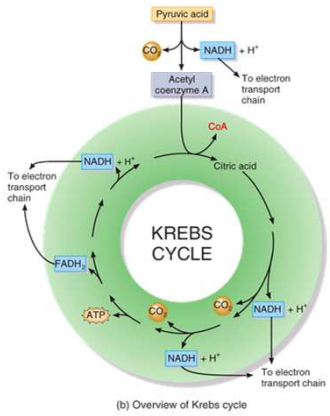


(a) Cellular respiration

Carbohydrate Metabolism

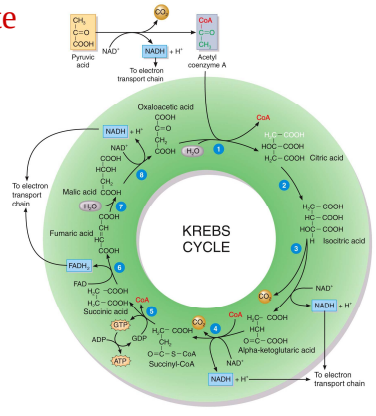
The **Krebs cycle** is also known as the **citric acid cycle**. This cycle occurs in the **matrix of mitochondria** and consists of **eight reactions**.

Carbohydrate Metabolism



(b) Overview of Krebs cycle

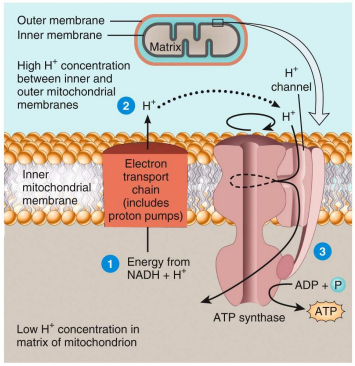
Carbohydrate Metabolism



Carbohydrate Metabolism

- The **electron transport chain** is a series of **electron carriers in the mitochondria**. Each carrier in the chain is reduced as it picks up electrons and oxidized as it gives up electrons. **Exergonic reactions release energy** used to form **ATP**.
- This mechanism links chemical reactions with the pumping of hydrogen ions and is known as **chemiosmosis**.

Carbohydrate Metabolism



Carbohydrate Metabolism

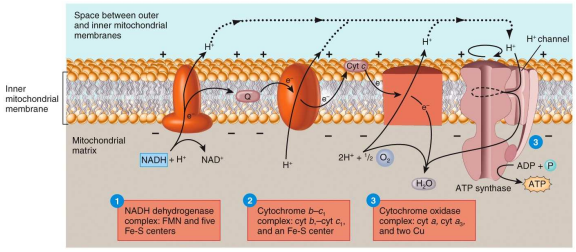
Electron carriers include:

- Flavin mononucleotide (FMN)
- Cytochromes
- Iron-sulfur centers
- Copper atoms
- Coenzyme Q

Carbohydrate Metabolism

Inside of the **inner mitochondrial membrane**, the carriers are clustered into three complexes, each acting as a **proton pump that expels H^+**.

Carbohydrate Metabolism



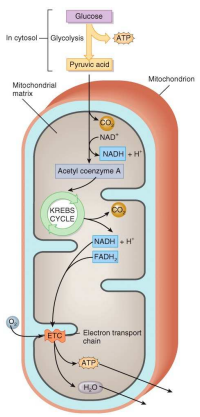
Carbohydrate Metabolism

Cellular respiration will generate either 30 or 32 ATP molecules for each molecule of glucose catabolized. The reaction is:

$$\underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6\ O_2} + 30 \text{ or } 32\ \text{ADPs} + 30 \text{ or } 32\ \textcircled{P} \longrightarrow$$

$$\underset{\text{Carbon dioxide}}{6\ CO_2} + \underset{\text{Water}}{6\ H_2O} + 30 \text{ or } 32\ \text{ATPs}$$

Carbohydrate Metabolism



Carbohydrate Metabolism

TABLE 25.1

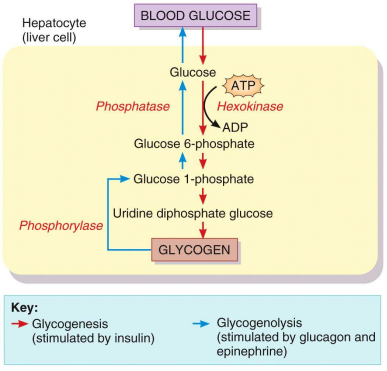
Summary of ATP Produced in Cellular Respiration

SOURCE	ATP YIELD PER GLUCOSE MOLECULE (PROCESS)
GLYCOLYSIS	
Oxidation of one glucose molecule to two pyruvic acid molecules	2 ATPs (substrate-level phosphorylation).
Production of 2 NADH + H^+	3 or 5 ATPs (oxidative phosphorylation).
FORMATION OF TWO MOLECULES OF ACETYL COENZYME A	
2 NADH + 2 H^+	5 ATPs (oxidative phosphorylation).
KREBS CYCLE AND ELECTRON TRANSPORT CHAIN	
Oxidation of succinyl-CoA to succinic acid	2 GTPs that are converted to 2 ATPs (substrate-level phosphorylation).
Production of 6 NADH + 6 H^+	15 ATPs (oxidative phosphorylation).
Production of 2 $FADH_2$	3 ATPs (oxidative phosphorylation).
Total	30 or 32 ATPs per glucose molecule.

Carbohydrate Metabolism

- Glucose not needed immediately is stored as **glycogen**. The process that creates it is **glycogenesis**.
- When ATP is needed for body activities, stored glycogen is broken down by a process called **glycogenolysis**.

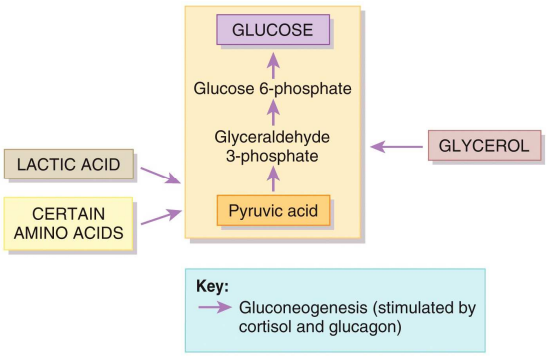
Carbohydrate Metabolism



Carbohydrate Metabolism

- Glucose may be formed from **proteins as well as the glycerol portion of triglycerides, lactic acid and certain amino acids**. The process is known as **gluconeogenesis**.
- **Cortisol, glucagon and thyroid hormones** stimulate gluconeogenesis.

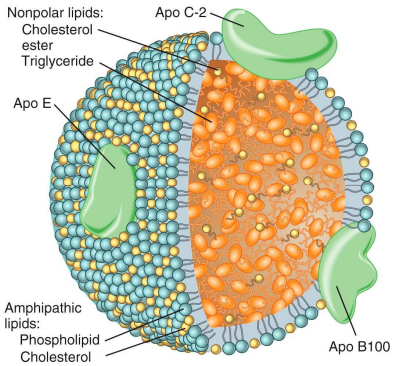
Carbohydrate Metabolism



Lipid Metabolism

Because most lipids are **nonpolar (hydrophobic)**, they do not dissolve in water. Because blood plasma is over 90% water, lipids must be **transported combined with proteins** produced by the liver and intestines. These are **lipoproteins**.

Lipid Metabolism



Lipid Metabolism

There are four classes of lipoproteins:

- **Chylomicrons**—transport dietary lipids to adipose tissue
- **Very-low-density lipoproteins (VLDLs)**—transport triglycerides from hepatocytes to adipocytes
- **Low-density lipoproteins (LDLs)**—carry about 75% of the total cholesterol in blood and deliver it to cells
- **High-density lipoproteins (HDLs)**—remove excess cholesterol from body cells and the blood and transport it to the liver for elimination

Lipid Metabolism

- **Cholesterol** comes from some foods (eggs, dairy, organ meats), but most is synthesized by **hepatocytes**.
- Increases in total cholesterol levels are associated with a greater risk of **coronary artery disease**.
- **Exercise**, **diet** and **certain drugs** are used to reduce high cholesterol levels

Lipid Metabolism

- Lipids may be oxidized to produce ATP.
- If the body does not need lipids at any given time, they get stored in **adipose tissue**.
- Some are used as **structural molecules** or to **synthesize other essential substances**.

Lipid Metabolism

TABLE 2.7
Types of Lipids in the Body

TYPE OF LIPID	FUNCTIONS
Fatty acids	Used to synthesize triglycerides and phospholipids or catabolized to generate adenosine triphosphate (ATP).
Triglycerides *(fats and oils)*	Protection, insulation, energy storage.
Phospholipids	Major lipid component of cell membranes.
Steroids	
Cholesterol	Minor component of all animal cell membranes; precursor of bile salts, vitamin D, and steroid hormones.
Bile salts	Needed for digestion and absorption of dietary lipids.
Vitamin D	Helps regulate calcium level in body; needed for bone growth and repair.
Adrenocortical hormones	Help regulate metabolism, resistance to stress, and salt and water balance.
Sex hormones	Stimulate reproductive functions and sexual characteristics.

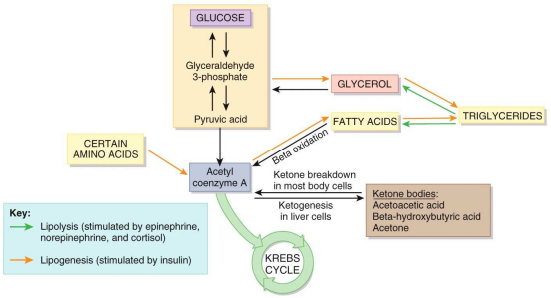
TABLE 2.7
Types of Lipids in the Body

TYPE OF LIPID	FUNCTIONS
Eicosanoids *(prostaglandins and leukotrienes)*	Have diverse effects on modifying responses to hormones, blood clotting, inflammation, immunity, stomach acid secretion, airway diameter, lipid breakdown, and smooth muscle contraction.
Other lipids	
Carotenes	Needed for synthesis of vitamin A (used to make visual pigments in eye); function as antioxidants.
Vitamin E	Promotes wound healing, prevents tissue scarring, contributes to normal structure and function of nervous system, and functions as antioxidant.
Vitamin K	Required for synthesis of blood-clotting proteins.
Lipoproteins	Transport lipids in blood, carry triglycerides and cholesterol to tissues, and remove excess cholesterol from blood.

Lipid Metabolism

- Adipose tissue is used to remove **triglycerides** from **chylomicrons** and **VLDLs**. These triglycerides constitute 98% of all body energy reserves.
- **Lipid catabolism (lipolysis)** is the process of splitting triglycerides into fatty acids and glycerol.
- **Lipid anabolism (lipogenesis)** is the process of synthesizing lipids from glucose or amino acids. It occurs when individuals consume more calories then needed.

Lipid Metabolism



Lipid Metabolism

Interactions Animation:

- Lipid Metabolism

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Protein Metabolism

- Digested proteins are broken down into **amino acids** which are not stored, but are either **oxidized to produce ATP** or **used to synthesize new proteins**.
- Many proteins function as **enzymes**, some are involved in transportation, serving as antibodies, clotting blood, being hormones, or being part of muscle fibers.

Protein Metabolism

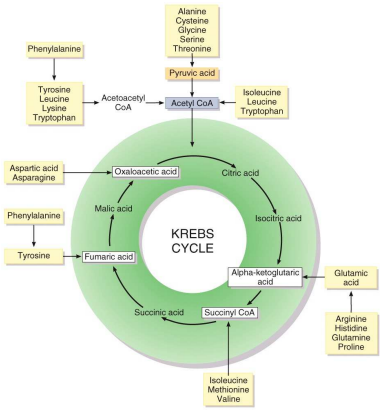
TABLE 2.8
Functions of Proteins

TYPE OF PROTEIN	FUNCTIONS
Structural	Form structural framework of various parts of body. *Examples:* collagen in bone and other connective tissues; keratin in skin, hair, and fingernails.
Regulatory	Function as hormones that regulate various physiological processes; control growth and development; as neurotransmitters, mediate responses of nervous system. *Examples:* the hormone insulin (regulates blood glucose level); the neurotransmitter known as substance P (mediates sensation of pain in nervous system).
Contractile	Allow shortening of muscle cells, which produces movement. *Examples:* myosin; actin.
Immunological	Aid responses that protect body against foreign substances and invading pathogens. *Examples:* antibodies; interleukins.
Transport	Carry vital substances throughout body. *Example:* hemoglobin (transports most oxygen and some carbon dioxide in blood).
Catalytic	Act as enzymes that regulate biochemical reactions. *Examples:* salivary amylase; sucrase; ATPase.

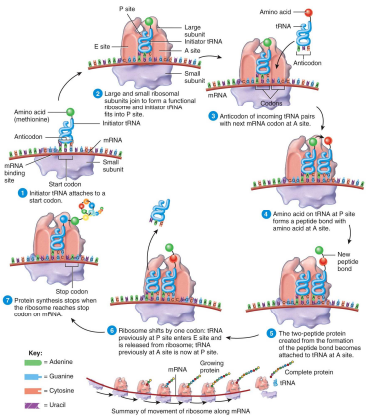
Protein Metabolism

- **Protein catabolism** (breaking down) yields amino acids which are converted to other amino acids, fatty acids, ketone bodies, or glucose.
- Cells oxidize amino acids to generate **ATP** via the **Krebs cycle**.
- **Protein anabolism (synthesis)** creates new proteins by bonding together amino acids on **ribosomes**.

Protein Metabolism



Protein Metabolism



Protein Metabolism

Interactions Animation:

- Protein Metabolism

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Key Molecules at Metabolic Crossroads

Of the thousands of different chemicals in cells, **glucose 6-phosphate**, **pyruvic acid** and **acetyl coenzyme A** are extremely important in metabolism.

Key Molecules at Metabolic Crossroads

Glucose 6-phosphate is involved in:

- Synthesis of glycogen
- Release of glucose into the bloodstream
- Synthesis of nucleic acids
- Glycolysis

Key Molecules at Metabolic Crossroads

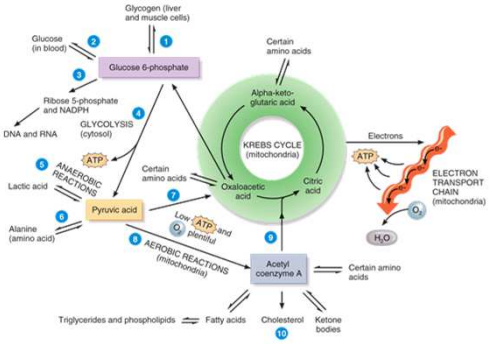
- Pyruvic acid is involved in:
- Production of lactic acid
- Production of alanine
- Gluconeogenesis

Key Molecules at Metabolic Crossroads

Acetyl coenzyme A is involved in:

- Helping 2-carbon acetyl groups enter the Krebs cycle
- Synthesis of lipids

Key Molecules at Metabolic Crossroads



Key Molecules at Metabolic Crossroads

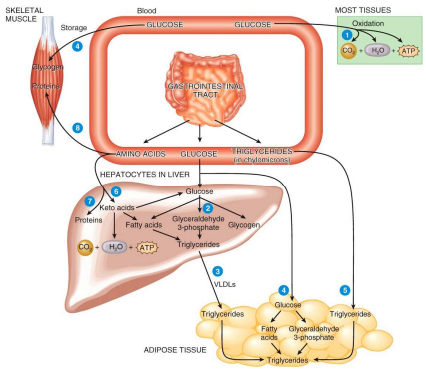
TABLE 25.2
Summary of Metabolism

PROCESS	COMMENTS
CARBOHYDRATES	
Glucose catabolism	Complete oxidation of glucose (cellular respiration) is chief source of ATP in cells; consists of glycolysis, Krebs cycle, and electron transport chain. Complete oxidation of 1 molecule of glucose yields maximum of 30 or 32 molecules of ATP.
Glycolysis	Conversion of glucose into pyruvic acid results in production of some ATP. Reactions do not require oxygen.
Krebs cycle	Cycle includes series of oxidation–reduction reactions in which coenzymes (NAD^+ and FAD) pick up hydrogen ions and hydride ions from oxidized organic acids; some ATP produced. CO_2 and H_2O are by-products. Reactions are aerobic.
Electron transport chain	Third set of reactions in glucose catabolism: another series of oxidation–reduction reactions, in which electrons are passed from one carrier to next; most ATP produced. Reactions require oxygen (aerobic cellular respiration).
Glucose anabolism	Some glucose is converted into glycogen (glycogenesis) for storage if not needed immediately for ATP production. Glycogen can be reconverted to glucose (glycogenolysis). Conversion of amino acids, glycerol, and lactic acid into glucose is called gluconeogenesis.
LIPIDS	
Triglyceride catabolism	Triglycerides are broken down into glycerol and fatty acids. Glycerol may be converted into glucose (gluconeogenesis) or catabolized via glycolysis. Fatty acids are catabolized via beta oxidation into acetyl coenzyme A that can enter Krebs cycle for ATP production or be converted into ketone bodies (ketogenesis).
Triglyceride anabolism	Synthesis of triglycerides from glucose and fatty acids is called lipogenesis. Triglycerides are stored in adipose tissue.
PROTEINS	
Protein catabolism	Amino acids are oxidized via Krebs cycle after deamination. Ammonia resulting from deamination is converted into urea in liver, passed into blood, and excreted in urine. Amino acids may be converted into glucose (gluconeogenesis), fatty acids, or ketone bodies.
Protein anabolism	Protein synthesis is directed by DNA and utilizes cells' RNA and ribosomes.

Metabolic Adaptations

- Regulation of metabolism depends on chemicals in the cells and signals from the nervous and endocrine systems.
- Some aspects of metabolism depend on time elapsed since the last meal.
- During the **absorptive state**, glucose is readily available.

Metabolic Adaptations



Metabolic Adaptations

TABLE 25.3

Hormonal Regulation of Metabolism in the Absorptive State

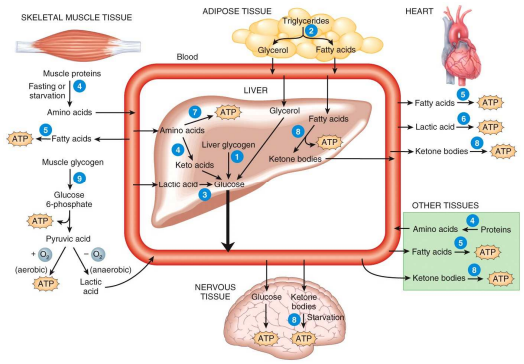
PROCESS	LOCATION(S)	MAIN STIMULATING HORMONE(S)
Facilitated diffusion of glucose into cells	Most cells.	Insulin.*
Active transport of amino acids into cells	Most cells.	Insulin.
Glycogenesis (glycogen synthesis)	Hepatocytes and muscle fibers.	Insulin.
Protein synthesis	All body cells.	Insulin, thyroid hormones, and insulinlike growth factors.
Lipogenesis (triglyceride synthesis)	Adipose cells and hepatocytes.	Insulin.

*Facilitated diffusion of glucose into hepatocytes (liver cells) and neurons is always "turned on" and does not require insulin.

Metabolic Adaptations

During the **postabsorptive state**, energy needs are met by fuels already in the body.

Metabolic Adaptations



Metabolic Adaptations

TABLE 25.4

Hormonal Regulation of Metabolism in the Postabsorptive State

PROCESS	LOCATION(S)	MAIN STIMULATING HORMONE(S)
Glycogenolysis (glycogen breakdown)	Hepatocytes and skeletal muscle fibers.	Glucagon and epinephrine.
Lipolysis (triglyceride breakdown)	Adipocytes.	Epinephrine, norepinephrine, cortisol, insulinlike growth factors, thyroid hormones, and others.
Protein breakdown	Most body cells, but especially skeletal muscle fibers.	Cortisol.
Gluconeogenesis (synthesis of glucose from noncarbohydrates)	Hepatocytes and kidney cortex cells.	Glucagon and cortisol.

Metabolic Adaptations

- During **fasting** and **starvation**, the body must make metabolic changes to survive.
- **Fasting** is going without food for several hours or a few days.
- **Starvation** is going without food or inadequate food intake for weeks or months.

Metabolic Adaptations

- The most dramatic metabolic change occurring with fasting and starvation is an increase in production of **ketone bodies** as catabolism of fatty acids increases.
- They may be used for energy by all cells.

Heat and Energy Balance

- The rates of metabolic reactions control the amount of heat produced by the body. The rate of heat loss must equal the rate of heat production to maintain homeostasis of body temperature.
- The **metabolic rate** is the overall rate at which metabolic reactions use energy.
- Metabolic rate is measured with the body in a quiet, resting and fasting state. This is **basal metabolic rate (BMR)**.

Heat and Energy Balance

Factors that affect metabolic rate (heat production) include:

- Exercise
- Hormones
- Nervous system
- Body temperature
- Ingestion of food
- Age
- Gender, climate, sleeping, malnutrition

Heat and Energy Balance

Heat is transferred from the body to the environment by:

- Conduction
- Convection
- Radiation
- Evaporation

Heat and Energy Balance

- The **preoptic area of the hypothalamus** is the body's **thermostat**.
- **Thermoreceptors** send information to the preoptic area which sends signals to the **heat-losing center and heat-promoting center of the hypothalamus**, depending on the body's needs.
- **Negative feedback mechanisms** conserve heat and increase heat production.

Heat and Energy Balance

Interactions Animation:

- Metabolic Rate, Heat and Thermoregulation

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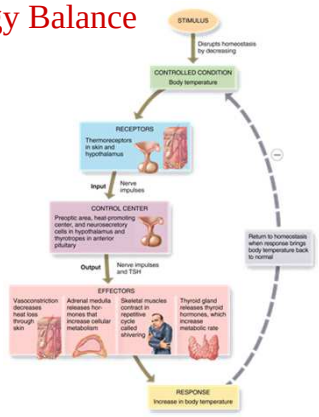
Heat and Energy Balance



Heat and Energy Balance

- **Energy intake** is directly dependent on the amount of food consumed.
- **Total energy expenditure** is based on:
  - Basal metabolic rate (60%)
  - Physical activity (30–35%)
  - Food-induced thermogenesis (5–10%)

Heat and Energy Balance

- The **arcuate nucleus** and the **paraventricular nucleus** of the hypothalamus are the areas that control hunger.
- The hormone **leptin** helps to decrease adiposity (body fat mass).
- **Neuropeptide Y** stimulates food intake.
- **Melanocortin** inhibits food intake.

Nutrition

Nutrients are chemicals in food that cells use for **growth, maintenance and repair**. They include:

- Water
- Carbohydrates
- Lipids
- Proteins
- Minerals
- Vitamins

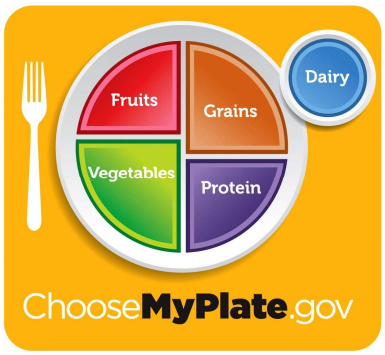
Nutrition

Recommended calorie distribution is:

- 50–60% from carbohydrates (less than 15% simple sugars)
- Less than 30% from fats (no more than 10% saturated)
- About 12–15% from protein

The US Department of Agriculture introduced **MyPlate** to emphasize how people should proportion their food intake.

Nutrition



Nutrition

- **Minerals** are inorganic elements that play important roles in maintaining a healthy body.
- **Vitamins** are nutrients required in small amounts to maintain growth and normal metabolism. Most cannot be synthesized by the body and must be consumed in foods.

Nutrition

TABLE 25.5
Minerals Vital to the Body

MINERAL	COMMENTS	IMPORTANCE
Calcium	Most abundant mineral in body. Appears in combination with phosphates. About 99% stored in bone and teeth. Blood Ca^{2+} level controlled by parathyroid hormone (PTH). Calcitriol promotes absorption of dietary calcium. Excess excreted in feces and urine. Sources: milk, egg yolk, shellfish, leafy green vegetables.	Formation of bones and teeth, blood clotting, normal muscle and nerve activity, endocytosis and exocytosis, cellular motility, chromosome movement during cell division, glycogen metabolism, release of neurotransmitters and hormones.
Phosphorus	About 80% found in bones and teeth as phosphate salts. Blood phosphate level controlled by parathyroid hormone (PTH). Excess excreted in urine; small amount eliminated in feces. Sources: dairy products, meat, fish, poultry, nuts.	Formation of bones and teeth. Phosphates ($H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3-}) constitute a major buffer system of blood. Role in muscle contraction and nerve activity. Component of many enzymes. Involved in energy transfer (ATP). Component of DNA and RNA.
Potassium	Major cation (K^+) in intracellular fluid. Excess excreted in urine. Present in most foods (meats, fish, poultry, fruits, nuts).	Needed for generation and conduction of action potentials in neurons and muscle fibers.
Sulfur	Component of many proteins (such as insulin and chondroitin sulfate), electron carriers in electron transport chain, and some vitamins (thiamine and biotin). Excreted in urine. Sources: beef, liver, lamb, fish, poultry, eggs, cheese, beans.	As component of hormones and vitamins, regulates various body activities. Needed for ATP production by electron transport chain.
Sodium	Most abundant cation (Na^+) in extracellular fluids; some found in bones. Excreted in urine and perspiration. Normal intake of NaCl (table salt) supplies more than required amounts.	Strongly affects distribution of water through osmosis. Part of bicarbonate buffer system. Functions in nerve and muscle action potential conduction.
Chloride	Major anion (Cl^-) in extracellular fluid. Excess excreted in urine. Sources: table salt (NaCl), soy sauce, processed foods.	Role in acid–base balance of blood, water balance, and formation of HCl in stomach.
Magnesium	Important cation (Mg^{2+}) in intracellular fluid. Excreted in urine and feces. Widespread in various foods, such as green leafy vegetables, seafood, and whole-grain cereals.	Required for normal functioning of muscle and nervous tissue. Participates in bone formation. Constituent of many coenzymes.
Iron	About 66% found in hemoglobin of blood. Normal losses of iron occur by shedding of hair, epithelial cells, and mucosal cells, and in sweat, urine, feces, bile, and blood lost during menstruation. Sources: meat, liver, shellfish, egg yolk, beans, legumes, dried fruits, nuts, cereals.	As component of hemoglobin, reversibly binds O_2. Component of cytochromes involved in electron transport chain.

Nutrition

TABLE 25.5

Minerals Vital to the Body

MINERAL	COMMENTS	IMPORTANCE
Iodide	Essential component of thyroid hormones. Excreted in urine. Sources: seafood, iodized salt, vegetables grown in iodine-rich soils.	Required by thyroid gland to synthesize thyroid hormones, which regulate metabolic rate.
Manganese	Some stored in liver and spleen. Most excreted in feces. Sources: spinach, romaine lettuce, pineapple.	Activates several enzymes. Needed for hemoglobin synthesis, urea formation, growth, reproduction, lactation, bone formation, and possibly production and release of insulin, and inhibition of cell damage.
Copper	Some stored in liver and spleen. Most excreted in feces. Sources: eggs, whole-wheat flour, beans, beets, liver, fish, spinach, asparagus.	Required with iron for synthesis of hemoglobin. Component of coenzymes in electron transport chain and enzyme necessary for melanin formation.
Cobalt	Constituent of vitamin B_{12}. Sources: liver, kidney, milk, eggs, cheese, meat.	As part of vitamin B_{12}, required for erythropoiesis.
Zinc	Important component of certain enzymes. Widespread in many foods, especially meats.	As component of carbonic anhydrase, important in carbon dioxide metabolism. Necessary for normal growth and wound healing, normal taste sensations and appetite, and normal sperm counts in males. As component of peptidases, involved in protein digestion.
Fluoride	Component of bones, teeth, other tissues. Sources: seafood, tea, gelatin.	Appears to improve tooth structure and inhibit tooth decay.
Selenium	Important component of certain enzymes. Sources: seafood, meat, chicken, tomatoes, egg yolk, milk, mushrooms, garlic, cereal grains grown in selenium-rich soil.	Needed for synthesis of thyroid hormones, sperm motility, and proper functioning of immune system. Also functions as antioxidant. Prevents chromosome breakage and may play role in preventing certain birth defects, miscarriage, prostate cancer, and coronary artery disease.
Chromium	Found in high concentrations in brewer's yeast. Also found in wine and some brands of beer.	Needed for normal activity of insulin in carbohydrate and lipid metabolism.

Nutrition

TABLE 25.6

The Principal Vitamins

VITAMIN	COMMENT AND SOURCE	FUNCTIONS	DEFICIENCY SYMPTOMS AND DISORDERS
Fat-soluble	All require bile salts and some dietary lipids for adequate absorption.		
A	Formed from provitamin beta-carotene (and other provitamins) in GI tract. Stored in liver. Sources of carotene and other provitamins: orange, yellow, and green vegetables. Sources of vitamin A: liver, milk.	Maintains general health and vigor of epithelial cells. Beta-carotene acts as antioxidant to inactivate free radicals. Essential for formation of light-sensitive pigments in photoreceptors of retina. Aids in growth of bones and teeth by helping to regulate activity of osteoblasts and osteoclasts.	Deficiency results in atrophy and keratinization of epithelium, leading to dry skin and hair; increased incidence of ear, sinus, respiratory, urinary, and digestive system infections; inability to gain weight; drying of cornea; and skin sores. **Night blindness** (decreased ability for dark adaptation). Slow and faulty development of bones and teeth.
D	Sunlight converts 7-dehydrocholesterol in skin to cholecalciferol (vitamin D_3). A liver enzyme then converts cholecalciferol to 25-hydroxycholecalciferol. A second enzyme in kidneys converts 25-hydroxycholecalciferol to calcitriol (1,25-dihydroxycalciferol), the active form of vitamin D. Most excreted in bile. Dietary sources: fish-liver oils, egg yolk, fortified milk.	Essential for absorption of calcium and phosphorus from GI tract. Works with parathyroid hormone (PTH) to maintain Ca^{2+} homeostasis.	Defective utilization of calcium by bones leads to **rickets** in children and **osteomalacia** in adults. Possible loss of muscle tone.
E (tocopherols)	Stored in liver, adipose tissue, and muscles. Sources: fresh nuts and wheat germ, seed oils, green leafy vegetables.	Inhibits catabolism of certain fatty acids that help form cell structures, especially membranes. Involved in formation of DNA, RNA, and red blood cells. May promote wound healing, contribute to normal structure and functioning of nervous system, and prevent scarring. May help protect liver from toxic chemicals such as carbon tetrachloride. Acts as antioxidant to inactivate free radicals.	May cause oxidation of monounsaturated fats, resulting in abnormal structure and function of mitochondria, lysosomes, and plasma membranes. Possible consequence is hemolytic anemia.
K	Produced by intestinal bacteria. Stored in liver and spleen. Dietary sources: spinach, cauliflower, cabbage, liver.	Coenzyme essential for synthesis of several clotting factors by liver, including prothrombin.	Delayed clotting time results in excessive bleeding.

Nutrition

TABLE 25.6

The Principal Vitamins

VITAMIN	COMMENT AND SOURCE	FUNCTIONS	DEFICIENCY SYMPTOMS AND DISORDERS
Water-soluble	Dissolved in body fluids. Most not stored in body. Excess intake eliminated in urine.		
B_1 (thiamine)	Rapidly destroyed by heat. Sources: whole-grain products, eggs, pork, nuts, liver, yeast.	Acts as coenzyme for many different enzymes that break carbon-to-carbon bonds and are involved in carbohydrate metabolism of pyruvic acid to CO_2 and H_2O. Essential for synthesis of neurotransmitter acetylcholine.	Improper carbohydrate metabolism leads to buildup of pyruvic and lactic acids and insufficient production of ATP for muscle and nerve cells. Deficiency leads to (1) **beriberi**, partial paralysis of smooth muscle of GI tract, causing digestive disturbances; skeletal muscle paralysis; and atrophy of limbs; (2) **polyneuritis**, due to degeneration of myelin sheaths; impaired reflexes, impaired sense of touch, stunted growth in children, and poor appetite.
B_2 (riboflavin)	Small amounts supplied by bacteria of GI tract. Dietary sources: yeast, liver, beef, veal, lamb, eggs, whole-grain products, asparagus, peas, beets, peanuts.	Component of certain coenzymes (for example, FAD and FMN) in carbohydrate and protein metabolism, especially in cells of eye, integument, mucosa of intestine, and blood.	Deficiency may lead to improper utilization of oxygen, resulting in blurred vision, cataracts, and corneal ulcerations. Also dermatitis and cracking of skin, lesions of intestinal mucosa, and one type of anemia.
Niacin (nicotinamide)	Derived from amino acid tryptophan. Sources: yeast, meats, liver, fish, whole-grain products, peas, beans, nuts.	Essential component of NAD and NADP, coenzymes in oxidation–reduction reactions. In lipid metabolism, inhibits production of cholesterol and assists in triglyceride breakdown.	Principal deficiency is **pellagra**, characterized by dermatitis, diarrhea, and psychological disturbances.
B_6 (pyridoxine)	Synthesized by bacteria of GI tract. Stored in liver, muscle, and brain. Other sources: salmon, yeast, tomatoes, yellow corn, spinach, whole grain products, liver, yogurt.	Essential coenzyme for normal amino acid metabolism. Assists production of circulating antibodies. May function as coenzyme in triglyceride metabolism.	Most common deficiency symptom is dermatitis of eyes, nose, and mouth. Other symptoms are retarded growth and nausea.

Nutrition

TABLE 25.6

The Principal Vitamins

VITAMIN	COMMENT AND SOURCE	FUNCTIONS	DEFICIENCY SYMPTOMS AND DISORDERS
Water-soluble	Dissolved in body fluids. Most not stored in body. Excess intake eliminated in urine.		
B_{12} (cyanocobalamin)	Only B vitamin not found in vegetables; only vitamin containing cobalt. Absorption from GI tract depends on intrinsic factor secreted by gastric mucosa. Sources: liver, kidney, milk, eggs, cheese, meat.	Coenzyme necessary for red blood cell formation, formation of amino acid methionine, entrance of some amino acids into Krebs cycle, and manufacture of choline (used to synthesize acetylcholine).	Pernicious anemia, neuropsychiatric abnormalities (ataxia, memory loss, weakness, personality and mood changes, and abnormal sensations), and impaired activity of osteoblasts.
Pantothenic acid	Some produced by bacteria of GI tract. Stored primarily in liver and kidneys. Other sources: kidneys, liver, yeast, green vegetables, cereal.	Constituent of coenzyme A, which is essential for transfer of acetyl group from pyruvic acid into Krebs cycle, conversion of lipids and amino acids into glucose, and synthesis of cholesterol and steroid hormones.	Fatigue, muscle spasms, insufficient production of adrenal steroid hormones, vomiting, and insomnia.
Folic acid (folate, folacin)	Synthesized by bacteria of GI tract. Dietary sources: green leafy vegetables, broccoli, asparagus, breads, dried beans, citrus fruits.	Component of enzyme systems synthesizing nitrogenous bases of DNA and RNA. Essential for normal production of red and white blood cells.	Production of abnormally large red blood cells (macrocytic anemia). Higher risk of neural tube defects in babies born to folate-deficient mothers.
Biotin	Synthesized by bacteria of GI tract. Dietary sources include yeast, liver, egg yolk, kidneys.	Essential coenzyme for conversion of pyruvic acid to oxaloacetic acid and synthesis of fatty acids and purines.	Mental depression, muscular pain, dermatitis, fatigue, and nausea.
C (ascorbic acid)	Rapidly destroyed by heat. Some stored in glandular tissue and plasma. Sources: citrus fruits, tomatoes, green vegetables.	Promotes protein synthesis, including laying down of collagen in formation of connective tissue. As coenzyme, may combine with poisons, rendering them harmless until excreted. Works with antibodies, promotes wound healing, and functions as an antioxidant.	Scurvy; anemia; many symptoms related to poor collagen formation, including tender swollen gums, loosening of teeth (alveolar processes also deteriorate), poor wound healing, bleeding (vessel walls are fragile because of connective tissue degeneration), and retardation of growth.

Nutrition

Anatomy Overview:

- Role of Nutrients

You must be connected to the Internet and in Slideshow Mode to run this animation.

End of Chapter 25