Nutrition, Metabolism, and Body Temperature Regulation

***I. Diet and Nutrition***

A. A nutrient is used by the body to promote normal growth and development. Those categorized as major nutrients are carbohydrates, lipids, and proteins; vitamins and minerals are micronutrients (p. 911; Fig. 24.1).

1. A healthy diet consists of food from each of five food groups: grains; fruits and vegetable; meats, beans, and fish; milk products; and oils. The basic dietary principles for health are to eat less, avoid junk food, and get more exercise.

B. Carbohydrates consist of sugars (monosaccharides and disaccharides) from fruits, sugarcane, sugar beets, honey, and milk; and polysaccharides from grains, fruits, and vegetables (p. 912; Table 24.1).

1. Glucose is used by the body as fuel for the reactions that synthesize ATP, and is required by neurons and red blood cells.

C. The most abundant dietary lipids are triglycerides, or neutral fats, and may be saturated—derived from animal sources, coconut oils, and hydrogenated shortenings (trans fats)—or unsaturated—derived from plant sources (pp. 912–913; Table 24.1).

1. Essential fatty acids linoleic acid and linolenic acid cannot be made by the body, so these must be consumed in the diet.

2. Cholesterol is found in egg yolk, meats, organ meats, shellfish, and milk, but about 85% of the body’s cholesterol is made by the liver.

3. Lipids help the body absorb fat-soluble vitamins, serve as a cellular fuel, are an integral component of myelin sheaths and cell membranes, form adipose tissues, and serve as regulatory molecules.

D. Proteins that have all essential amino acids are complete proteins, and are found in eggs, milk, fish, and meats; proteins that are low or lacking in one or more of the essential amino acids are incomplete, and are found in legumes, nuts, and cereals (pp. 914–915; Fig. 24.2; Table 24.1).

1. Proteins are important structural and functional molecules in the body.

2. The amino acids from proteins may be used for synthesis of new molecules, or may be burned for energy.

3. Healthy rates of protein synthesis require a homeostatically regulated nitrogen balance, which compares the rate of incorporation of new proteins into tissue to the rate of protein breakdown to supply energy demands.

E. Vitamins are micronutrients that mostly serve as coenzymes, many of which are not made by the body and must be consumed (pp. 915–916; Table 24.2).

1. Vitamins A, D, E, and K are fat soluble, and are absorbed when bound to ingested lipids.

2. Water-soluble vitamins, such as B-complex vitamins and vitamin C, are absorbed along with water in the gastrointestinal tract.

F. Minerals are used by the body to work with other molecules, may be incorporated into tissues to give added strength, or may be ionized in body fluids or bound to organic compounds (pp. 917–918; Table 24.3).

1. Moderate amounts of seven minerals are required by the body: calcium, phosphorus, potassium, sulfur, sodium, chlorine, and magnesium.

***II. Overview of Metabolic Reactions***

A. Metabolic processes are either anabolic, in which larger molecules are synthesized from smaller ones, or catabolic, in which large molecules are broken down to simpler ones (pp. 918–920; Fig. 24.3).

B. Oxidation-reduction reactions are coupled reactions that involve the transfer of electrons from one molecule to another, resulting in a transfer of energy between molecules (pp. 920–921).

1. In the body, oxidation-reduction reactions are enzyme-catalyzed reactions requiring specific coenzymes that transfer the energy contained in food fuels to other molecules, ultimately leading to the synthesis of ATP from ADP.

C. ATP synthesis may occur through two mechanisms: substrate-level phosphorylation, in which high-energy phosphate groups are transferred directly from phosphorylated substrates to ADP, or oxidative phosphorylation, in which some energy from food fuels is used to create a proton gradient that is used to attach phosphates to ADP (pp. 921–922; Figs. 24.4–24.5).

***III. Metabolism of Major Nutrients***

A. Carbohydrate Metabolism

1. Glucose enters the cell by facilitated diffusion, and is phosphorylated to glucose-6-phosphate, essentially trapping glucose within the cell.

2. Glucose enters glycolysis, an anaerobic process that occurs in the cytosol.

a. In phase 1 of glycolysis, glucose is phosphorylated in a series of steps to fructose-6-phosphate to provide the activation energy for events that occur later in the pathway.

b. In phase 2 of glycolysis, fructose-6-phosphate is split into two three-carbon fragments: glyceraldehyde-3-phosphate and dihydroxyacetone phosphate.

c. In phase 3 of glycolysis, the pair of three-carbon fragments produced in phase 2 are oxidized to transfer hydrogen to NAD+, and the oxidized fragments are phosphorylated.

d. The final products of this series of reactions are two pyruvic acid molecules, two molecules of NADH, and four molecules of ATP, although two ATPs were consumed at the beginning of the process.

3. The two pyruvic acid molecules can follow two distinct pathways, depending on the availability of oxygen.

a. If adequate oxygen is present in the cell, glycolysis continues, and NADH delivers its electrons to the electron transport chain.

b. If there is not adequate oxygen available, NADH returns its hydrogen to pyruvic acid, forming lactic acid, which allows NAD+ to continue to act as an electron acceptor.

c. Once enough oxygen is available within the cell, lactic acid is oxidized back to pyruvic acid and enters aerobic pathways.

4. In aerobic pathways, pyruvic acid is transported into the mitochondrion, where it enters the Krebs cycle.

a. Pyruvic acid is first converted to acetyl CoA by removing a carbon, oxidizing the acetic acid fragment, and adding coenzyme A.

b. Acetyl CoA enters the Krebs cycle, where it proceeds through eight successive steps that produce a series of ketoacids, ultimately ending at the production of oxaloacetic acid.

c. The net yield of the Krebs cycle is four molecules of CO2, six molecules of NADH, two molecules of FADH2, and two molecules of ATP per pair of acetyl CoA molecules that were produced from glucose.

5. The electron transport chain is the oxygen-requiring process of aerobic respiration involving the pickup of hydrogens removed from food fuels during oxidation by O2, resulting in the formation of water, a process called oxidative phosphorylation.

a. In the electron transport chain, hydrogens from NADH and FADH2 are shuttled through a series of coenzymes, which results in the transport of H+ from the mitochondrial matrix to the intermembrane space.

b. H+ diffuses back to the mitochondrial membrane through an enzyme, ATP synthase, which phosphorylates ADP to ATP as the H+ diffuses.

6. Because the cell cannot store large amounts of ATP, other processes are used to handle glucose in excess of what can be used in ATP synthetic pathways.

a. Glycogenesis is a process that forms glycogen from glucose when high cellular ATP begins to inhibit glycolysis.

b. Glycogenolysis is a process that breaks down glycogen to glucose when blood glucose levels begin to fall.

c. Gluconeogenesis is a process that forms glucose from nonglucose molecules to maintain blood glucose when dietary sources and glucose reserves begin to be depleted.

B. Lipid Metabolism (pp. 930–932; Figs. 24.14–24.15; Table 24.4)

1. Lipids are the body’s most concentrated source of energy, producing approximately twice the energy of either carbohydrates or proteins.

2. Catabolism of triglycerides involves the splitting of the molecule into glycerol and fatty acids: the glycerol portion is converted to glyceraldehyde phosphate, which enters into glycolysis, and the fatty acids are converted to acetyl CoA through beta oxidation.

3. Lipogenesis is a process used to store excess glycerol and fatty acids in adipose tissue as triglycerides.

4. Lipolysis is a process that breaks down stored triglycerides into glycerol and fatty acids, to be directed into lipid catabolism.

C. Protein Metabolism (pp. 932–934; Fig. 24.16; Table 24.4)

1. Before amino acids can be oxidized for energy, they must have the amine group removed, a process called deamination.

2. The deaminated amino acid molecule is converted to pyruvic acid, or a Krebs cycle ketoacid intermediate.

3. Deaminated amino acids may also be reconverted to glucose and contribute to gluconeogenesis.

4. Amino acids are the most important anabolic nutrient, and can be used to synthesize structural and functional proteins of the body.

***IV. Metabolic States of the Body (pp. 935–941; Figs. 24.17–24.22; Tables 24.5–24.6)***

A. Catabolic-Anabolic Steady State of the Body (pp. 935–936; Figs. 24.17–24.18; Table 24.5)

1. There is a dynamic catabolic-anabolic state of the body as molecules are broken down and rebuilt.

2. The body draws molecules to meet these needs from various nutrient pools: amino acid, carbohydrate, and fat stores.

B. During the absorptive state, anabolism exceeds catabolism (pp. 936–938; Figs. 24.19–24.20).

1. All absorbed monosaccharides are made into glucose by the liver, and released to the blood or converted to glycogen or fat.

2. Most fats enter the lymph as chylomicrons, which are broken down to glycerol and fatty acids to enable them to pass into capillaries.

a. Adipose cells, skeletal and cardiac muscle cells, and the liver use triglycerides to synthesize plasma proteins, while most amino acids passing through the liver remain in the blood for uptake by other body cells.

C. In the postabsorptive state, net synthesis of fat, glycogen, and proteins ends, and the body shifts to catabolism of these molecules (pp. 938–941; Figs. 24.21–24.22; Table 24.6).

1. Blood glucose is obtained by promoting glycogenolysis in the liver and skeletal muscle, lipolysis in the liver and adipose tissues, and catabolism of cellular protein.

2. If the body experiences prolonged fasting, it will enter glucose sparing, which is aimed at conservation of blood glucose by promoting increased use of noncarbohydrate fuel molecules, especially triglycerides.

a. The brain continues to use glucose, unless fasting continues for longer than four or five days, at which time it begins to use ketone bodies as an alternate fuel source.

3. Hormonal controls of the postabsorptive state inhibit the release of insulin and promote release of glucagon, which stimulates a rise in blood glucose level by causing enhanced glycogenolysis, lipolysis, and gluconeogenesis.

***V. The Metabolic Role of the Liver (pp. 941–944; Fig. 24.23; Table 24.7)***

A. Cholesterol Metabolism and Regulation of Blood Cholesterol Levels (pp. 943–944; Fig. 24.23)

1. Cholesterol is transported in the blood bound to lipoprotein complexes, which solubilize lipids and regulate entry and exit at specific target cells.

2. Lipoprotein complexes vary in the percentage of lipid they contain, but all contain triglycerides, phospholipids, and cholesterol, in addition to protein.

3. The greater the proportion of lipid in the lipoprotein, the lower its density, and there are very-low-density lipoproteins (VLDLs), low-density lipoproteins (LDLs), and high-density lipoproteins (HDLs).

a. VLDLs transport triglycerides from the liver to peripheral tissues, LDLs transport cholesterol to peripheral tissues, and HDLs transport excess cholesterol from peripheral tissues to the liver and provide cholesterol to steroid-producing organs.

4. High levels of HDL are considered beneficial, as the cholesterol they contain is bound for removal, but high levels of LDL are considered a risk, because the cholesterol they contain may be laid down on vessel walls, forming plaques.

5. Blood levels of cholesterol are partly regulated through negative feedback, and a high intake of cholesterol will somewhat inhibit cholesterol synthesis by the liver.

6. Diets high in saturated fats stimulate liver synthesis of cholesterol and reduce its elimination from the body, while unsaturated fatty acids enhance excretion of cholesterol to bile for removal from the body.

***VI. Energy Balance (pp. 944–954; Figs. 24.24–24.27)***

A. There is a balance between the body’s energy intake, defined as the energy produced during food oxidation, and energy output, which includes energy lost as heat, used to do work, or stored as fat or glycogen (pp. 944–945).

1. When energy intake and energy output are balanced, body weight remains stable, but when they are not, weight is gained or lost.

B. Obesity is defined as an individual having a body mass index (BMI) greater than 30 (p. 945).

1. BMI = weight (lb) x 705/height (inches)2

2. Obesity places individuals at higher risk for atherosclerosis, diabetes mellitus, hypertension, heart disease, and osteoarthritis.

C. Regulation of Food Intake (pp. 945–947; Fig. 24.24)

1. The hypothalamus produces several peptides controlling feeding behavior, which ultimately reflect two sets of neurons: one set promoting hunger and the other set promoting satiety.

2. Short-term regulation of food intake involves neural signals from the digestive tract, blood levels of nutrients, and GI hormones.

3. Long-term regulation of food intake relies on the hormone leptin, secreted by adipose cells.

a. Leptin is a hormone that is secreted in response to an increase in the body’s fat mass, and suppresses activity of the neurons that promote hunger while increasing activity of neurons that promote satiety.

4. Other factors that may affect food-seeking behaviors are changes in ambient temperature, stress, other psychological factors, infections, sleep deprivation, or composition of gut bacteria.

D. Metabolic Rate and Heat Production (pp. 947–949)

1. The body’s rate of energy output is called the metabolic rate.

2. The basal metabolic rate reflects the amount of energy required for performance of only the essential activities of the body, and is expressed as kilocalories per square meter of body surface area.

3. Factors that influence the basal metabolic rate include body surface area, age, gender, stress, and hormones.

a. The most important factor is surface area, because of its impact on heat loss from the body.

4. Basal metabolic rate is higher if the individual is younger, or male, and tends to rise and fall with body temperature.

5. The most important hormonal factor affecting basal metabolic rate is thyroxine, which increases O2 consumption and heat production.

E. Regulation of Body Temperature (pp. 950–954; Figs. 24.25–24.27)

1. Body temperature averages 37°C, and is usually maintained between 35.8–38.2°C.

2. Temperature homeostasis keeps body temperature at a value that is optimal for enzymatic activity within the body.

3. The core of the body, which includes organs within the skull, thoracic, and abdominal cavities, has the highest body temperature, while the shell (mostly the skin) has the lowest temperature.

4. Heat exchange between our skin and the external environment occurs through radiant flow of heat, conductive flow of warmth from warmer to cooler objects, convective movement of warm air away from the body, and heat loss due to evaporation of fluids from the lungs, oral mucosa, and the skin.

5. The hypothalamus contains the heat-loss and heat-promoting centers that aid in the regulation of behavioral and physiological mechanisms to maintain normal body temperature.

6. Heat-promoting mechanisms maintain or increase body core temperature, and include constriction of cutaneous blood vessels, shivering, increase in metabolic rate, and increased release of thyroxine.

7. Heat-loss mechanisms protect the body from excessively high temperatures, and include dilation of cutaneous blood vessels, enhanced sweating, and behaviors that promote heat loss or reduce heat gain.

***VII. Developmental Aspects of Nutrition and Metabolism (pp. 954–955)***

A. Inadequate nutrition during pregnancy and in the first three years of life seriously compromises brain growth and development, as well as muscle and bone development (p. 954).

B. Several genetic disorders affect metabolism, such as cystic fibrosis, phenylketonuria, and glycogen storage disease (p. 954).

C. With the exception of insulin-dependent diabetes mellitus, genetically normal children rarely exhibit metabolic disorders, but by middle and old age, non-insulin-dependent diabetes mellitus becomes a significant problem (p. 954).

D. Metabolic rate declines throughout life, and this decline may affect the body’s ability to digest and absorb nutrients (pp. 954–955).

**Cross References From Chapters 1-15**

*Additional information on topics covered in Chapter 24 can be found in the chapters listed below.*

1. Chapter 2: Chemical bonding; carbohydrates; lipids; proteins; water; ATP; oxidation/reduction; chemical equations; patterns of chemical reactions; reversibility of reactions; enzymes

2. Chapter 3: Membrane transport; cytoplasm; mitochondria

3. Chapter 12: Hypothalamus

4. Chapter 13: Receptors

**Online Resources for Students**

***myA&P™***

www.myaandp.com

*The following shows the organization of the Chapter Guide page in* myA&P™. *The Chapter Guide organizes all the chapter-specific online media resources for Chapter 24 in one convenient location, with e-book links to each section of the textbook. Students can also access* A&P Flix *animations,* MP3 Tutor Sessions, Interactive Physiology® 10-System Suite, Practice Anatomy Lab™ 2.0, PhysioEx™ 8.0, *and much more.*

**Answers to End-of-Chapter Questions**

*Multiple-Choice and Matching Question answers appear in Appendix G of the main text.*

**Short Answer Essay Questions**

16. Cellular respiration is a group of reactions that break down (oxidize) glucose, fatty acids, and amino acids in the cell. Some of the energy released is used to synthesize ATP. FAD and NAD+ function as reversible hydrogen acceptors that deliver the accepted hydrogen to the electron transport chain. (pp. 919–920)

17. Glycolysis occurs in the cytoplasm of cells. It may be separated into three major events: (1) sugar activation, (2) sugar cleavage, and (3) oxidation and ATP formation. During sugar activation, glucose is phosphorylated, converted to fructose, and phosphorylated again to yield fructose-1,6-diphosphate; two molecules of ATP are used. These reactions provide the activation energy for the later events of glycolysis. During sugar cleavage, fructose-1,6-diphosphate is split into two 3-carbon fragments: glyceraldehyde-3-phosphate or dihydroxyacetone phosphate. During oxidation and ATP formation, the 3-carbon molecules are oxidized by the removal of hydrogen (which is picked up by NAD). Inorganic phosphate groups that are attached to each oxidized fragment by high-energy bonds are cleaved off, capturing enough energy to form four ATP molecules. The final products of glycolysis are two molecules of pyruvic acid, two molecules of reduced NAD, and a net gain of two ATP molecules per glucose molecule. (pp. 923–924)

18. Pyruvic acid is converted to acetyl CoA, which enters the Krebs cycle. For pyruvic acid to be converted to acetyl CoA, the following must take place: decarboxylation to remove a carbon, oxidation to remove hydrogen atoms, and combination of the resulting acetic acid with coenzyme A to produce acetyl CoA. (p. 924)

19. Glycogenesis is the process by which glucose molecules are combined in long chains to form glycogen. Gluconeogenesis is the formation of new sugar from noncarbohydrate molecules. Lipogenesis is the term for triglyceride synthesis.

a. Glycogenesis (and perhaps lipogenesis) is likely to occur after a carbohydrate-rich meal.

b. Gluconeogenesis is likely to occur just before waking up in the morning. (pp. 929–930)

20. Metabolic acidosis due to ketosis is the result of excessive amounts of fats being burned for energy. Starvation, unwise dieting, and diabetes mellitus can result in ketosis. (p. 932)

21. [INSERT ART HERE]

(p. 937)

22. HDLs function to transport cholesterol from the peripheral tissues to the liver. LDLs transport cholesterol to the peripheral tissues. (p. 943)

23. Factors influencing plasma cholesterol levels include diet (through intake of cholesterol and/or saturated fatty acids), smoking, drinking, and stress. Sources of cholesterol in the body include the intake of animal foods and production from acetyl coenzyme A in the liver (and intestinal cells). Cholesterol is lost from the body when it is catabolized and secreted in bile salts that are eventually excreted in feces. It is used by body cells in plasma membranes and in synthesizing vitamin D and steroid hormones. (p. 944)

24. “Body energy balance” means that energy intake is equal to total energy output. If the body is not in exact balance, weight is either gained or lost. (p. 944)

25. Metabolic rate is increased with increased production of thyroxine. Eating increases metabolic rate, an effect called chemical thermogenesis. A higher ratio of body surface area to body volume requires a higher metabolic rate, because heat exchange surface area is greater. Muscular exercise and emotional stress increase metabolic rate. Starvation decreases metabolic rate. (pp. 947–948)

26. The body’s core includes organs within the skull and the thoracic and abdominal cavities. The core has the highest temperature. The shell, or skin, has the lowest temperature. Blood serves as the heat transfer agent between the core and shell. (p. 950)

27. Heat-promoting mechanisms to maintain or increase body temperature include vasoconstriction in the shell, which inhibits heat loss via radiation; conduction and convection; increase in metabolic rate due to epinephrine release; and shivering. Heat-loss mechanisms include vasodilation of blood vessels in the skin and sweating (which enhances heat transfer via evaporation).

Whenever core temperature increases above or decreases below normal, peripheral and central thermoreceptors send input to the hypothalamus. Much like a thermostat, the hypothalamus responds to the input by initiating the appropriate heat-promoting or heat-loss reflex mechanisms via autonomic effector pathways. (pp. 950–953)

**Critical Thinking and Clinical Application Questions**

1. The number of ATP molecules resulting from the complete oxidation of a particular fatty acid can be calculated easily by counting the number of carbon atoms in the fatty acid and dividing by two to determine the number of acetyl CoA molecules produced. For our example, an 18-carbon fatty acid yields 9 acetyl CoA molecules. Because each of these yield 12 ATP molecules per turn of the Krebs cycle, a total of 108 ATP molecules is provided from the oxidative pathways: 9 from electron transport oxidation of 3 NADH + H+, 2 from the oxidation of 1 FADH2, and a net yield of 1 ATP during the Krebs cycle. Also, for every acetyl CoA released during beta oxidation, an additional molecule each of NADH + H+ and FADH2 is produced, which, when reoxidized, yield a total of 5 ATP molecules more. In an 18-carbon fatty acid, this would occur 8 times, yielding 40 more ATP molecules. After subtracting the ATP needed to get the process going, this adds up to a grand total of 147 ATP molecules from that single 18-carbon fatty acid! (pp. 928–929, 931)

2. Hypothermia is abnormally depressed body temperature. It kills by dropping the body temperature below the relatively narrow range in which biochemical reactions can take place. The elderly have less subcutaneous tissue. Also, their metabolic rate (and heat-generating capacity) is slower. (p. 953)

3. With a diagnosis of high cholesterol and severe arteriosclerosis, he should avoid foods containing saturated fatty acids and avoid eating eggs and large amounts of red meat. He should substitute foods containing unsaturated fatty acids and add fish to his diet. He should also stop smoking, cut down on his coffee, avoid stress situations when possible, and increase his amount of aerobic exercise. (p. 944)

4. The chemiosmotic machinery concerns the operation of the electron transport chain and generation of the proton gradient during which most ATP is harvested in the mitochondria. If uncoupled, cells will use more and more nutrients in an effort to generate needed ATP, leaving fewer “calories” for protein synthesis and tissue maintenance. (pp. 922, 925–928)

5. Simon is exhibiting signs of vitamin C deficiency, otherwise known as scurvy. Although he has rich sources of many nutrients on his island, his diet is lacking fruits and green leafy vegetables as a source of vitamin C. (p. 917)

6. Gregor’s blood tests probably revealed high cholesterol and high triglyceride levels. Cutting down on saturated fats such as steak and butter is a good idea. The fat in cottage cheese is also saturated and should be ingested in moderation. Gregor should increase his intake of the unsaturated fats such as olive oil and also add omega-3 fatty acids from fish. Gregor can replace the animal proteins with soy proteins to further lower his cholesterol levels. In addition to dietary changes Gregor needs to begin exercising to further lower his levels and help with his “bad” blood results. (p. 944)