Introduction to Metabolism

- Cells break down organic molecules to obtain energy
  - Used to generate ATP
- Most energy production takes place in mitochondria
Metabolism

- Body chemicals
  - Oxygen
  - Water
- Nutrients
  - Vitamins
  - Mineral ions
  - Organic substrates
Metabolism

- Body chemicals
  - Cardiovascular system
    - Carries materials through body
  - Materials diffuse
    - From bloodstream into cells
Metabolism

- **Metabolism** refers to all chemical reactions in an organism

- Cellular Metabolism
  - Includes all chemical reactions within cells
  - Provides energy to maintain homeostasis and perform essential functions
Metabolism

- Essential Functions
  - Metabolic turnover
    - Periodic replacement of cell’s organic components
  - Growth and cell division
  - Special processes, such as secretion, contraction, and the propagation of action potentials
Figure 25–1 An Introduction to Cellular Metabolism.
The Nutrient Pool

- Contains all organic building blocks cell needs
  - To provide energy
  - To create new cellular components
- Is source of substrates for catabolism and anabolism
Metabolism

- **Catabolism**
  - Is the breakdown of organic substrates
  - Releases energy used to synthesize high-energy compounds (e.g., ATP)

- **Anabolism**
  - Is the synthesis of new organic molecules
Metabolism

- In energy terms
  - Anabolism is an “uphill” process that forms new chemical bonds
Metabolism

- Functions of Organic Compounds
  - Perform structural maintenance and repairs
  - Support growth
  - Produce secretions
  - Store nutrient reserves
Metabolism

- Organic Compounds
  - Glycogen
    - Most abundant storage carbohydrate
    - A branched chain of glucose molecules
  - Triglycerides
    - Most abundant storage lipids
    - Primarily of fatty acids
  - Proteins
    - Most abundant organic components in body
    - Perform many vital cellular functions
Figure 25–2 Nutrient Use in Cellular Metabolism.
Generates ATP and other high-energy compounds by breaking down carbohydrates:

\[ \text{glucose + oxygen} \rightarrow \text{carbon dioxide + water} \]
Carbohydrate Metabolism

- Glucose Breakdown
  - Occurs in small steps
    - Which release energy to convert ADP to ATP
  - One molecule of glucose nets 36 molecules of ATP
- Glycolysis
  - Breaks down glucose in cytosol into smaller molecules used by mitochondria
  - Does not require oxygen: anaerobic reaction
- Aerobic Reactions
  - Also called **aerobic metabolism** or cellular respiration
  - Occur in mitochondria, consume oxygen, and produce ATP
Carbohydrate Metabolism

- Glycolysis
  - Breaks 6-carbon glucose
  - Into two 3-carbon pyruvic acid
- Pyruvate
  - Ionized form of pyruvic acid
Carbohydrate Metabolism

- Glycolysis Factors
  - Glucose molecules
  - Cytoplasmic enzymes
  - ATP and ADP
  - Inorganic phosphates
  - NAD (coenzyme)
Figure 25–3 Glycolysis.
Carbohydrate Metabolism

- Mitochondrial ATP Production
  - If oxygen supplies are adequate, mitochondria absorb and break down pyruvic acid molecules:
    - H atoms of pyruvic acid are removed by coenzymes and are primary source of energy gain
    - C and O atoms are removed and released as CO$_2$ in the process of **decarboxylation**
Carbohydrate Metabolism

- Mitochondrial Membranes
  - Outer membrane
    - Contains large-diameter pores
    - Permeable to ions and small organic molecules (pyruvic acid)
  - Inner membrane
    - Contains carrier protein
    - Moves pyruvic acid into mitochondrial matrix
  - Intermembrane space
    - Separates outer and inner membranes
The TCA Cycle (citric acid cycle)

- The function of the citric acid cycle is
  - To remove hydrogen atoms from organic molecules and transfer them to coenzymes

- In the mitochondrion
  - Pyruvic acid reacts with NAD and coenzyme A (CoA)
  - Producing 1 CO₂, 1 NADH, 1 acetyl-CoA

- Acetyl group transfers
  - From acetyl-CoA to oxaloacetic acid
  - Produces citric acid
The TCA Cycle

- CoA is released to bind another acetyl group
- One TCA cycle removes two carbon atoms
  - Regenerating 4-carbon chain
- Several steps involve more than one reaction or enzyme
- H₂O molecules are tied up in two steps
- CO₂ is a waste product
- The product of one TCA cycle is
  - One molecule of GTP (guanosine triphosphate)
Summary: The TCA Cycle

\[ \text{CH}_3\text{CO} - \text{CoA} + 3\text{NAD} + \text{FAD} + \text{GDP} + P_i + 2 \text{H}_2\text{O} \rightarrow \]

\[ \text{CoA} + 2 \text{CO}_2 + 3\text{NADH} + \text{FADH}_2 + 2 \text{H}^+ + \text{GTP} \]
Figure 25–4a The TCA Cycle.
Figure 25–4 The TCA Cycle.
Carbohydrate Metabolism

- Oxidative Phosphorylation and the ETS
  - Is the generation of ATP
    - Within mitochondria
    - In a reaction requiring coenzymes and oxygen
  - Produces more than 90% of ATP used by body
  - Results in $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$
The Electron Transport System (ETS)

- Is the key reaction in oxidative phosphorylation
- Is in inner mitochondrial membrane
- Electrons carry chemical energy
  - Within a series of integral and peripheral proteins
Oxidation and Reduction

- **Oxidation** (loss of electrons)
  - Electron donor is oxidized

- **Reduction** (gain of electrons)
  - Electron recipient is reduced

- The two reactions are always paired
Carbohydrate Metabolism

Energy Transfer

- Electrons transfer energy
- Energy performs physical or chemical work (ATP formation)

Electrons
- Travel through series of oxidation–reduction reactions
- Ultimately combine with oxygen to form water
Coenzymes

- Play key role in oxidation-reduction reactions
- Act as intermediaries
  - Accept electrons from one molecule
  - Transfer them to another molecule
- In TCA cycle
  - Are NAD and FAD
  - Remove hydrogen atoms from organic substrates
- Each hydrogen atom consists of an electron and a proton
Carbohydrate Metabolism

- Oxidation-Reduction Reactions
  - Coenzyme
    - Accepts hydrogen atoms
    - Is reduced
    - Gains energy
  - Donor molecule
    - Gives up hydrogen atoms
    - Is oxidized
    - Loses energy
Carbohydrate Metabolism

- Oxidation-Reduction Reactions
  - Protons and electrons are released
  - Electrons
    - Enter electron transport system
    - Transfer to oxygen
    - \( \text{H}_2\text{O} \) is formed
  - Energy is released
    - Synthesize ATP from ADP
Carbohydrate Metabolism

- Coenzyme FAD
  - Accepts two hydrogen atoms from TCA cycle:
    - Gaining two electrons

- Coenzyme NAD
  - Accepts two hydrogen atoms
  - Gains two electrons
  - Releases one proton
  - Forms NADH + H⁺
Carbohydrate Metabolism

The Electron Transport System (ETS)
- Also called respiratory chain
- Is a sequence of proteins (cytochromes)
  - Protein:
    - embedded in inner membrane of mitochondrion
    - surrounds pigment complex
  - Pigment complex:
    - contains a metal ion (iron or copper)
Carbohydrate Metabolism

- ETS: Step 1
  - Coenzyme strips two hydrogens from substrate molecule
    - Glycolysis occurs in cytoplasm
    - NAD is reduced to NADH
  - In mitochondria
    - NAD and FAD in TCA cycle
Carbohydrate Metabolism

- ETS: Step 2
  - NADH and FADH$_2$ deliver H atoms to coenzymes
    - In inner mitochondrial membrane
    - Protons are released
    - Electrons are transferred to ETS
  - Electron Carriers
    - NADH sends electrons to FMN (flavin mononucleotide)
    - FADH$_2$ proceeds directly to coenzyme Q (CoQ; ubiquinone)
    - FMN and CoQ bind to inner mitochondrial membrane
Carbohydrate Metabolism

- **ETS: Step 3**
  - CoQ releases protons and passes electrons to Cytochrome b

- **ETS: Step 4**
  - Electrons pass along electron transport system
    - Losing energy in a series of small steps

- **ETS: Step 5**
  - At the end of ETS
    - Oxygen accepts electrons and combines with H\(^+\) to form H\(_2\)O
Carbohydrate Metabolism

Figure 25–5a Oxidative Phosphorylation.

1. A coenzyme strips 2 hydrogen atoms from a substrate molecule.
2. NADH and FADH$_2$ deliver hydrogen atoms to coenzymes embedded in the inner membrane of a mitochondrion.
3. Coenzyme Q releases hydrogen ions and passes electrons to cytochrome $b$.
4. Electrons are passed along the Electron Transport System, losing energy in a series of small steps.
5. Oxygen accepts the low energy electrons, and with hydrogen ions, forms water.

Substrate-H$_2$ → NADH + H$^+$ → FMN → CoQ → Cytochrome $b$ → Cytochrome $c$ → Cytochrome $a$ → Cytochrome $a_3$ → O → H$_2$O
Carbohydrate Metabolism

Figure 25–5b Oxidative Phosphorylation.
ATP Generation and the ETS

- Does not produce ATP directly
- Creates steep concentration gradient across inner mitochondrial membrane
- Electrons along ETS release energy
  - As they pass from coenzyme to cytochrome
  - And from cytochrome to cytochrome
- Energy released drives H ion (H⁺) pumps
  - That move H⁺ from mitochondrial matrix
  - Into intermembrane space
Carbohydrate Metabolism

- Ion Pumps
  - Create concentration gradient for $H^+$ across inner membrane
  - Concentration gradient provides energy to convert ADP to ATP
- Ion Channels
  - In inner membrane permit diffusion of $H^+$ into matrix
Chemiosmosis

- Also called chemiosmotic phosphorylation
- Ion channels and coupling factors use kinetic energy of hydrogen ions to generate ATP
Ion Pumps

Hydrogen ions are pumped, as

- FMN reduces coenzyme Q
- Cytochrome \( b \) reduces cytochrome \( c \)
- Electrons pass from cytochrome \( a \) to cytochrome \( A_3 \)
Carbohydrate Metabolism

- **NAD and ATP Generation**
  - Energy of one electron pair removed from substrate in TCA cycle by NAD
    - Pumps six hydrogen ions into intermembrane space
    - Reentry into matrix generates three molecules of ATP

- **FAD and ATP Generation**
  - Energy of one electron pair removed from substrate in TCA cycle by FAD
    - Pumps four hydrogen ions into intermembrane space
    - Reentry into matrix generates two molecules of ATP
The Importance of Oxidative Phosphorylation

- Is the most important mechanism for generation of ATP
- Requires oxygen and electrons
  - Rate of ATP generation is limited by oxygen or electrons
- Cells obtain oxygen by diffusion from extracellular fluid
Carbohydrate Metabolism

- Energy Yield of Glycolysis and Cellular Respiration
  - For most cells, reaction pathway
    - Begins with glucose
    - Ends with carbon dioxide and water
    - Is main method of generating ATP
Carbohydrate Metabolism

- **Glycolysis**
  - One glucose molecule is broken down anaerobically to two pyruvic acid
  - Cell gains a net two molecules of ATP

- **Transition Phase**
  - Two molecules NADH pass electrons to FAD:
    - Via intermediate in intermembrane space
    - To CoQ and electron transport system
    - Producing an additional 4 ATP molecules
ETS

- Each of eight NADH molecules
  - Produces 3 ATP + 1 water molecule
- Each of two FADH$_2$ molecules
  - Produces 2 ATP + 1 water molecule
- Total yield from TCA cycle to ETS
  - 28 ATP
Carbohydrate Metabolism

- TCA Cycle
  - Breaks down two pyruvic acid molecules
  - Produces two ATP by way of GTP
  - Transfers H atoms to NADH and FADH\(_2\)
  - Coenzymes provide electrons to ETS
Carbohydrate Metabolism

Summary: ATP Production

- For one glucose molecule processed, cell gains 36 molecules of ATP
  - 2 from glycolysis
  - 4 from NADH generated in glycolysis
  - 2 from TCA cycle (through GTP)
  - 28 from ETS
Figure 25–6 A Summary of the Energy Yield of Aerobic Metabolism.
Gluconeogenesis

- Is the synthesis of glucose from noncarbohydrate precursors
  - Lactic acid
  - Glycerol
  - Amino acids
- Stores glucose as glycogen in liver and skeletal muscle
Carbohydrate Metabolism

- **Glycogenesis**
  - Is the formation of glycogen from glucose
  - Occurs slowly
  - Requires high-energy compound uridine triphosphate (UTP)
Carbohydrate Metabolism

- **Glycogenolysis**
  - Is the breakdown of glycogen
  - Occurs quickly
  - Involves a single enzymatic step
Carbohydrate Metabolism

Figure 25–7 Carbohydrate Breakdown and Synthesis.
Lipid molecules contain carbon, hydrogen, and oxygen

- In different proportions than carbohydrates

- Triglycerides are the most abundant lipid in the body
Lipid Metabolism

- **Lipid Catabolism (also called lipolysis)**
  - Breaks lipids down into pieces that can be
    - Converted to pyruvic acid
    - Channeled directly into TCA cycle
  - Hydrolysis splits triglyceride into component parts
    - One molecule of glycerol
    - Three fatty acid molecules
Lipid Metabolism

- Lipid Catabolism
  - Enzymes in cytosol convert glycerol to pyruvic acid
    - Pyruvic acid enters TCA cycle
  - Different enzymes convert fatty acids to acetyl-CoA (beta-oxidation)
Lipid Metabolism

- Beta-Oxidation
  - A series of reactions
  - Breaks fatty acid molecules into 2-carbon fragments
  - Occurs inside mitochondria
  - Each step
    - Generates molecules of acetyl-CoA and NADH
    - Leaves a shorter carbon chain bound to coenzyme A
Figure 25–8 Beta-Oxidation.
Lipid Metabolism

Lipids and Energy Production

1. For each 2-carbon fragment removed from fatty acid, cell gains:
   - 12 ATP from acetyl-CoA in TCA cycle
   - 5 ATP from NADH

2. Cell can gain 144 ATP molecules from breakdown of one 18-carbon fatty acid molecule

3. Fatty acid breakdown yields about 1.5 times the energy of glucose breakdown
Lipid Metabolism

- Lipid Storage
  - Is important as energy reserves
  - Can provide large amounts of ATP, but slowly
  - Saves space, but hard for water-soluble enzymes to reach
Lipid Metabolism

- **Lipid Synthesis** (also called lipogenesis)
  - Can use almost any organic substrate
    - Because lipids, amino acids, and carbohydrates can be converted to acetyl-CoA
  - **Glycerol**
    - Is synthesized from dihydroxyacetone phosphate (intermediate product of glycolysis)
  - **Other Lipids**
    - Nonessential fatty acids and steroids are examples
    - Are synthesized from acetyl-CoA
Lipid Metabolism

- Lipid Transport and Distribution
  - Cells require lipids
    - To maintain plasma membranes
  - Steroid hormones must reach target cells in many different tissues
Lipid Metabolism

- **Solubility**
  - Most lipids are not soluble in water
    - Special transport mechanisms carry lipids from one region of body to another

- **Circulating Lipids**
  - Most lipids circulate through bloodstream as **lipoproteins**
  - Free fatty acids are a small percentage of total circulating lipids
Free Fatty Acids (FFAs)

- Are lipids
- Can diffuse easily across plasma membranes
- In blood, are generally bound to albumin (most abundant plasma protein)

Sources of FFAs in blood

- Fatty acids not used in synthesis of triglycerides diffuse out of intestinal epithelium into blood
- Fatty acids diffuse out of lipid stores (in liver and adipose tissue) when triglycerides are broken down
Lipid Metabolism

- Free Fatty Acids
  - Are an important energy source
    - During periods of starvation
    - When glucose supplies are limited
  - Liver cells, cardiac muscle cells, skeletal muscle fibers, and so forth
    - Metabolize free fatty acids
Lipid Metabolism

- **Lipoproteins**
  - Are lipid–protein complexes
  - Contain large insoluble glycerides and cholesterol
  - Five classes of lipoproteins
    - Chylomicrons
    - Very low-density lipoproteins (VLDLs)
    - Intermediate-density lipoproteins (IDLs)
    - Low-density lipoproteins (LDLs)
    - High-density lipoproteins (HDLs)
Lipid Metabolism

- Chylomicrons
  - Are produced in intestinal tract
  - Are too large to diffuse across capillary wall
  - Enter lymphatic capillaries
  - Travel through thoracic duct
    - To venous circulation and systemic arteries
Figure 25–9a Lipid Transport and Utilization.
Lipid Metabolism

1. Liver cells synthesize VLDLs for discharge into the bloodstream.
2. In peripheral capillaries, lipoprotein lipase removes many of the triglycerides from VLDLs, leaving IDLs.
3. When IDLs reach the liver, additional triglycerides are removed and the protein content is altered. This process creates LDLs.
4. LDLs leave the bloodstream through capillary pores or cross the endothelium by vesicular transport.
5. Once in peripheral tissues, the LDLs are absorbed by means of receptor-mediated endocytosis.
6. The cholesterol not used diffuses out of the cell.
7. The cholesterol then reenters the bloodstream, where it is absorbed by HDLs and returned to the liver.
8. In the liver, the HDLs are absorbed and the cholesterol is extracted. Some of the recovered cholesterol is used in the synthesis of LDLs.
9. The HDLs stripped of their cholesterol are released into the bloodstream to travel to peripheral tissues and absorb additional cholesterol.

Figure 25–9b Lipid Transport and Utilization.
Protein Metabolism

- The body synthesizes 100,000 to 140,000 proteins
  - Each with different form, function, and structure
- All proteins are built from the 20 amino acids
- Cellular proteins are recycled in cytosol
  - Peptide bonds are broken
  - Free amino acids are used in new proteins
Protein Metabolism

- If other energy sources are inadequate
  - Mitochondria generate ATP by breaking down amino acids in TCA cycle
- Not all amino acids enter cycle at same point, so ATP benefits vary
Protein Metabolism

- Amino Acid Catabolism
  - Removal of amino group by transamination or deamination
  - Requires coenzyme derivative of vitamin B₆ (pyridoxine)
Protein Metabolism

- Transamination
  - Attaches amino group of amino acid
    - To keto acid
  - Converts keto acid into amino acid
    - That leaves mitochondrion and enters cytosol
    - Available for protein synthesis
Protein Metabolism

- Deamination
  - Prepares amino acid for breakdown in TCA cycle
  - Removes amino group and hydrogen atom
    - Reaction generates ammonium ion
Figure 25–10a Amino Acid Catabolism.
Figure 25–10b Amino Acid Catabolism.

Glutamic acid → Keto acid + NH₄⁺

Deaminase

(b) Deamination

H₂O, NAD, NADH

Protein Metabolism

Copyright © 2009 Pearson Education, Inc., publishing as Pearson Benjamin Cummings
Protein Metabolism

- Ammonium Ions
  - Are highly toxic, even in low concentrations
  - Liver cells (primary sites of deamination) have enzymes that use ammonium ions to synthesize \textbf{urea} (water-soluble compound excreted in urine)
Protein Metabolism

- Urea Cycle
  - Is the reaction sequence that produces urea
Protein Metabolism

(c) Urea cycle

Figure 25–10c Amino Acid Catabolism.

NH₄⁺ + CO₂ → Urea cycle

Ammonium ion + Carbon dioxide

Urea

H₂N—C—NH₂
Protein Metabolism

- Proteins and ATP Production
  - When glucose and lipid reserves are inadequate, liver cells
    - Break down internal proteins
    - Absorb additional amino acids from blood
  - Amino acids are deaminated
    - Carbon chains broken down to provide ATP
Protein Metabolism

Three Factors Against Protein Catabolism

- Proteins are more difficult to break apart than complex carbohydrates or lipids
- A byproduct, ammonium ion, is toxic to cells
- Proteins form the most important structural and functional components of cells
Protein Metabolism

- **Protein Synthesis**
  - The body synthesizes half of the amino acids needed to build proteins

  - **Nonessential amino acids**
    - Amino acids made by the body on demand
Protein Metabolism

- **Protein Synthesis**
  - **Ten Essential Amino Acids**
    - Eight not synthesized:
      - isoleucine, leucine, lysine, threonine, tryptophan, phenylalanine, valine, and methionine
    - Two insufficiently synthesized:
      - arginine and histidine
Protein Metabolism

α-Ketoglutarate

\[
\begin{array}{c}
\text{O} \\
\text{C} \\
\text{=O} \\
\text{CH}_2 \\
\text{CH}_2 \\
\text{O} \\
\end{array}
\begin{array}{c}
\text{OH} \\
\end{array}
\]

\[\text{NH}_4^+\]

\[\text{H}_2\text{O}\]

\[\text{NADH}\]

\[\text{NAD}\]

\[\text{Glutamic acid}\]

\[
\begin{array}{c}
\text{O} \\
\text{C} \\
\text{=O} \\
\text{CH}_2 \\
\text{CH}_2 \\
\text{O} \\
\end{array}
\begin{array}{c}
\text{OH} \\
\end{array}
\]

\[
\begin{array}{c}
\text{H} \\
\text{C} \\
\text{CH}_2 \\
\text{CH}_2 \\
\text{O} \\
\end{array}
\begin{array}{c}
\text{NH}_2 \\
\end{array}
\]

Figure 25–11 Animation.
Figure 25–12 A Summary of the Pathways of Catabolism and Anabolism.
Absorptive and Postabsorptive States

- Nutrient Requirements
  - Of each tissue vary with types and quantities of enzymes present in cell
Absorptive and Postabsorptive States

- Five Metabolic Tissues
  - Liver
  - Adipose tissue
  - Skeletal muscle
  - Neural tissue
  - Other peripheral tissues
Absorptive and Postabsorptive States

- The Liver
  - Is focal point of metabolic regulation and control
  - Contains great diversity of enzymes that break down or synthesize carbohydrates, lipids, and amino acids
- Hepatocytes
  - Have an extensive blood supply
  - Monitor and adjust nutrient composition of circulating blood
  - Contain significant energy reserves (glycogen deposits)
Absorptive and Postabsorptive States

- Adipose Tissue
  - Stores lipids, primarily as triglycerides
  - Is located in
    - Areolar tissue
    - Mesenteries
    - Red and yellow marrows
    - Epicardium
    - Around eyes and kidneys
Absorptive and Postabsorptive States

- **Skeletal Muscle**
  - Maintains substantial glycogen reserves
  - Contractile proteins can be broken down
    - Amino acids used as energy source
Absorptive and Postabsorptive States

- Neural Tissue
  - Does not maintain reserves of carbohydrates, lipids, or proteins
  - Requires reliable supply of glucose
    - Cannot metabolize other molecules
  - In CNS, cannot function in low-glucose conditions
    - Individual becomes unconscious
Absorptive and Postabsorptive States

- **Other Peripheral Tissues**
  - Do not maintain large metabolic reserves
  - Can metabolize glucose, fatty acids, and other substrates
  - Preferred energy source varies
    - According to instructions from endocrine system
Absorptive and Postabsorptive States

- Metabolic Interactions
  - Relationships among five components change over 24-hour period
  - Body has two patterns of daily metabolic activity
    - Absorptive state
    - Postabsorptive state
Absorptive and Postabsorptive States

- **The Absorptive State**
  - Is the period following a meal when nutrient absorption is under way

- **The Postabsorptive State**
  - Is the period when nutrient absorption is not under way
  - Body relies on internal energy reserves for energy demands
  - Liver cells conserve glucose
    - Break down lipids and amino acids
# Absorptive and Postabsorptive States

## TABLE 25–1 Regulatory Hormones and Their Effects on Peripheral Metabolism

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Effect on General Peripheral Tissues</th>
<th>Selective Effects on Target Tissues</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ABSORPTIVE STATE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulin</td>
<td>Increased glucose uptake and utilization</td>
<td><em>Liver</em>: Glycogenesis</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Adipose tissue</em>: Lipogenesis</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Skeletal muscle</em>: Glycogenogenesis</td>
</tr>
<tr>
<td>Insulin and growth hormone</td>
<td>Increased amino acid uptake and protein synthesis</td>
<td><em>Skeletal muscle</em>: Fatty acid catabolism</td>
</tr>
<tr>
<td>Androgens, estrogens</td>
<td>Increased amino acid use in protein synthesis</td>
<td><em>Skeletal muscle</em>: Muscle hypertrophy (especially androgens)</td>
</tr>
<tr>
<td><strong>POSTABSORPTIVE STATE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucagon</td>
<td></td>
<td><em>Liver</em>: Glycogenolysis</td>
</tr>
<tr>
<td>Epinephrine</td>
<td></td>
<td><em>Liver</em>: Glycogenolysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Adipose tissue</em>: Lipolysis</td>
</tr>
<tr>
<td>Glucocorticoids</td>
<td>Decreased use of glucose; increased reliance on ketone bodies and fatty acids</td>
<td><em>Liver</em>: Glycogenolysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Adipose tissue</em>: Lipolysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Skeletal muscle</em>: Glycogenolysis, protein breakdown, amino acid release</td>
</tr>
<tr>
<td>Growth hormone</td>
<td>Complements effects of glucocorticoids</td>
<td>Acts with glucocorticoids</td>
</tr>
</tbody>
</table>
Absorptive and Postabsorptive States

- Lipid and Amino Acid Catabolism
  - Generates acetyl-CoA
  - Increased concentration of acetyl-CoA
    - Causes ketone bodies to form
Absorptive and Postabsorptive States

- Ketone Bodies
  - Three types
    - Acetoacetate
    - Acetone
    - Betahydroxybutyrate
  - Liver cells do not catabolize ketone bodies
    - Peripheral cells absorb ketone bodies and reconver to acetyl-CoA for TCA cycle
  - They are acids that dissociate in solution
  - Fasting produces ketosis
    - A high concentration of ketone bodies in body fluids
Absorptive and Postabsorptive States

- **Ketonemia**
  - Is the appearance of ketone bodies in bloodstream
  - Lowers plasma pH, which must be controlled by buffers
  - **Ketoacidosis** is a dangerous drop in blood pH caused by high ketone levels
  - In severe ketoacidosis, circulating concentration of ketone bodies can reach 200 mg dL, and the pH may fall below 7.05
    - May cause coma, cardiac arrhythmias, death
Nutrition

- Homeostasis can be maintained only if digestive tract absorbs enough fluids, organic substrates, minerals, and vitamins to meet cellular demands.
- Nutrition is the absorption of nutrients from food.
- The body’s requirement for each nutrient varies.
Nutrition

- Food Groups and MyPyramid Plan
  - A balanced diet contains all components needed to maintain homeostasis
    - Substrates for energy generation
    - Essential amino acids and fatty acids
    - Minerals and vitamins
  - Must also include water to replace urine, feces, evaporation
## TABLE 25–2 Basic Food Groups of the 2005 Dietary Guidelines and Their General Effects on Health

<table>
<thead>
<tr>
<th>Nutrient Group</th>
<th>Provides</th>
<th>Health Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grains (recommended: at least half of the total eaten as whole grains)</strong></td>
<td>Carbohydrates; vitamins E, thiamine, niacin, folate; calcium; phosphorus; iron; sodium; dietary fiber</td>
<td>Whole grains prevent rapid rise in blood glucose levels, and consequent rapid rise in insulin levels</td>
</tr>
<tr>
<td><strong>Vegetables (recommended: especially dark-green and orange vegetables)</strong></td>
<td>Carbohydrates; vitamins A, C, E, folate; dietary fiber; potassium</td>
<td>Reduce risk of cardiovascular disease; protect against colon cancer (folate) and prostate cancer (lycopene in tomatoes)</td>
</tr>
<tr>
<td><strong>Fruits (recommended: a variety of fruit each day)</strong></td>
<td>Carbohydrates; vitamins A, C, E, folate; dietary fiber; potassium</td>
<td>Reduce risk of cardiovascular disease; protect against colon cancer (folate)</td>
</tr>
<tr>
<td><strong>Milk (recommended: low-fat or fat-free milk, yogurt, and cheese)</strong></td>
<td>Complete proteins; fats; carbohydrates; calcium; potassium; magnesium; sodium; phosphorus; vitamins A, B₁₂, pantothenic acid, thiamine, riboflavin</td>
<td>Whole milk: High in calories, may cause weight gain; saturated fats correlated with heart disease</td>
</tr>
<tr>
<td><strong>Meat and Beans (recommended: lean meats, fish, poultry, eggs, dry beans, nuts, legumes)</strong></td>
<td>Complete proteins; fats; calcium; potassium; phosphorus; iron; zinc; vitamins E, thiamine, B₆</td>
<td>Fish and poultry lower risk of heart disease and colon cancer (compared to red meat). Consumption of up to one egg per day does not appear to increase incidence of heart disease; nuts and legumes improve blood cholesterol ratios, lower risk of heart disease and diabetes</td>
</tr>
</tbody>
</table>
Nutrition

- **MyPyramid Plan**
  - Is an arrangement of **food groups**
    - According to number of recommended daily servings
    - Considers level of physical activity
Figure 25–13 The MyPyramid Plan.
Nutrition

- **Nitrogen Balance**
  - **Complete proteins** provide all essential amino acids in sufficient quantities
    - Found in beef, fish, poultry, eggs, and milk
  - **Incomplete proteins** are deficient in one or more essential amino acids
    - Found in plants
Four Types of Nitrogen Compounds

- Amino acids:
  - Framework of all proteins, glycoproteins, and lipoproteins
- Purines and pyrimidines:
  - Nitrogenous bases of RNA and DNA
- Creatine:
  - Energy storage in muscle (creatine phosphate)
- Porphyrins:
  - Bind metal ions
  - Essential to hemoglobin, myoglobin, and cytochromes
Nitrogen Atoms (N)
- Are not stored in the body
- Must be obtained by
  - Recycling N in body
  - Or from diet
Nutrition

- **Nitrogen Balance**
  - Occurs when
    - Nitrogen absorbed from diet balances nitrogen lost in urine and feces
Nutrition

- **Positive Nitrogen Balance**
  - Individuals actively synthesizing N compounds:
    - Need to absorb more nitrogen than they excrete
    - For example, growing children, athletes, and pregnant women

- **Negative Nitrogen Balance**
  - When excretion exceeds ingestion
Nutrition

- Minerals and Vitamins
  - Are essential components of the diet
  - The body does not synthesize minerals
  - Cells synthesize only small quantities of a few vitamins
Minerals

- Are inorganic ions released through dissociation of electrolytes
- Ions such as sodium, chloride, and potassium determine osmotic concentrations of body fluids
- Ions are essential
  - Cofactors in many enzymatic reactions
Nutrition

- Metals
  - Each component of ETS requires an iron atom
  - Final cytochrome of ETS requires a copper ion
Nutrition

- Mineral Reserves
  - The body contains significant mineral reserves
    - That help reduce effects of variations in diet
<table>
<thead>
<tr>
<th>Mineral</th>
<th>Significance</th>
<th>Total Body Content</th>
<th>Primary Route of Excretion</th>
<th>Recommended Daily Intake (RDA or AI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BULK MINERALS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td>Major cation in body fluids; essential for normal membrane function</td>
<td>110 g, primarily in body fluids</td>
<td>Urine, sweat, feces</td>
<td>1.5 g</td>
</tr>
<tr>
<td>Potassium</td>
<td>Major cation in cytoplasm; essential for normal membrane function</td>
<td>140 g, primarily in cytoplasm</td>
<td>Urine</td>
<td>4.7 g</td>
</tr>
<tr>
<td>Chloride</td>
<td>Major anion in body fluids</td>
<td>89 g, primarily in body fluids</td>
<td>Urine, sweat</td>
<td>2.3 g</td>
</tr>
<tr>
<td>Calcium</td>
<td>Essential for normal muscle and neuron function and normal bone structure</td>
<td>1.36 kg, primarily in skeleton</td>
<td>Urine, feces</td>
<td>1000–1200 mg</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>In high-energy compounds, nucleic acids, and bone matrix (as phosphate)</td>
<td>744 g, primarily in skeleton</td>
<td>Urine, feces</td>
<td>700 mg</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Cofactor of enzymes, required for normal membrane functions</td>
<td>29 g (skeleton, 17 g; cytoplasm and body fluids, 12 g)</td>
<td>Urine</td>
<td>310–400 mg</td>
</tr>
</tbody>
</table>
## TABLE 25–3  Minerals and Mineral Reserves*

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Significance</th>
<th>Total Body Content</th>
<th>Primary Route of Excretion</th>
<th>Recommended Daily Intake (RDA or AI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TRACE MINERALS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td>Component of hemoglobin, myoglobin, cytochromes</td>
<td>3.9 g (1.6 g stored as ferritin or hemosiderin)</td>
<td>Urine (traces)</td>
<td>8–18 mg</td>
</tr>
<tr>
<td>Zinc</td>
<td>Cofactor of enzyme systems, notably carbonic anhydrase</td>
<td>2 g</td>
<td>Urine, hair (traces)</td>
<td>8–11 mg</td>
</tr>
<tr>
<td>Copper</td>
<td>Required as cofactor for hemoglobin synthesis</td>
<td>127 mg</td>
<td>Urine, feces (traces)</td>
<td>900 μg</td>
</tr>
<tr>
<td>Manganese</td>
<td>Cofactor for some enzymes</td>
<td>11 mg</td>
<td>Feces, urine (traces)</td>
<td>1.8–2.3 mg</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Cofactor for transaminations; mineral in vitamin B₁₂ (cobalamin)</td>
<td>1.1 g</td>
<td>Feces, urine</td>
<td>0.0001 mg</td>
</tr>
<tr>
<td>Selenium</td>
<td>Antioxidant</td>
<td>Variable</td>
<td>Feces, urine</td>
<td>55 μg</td>
</tr>
<tr>
<td>Chromium</td>
<td>Cofactor for glucose metabolism</td>
<td>0.0006 mg</td>
<td>Feces, urine</td>
<td>20–35 μg</td>
</tr>
</tbody>
</table>

*For information on the effects of deficiencies and excesses, see Table 27–2, p. 1021. The recommended intakes are reported as either RDA (recommended dietary allowance for most people) or AI (adequate intake) when RDA data is lacking. Ranges indicate the differences between males and females and/or ages.
Fat-Soluble Vitamins

- Vitamins A, D, E, and K
  - Are absorbed primarily from the digestive tract along with lipids of micelles
  - Normally diffuse into plasma membranes and lipids in liver and adipose tissue
Nutrition

- **Vitamin A**
  - A structural component of visual pigment retinal

- **Vitamin D**
  - Is converted to calcitriol, which increases rate of intestinal calcium and phosphorus absorption

- **Vitamin E**
  - Stabilizes intracellular membranes

- **Vitamin K**
  - Helps synthesize several proteins, including three clotting factors
# TABLE 25–4 The Fat-Soluble Vitamins

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Significance</th>
<th>Sources</th>
<th>Recommended Daily Intake (RDA or AI)</th>
<th>Effects of Deficiency</th>
<th>Effects of Excess</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Maintains epithelia; required for synthesis of visual pigments; supports immune system; promotes growth and bone remodeling</td>
<td>Leafy green and yellow vegetables</td>
<td>700–900 µg</td>
<td>Retarded growth, night blindness, deterioration of epithelial membranes</td>
<td>Liver damage, skin paling, CNS effects (nausea, anorexia)</td>
</tr>
<tr>
<td>D (steroids, including cholecalciferol, or D₃)</td>
<td>Required for normal bone growth, calcium and phosphorus absorption at gut and retention at kidneys</td>
<td>Synthesized in skin exposed to sunlight</td>
<td>5–15 µg*</td>
<td>Rickets, skeletal deterioration</td>
<td>Calcium deposits in many tissues, disrupting functions</td>
</tr>
<tr>
<td>E (tocopherols)</td>
<td>Prevents breakdown of vitamin A and fatty acids</td>
<td>Meat, milk, vegetables</td>
<td>15 mg</td>
<td>Anemia, other problems suspected</td>
<td>Nausea, stomach cramps, blurred vision, fatigue</td>
</tr>
<tr>
<td>K</td>
<td>Essential for liver synthesis of prothrombin and other clotting factors</td>
<td>Vegetables; production by intestinal bacteria</td>
<td>90–120 µg</td>
<td>Bleeding disorders</td>
<td>Liver dysfunction, jaundice</td>
</tr>
</tbody>
</table>

*Unless exposure to sunlight is inadequate for extended periods and alternative sources (fortified milk products) are unavailable.
Nutrition

- Vitamin Reserves
  - The body contains significant reserves of fat-soluble vitamins
  - Normal metabolism can continue several months without dietary sources
Water-Soluble Vitamins

- Are components of coenzymes
- Are rapidly exchanged between fluid in digestive tract and circulating blood
  - Excesses are excreted in urine
<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Significance</th>
<th>Sources</th>
<th>Recommended Daily Intake (RDA or AI)</th>
<th>Effects of Deficiency</th>
<th>Effects of Excess</th>
</tr>
</thead>
<tbody>
<tr>
<td>B₁ (thiamine)</td>
<td>Coenzyme in decarboxylations</td>
<td>Milk, meat, bread</td>
<td>1.1–1.2 mg</td>
<td>Muscle weakness, CNS and cardiovascular problems, including heart disease; called Beriberi</td>
<td>Hypotension</td>
</tr>
<tr>
<td>B₂ (riboflavin)</td>
<td>Part of FMN and FAD</td>
<td>Milk, meat</td>
<td>1.1–1.3 mg</td>
<td>Epithelial and mucosal deterioration</td>
<td>Itching, tingling</td>
</tr>
<tr>
<td>Niacin (nicotinic acid)</td>
<td>Part of NAD</td>
<td>Meat, bread, potatoes</td>
<td>14–16 mg</td>
<td>CNS, GI, epithelial, and mucosal deterioration; called Pellagra</td>
<td>Itching, burning; vasodilation; death after large dose</td>
</tr>
<tr>
<td>B₅ (pantothenic acid)</td>
<td>Part of acetyl-CoA</td>
<td>Milk, meat</td>
<td>5 mg</td>
<td>Retarded growth, CNS disturbances</td>
<td>None reported</td>
</tr>
<tr>
<td>B₆ (pyridoxine)</td>
<td>Coenzyme in amino acid and lipid metabolisms</td>
<td>Meat</td>
<td>1.3–1.7 mg</td>
<td>Retarded growth, anemia, convulsions, epithelial changes</td>
<td>CNS alterations, perhaps fatal</td>
</tr>
<tr>
<td>Vitamin</td>
<td>Significance</td>
<td>Sources</td>
<td>Recommended Daily Intake (RDA or AI)</td>
<td>Effects of Deficiency</td>
<td>Effects of Excess</td>
</tr>
<tr>
<td>------------------</td>
<td>--------------------------------------------</td>
<td>------------------------</td>
<td>-------------------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>Folate (folic acid)</td>
<td>Coenzyme in amino acid and nucleic acid metabolisms</td>
<td>Vegetables, cereal, bread</td>
<td>400 μg</td>
<td>Retarded growth, anemia, gastrointestinal disorders, developmental abnormalities</td>
<td>Few noted, except at massive doses</td>
</tr>
<tr>
<td>B₁₂ (cobalamin)</td>
<td>Coenzyme in nucleic acid metabolism</td>
<td>Milk, meat</td>
<td>2.4 μg</td>
<td>Impaired RBC production, causing pernicious anemia</td>
<td>Polycythemia</td>
</tr>
<tr>
<td>Biotin</td>
<td>Coenzyme in decarboxylations</td>
<td>Eggs, meat, vegetables</td>
<td>30 μg</td>
<td>Fatigue, muscular pain, nausea, dermatitis</td>
<td>None reported</td>
</tr>
<tr>
<td>C (ascorbic acid)</td>
<td>Coenzyme; delivers hydrogen ions, antioxidant</td>
<td>Citrus fruits</td>
<td>75–90 mg Smokers: add 35 mg</td>
<td>Epithelial and mucosal deterioration; called scurvy</td>
<td>Kidney stones</td>
</tr>
</tbody>
</table>
Nutrition

- Vitamins and Bacteria
  - Bacterial inhabitants of intestines produce small amounts of
    - Fat-soluble vitamin K
    - Five water-soluble vitamins
Nutrition

- Vitamin $B_{12}$
  - Intestinal epithelium absorbs all water-soluble vitamins except $B_{12}$
    - $B_{12}$ molecule is too large:
      - must bind to intrinsic factor before absorption
Diet and Disease

- Average U.S. diet contains excessive amounts of sodium, calories, and lipids
- Poor diet contributes to
  - Obesity
  - Heart disease
  - Atherosclerosis
  - Hypertension
  - Diabetes
Metabolic Rate

- Energy Gains and Losses
  - Energy is released
    - When chemical bonds are broken
  - In cells
    - Energy is used to synthesize ATP
    - Some energy is lost as heat
Metabolic Rate

- **Calorimetry**
  - Measures total energy released when bonds of organic molecules are broken
  - Food is burned with oxygen and water in a calorimeter
Metabolic Rate

- **Calories**
  - Energy required to raise 1 g of water 1 degree Celsius is a **calorie (cal)**
  - Energy required to raise 1 kilogram of water 1 degree Celsius is a **Calorie (Cal) = kilocalorie (kcal)**

- **The Energy Content of Food**
  - Lipids release 9.46 Cal/g
  - Carbohydrates release 4.18 Cal/g
  - Proteins release 4.32 Cal/g
Metabolic Rate

- Energy Expenditure: Metabolic Rate
  - Clinicians examine metabolism to determine calories used and measured in:
    - Calories per hour
    - Calories per day
    - Calories per unit of body weight per day
Metabolic Rate

- Energy Expenditure: Metabolic Rate
  - Is the sum of all anabolic and catabolic processes in the body
  - Changes according to activity
Metabolic Rate

- **Basal Metabolic Rate (BMR)**
  - Is the minimum resting energy expenditure
    - Of an awake and alert person
    - Measured under standardized testing conditions
  - Measuring BMR
    - Involves monitoring respiratory activity
    - Energy utilization is proportional to oxygen consumption
Metabolic Rate

- Metabolic Rate
  - If daily energy intake exceeds energy demands
    - Body stores excess energy as triglycerides in adipose tissue
  - If daily caloric expenditures exceeds dietary supply
    - Body uses energy reserves, loses weight
Metabolic Rate

- Hormonal Effects
  - Thyroxine controls overall metabolism
    - $T_4$ assay measures thyroxine in blood
  - Cholecystokinin (CCK) and adrenocorticotrophic hormone (ACTH) suppress appetite
  - Leptin is released by adipose tissues during absorptive state and binds to CNS neurons that suppress appetite
Metabolic Rate

- Thermoregulation
  - Heat production
    - BMR estimates rate of energy use
    - Energy not captured is released as heat:
      - serves important homeostatic purpose
Metabolic Rate

- **Body Temperature**
  - Enzymes operate in a limited temperature range
  - Homeostatic mechanisms keep body temperature within limited range (thermoregulation)
Metabolic Rate

- **Thermoregulation**
  - The body produces heat as byproduct of metabolism
  - Increased physical or metabolic activity generates more heat
  - Heat produced is retained by water in body
  - For body temperature to remain constant
    - Heat must be lost to environment
  - Body controls heat gains and losses to maintain homeostasis
Metabolic Rate

- Mechanisms of Heat Transfer
  - Heat exchange with environment involves four processes
    - Radiation
    - Conduction
    - Convection
    - Evaporation
Metabolic Rate

- **Radiation**
  - Warm objects lose heat energy as infrared radiation
    - Depending on body and skin temperature
  - About 50% of indoor heat is lost by radiation

- **Conduction**
  - Is direct transfer of energy through physical contact
  - Is generally not effective in heat gain or loss
Metabolic Rate

- **Convection**
  - Results from conductive heat loss to air at body surfaces
  - As body conducts heat to air, that air warms and rises and is replaced by cooler air
  - Accounts for about 15% of indoor heat loss

- **Evaporation**
  - Absorbs energy (0.58 Cal per gram of water evaporated)
  - Cools surface where evaporation occurs
  - Evaporation rates at skin are highly variable
Metabolic Rate

- **Insensible Water Loss**
  - Each hour, 20–25 mL of water crosses epithelia and evaporates from alveolar surfaces and skin surface
  - Accounts for about 20% of indoor heat loss

- **Sensible Perspiration**
  - From sweat glands
  - Depends on wide range of activity
    - From inactivity to secretory rates of 2–4 liters (2.1-4.2 quarts) per hour
The Regulation of Heat Gain and Heat Loss

- Is coordinated by heat-gain center and heat-loss center in preoptic area of anterior hypothalamus
  - Modify activities of other hypothalamic nuclei
Metabolic Rate

- **Temperature Control**
  - Is achieved by regulating
    - Rate of heat production
    - Rate of heat loss to environment
  - Further supported by behavioral modifications
Metabolic Rate

- Mechanisms for Increasing Heat Loss
  - When temperature at preoptic nucleus exceeds set point
    - The heat-loss center is stimulated
Metabolic Rate

- Three Actions of Heat-Loss Center
  - Inhibition of vasomotor center:
    - Causes peripheral vasodilation
    - Warm blood flows to surface of body and skin temperatures rise
    - Radiational and convective losses increase
  - Sweat glands are stimulated to increase secretory output:
    - Perspiration flows across body surface
    - Evaporative heat losses increase
  - Respiratory centers are stimulated:
    - Depth of respiration increases
Metabolic Rate

- Mechanisms for Promoting Heat Gain
  - The heat-gain center prevents low body temperature (hypothermia)
  - When temperature at preoptic nucleus drops
    - Heat-loss center is inhibited
    - Heat-gain center is activated
Metabolic Rate

- Heat Conservation
  - Sympathetic vasomotor center decreases blood flow to dermis
    - Reducing losses by radiation, convection, and conduction
  - In cold conditions
    - Blood flow to skin is restricted
    - Blood returning from limbs is shunted to deep, insulated veins (*countercurrent exchange*)
Metabolic Rate

- Heat Conservation
  - Countercurrent Exchange
    - Is heat exchange between fluids moving in opposite directions:
      - traps heat close to body core
      - restricts heat loss in cold conditions
Metabolic Rate

- **Mechanism of Countercurrent Exchange**
  - Blood is diverted to a network of deep, insulated veins
  - Venous network wraps around deep arteries
  - Heat is conducted from warm blood flowing outward
    - To cooler blood returning from periphery
Heat Dissipation

In warm conditions

- Blood flows to superficial venous network
- Heat is conducted outward to cooler surfaces
Figure 25–14a, b Vascular Adaptations for Heat Loss and Conservation
Metabolic Rate

Figure 25–14c Vascular Adaptations for Heat Loss and Conservation
Metabolic Rate

- Two mechanisms for generating heat
  - **Shivering thermogenesis**
    - Increased muscle tone increases energy consumption of skeletal muscle, which produces heat
    - Involves agonists and antagonists, and degree of stimulation varies with demand
    - Shivering increases heat generation up to 400%
  - **Nonshivering thermogenesis**
    - Releases hormones that increase metabolic activity
    - Raises heat production in adults 10–15% over extended time period
Metabolic Rate

- **Hormones and Thermogenesis**
  - Heat-gain center stimulates suprarenal medullae
    - Via sympathetic division of ANS
    - Releasing epinephrine
  - Epinephrine increases
    - Glycogenolysis in liver and skeletal muscle
    - Metabolic rate of most tissues
  - Preoptic nucleus regulates thyrotropin-releasing hormone (TRH) production by hypothalamus
Metabolic Rate

Hormones and Thermogenesis

- In children, low body temperature stimulates additional TRH release
  - Stimulating thyroid-stimulating hormone (TSH)
  - Released by adenohypophysis (anterior lobe of pituitary gland)

- TSH stimulates thyroid gland
  - Increasing thyroxine release into blood

- Thyroxine increases
  - Rate of carbohydrate catabolism
  - Rate of catabolism of all other nutrients
Metabolic Rate

- Sources of Individual Variation in Thermoregulation
  - Thermoregulatory responses differ among individuals due to
    - **Acclimatization** (adjustment to environment over time)
    - Variations in body size
Body Size and Thermoregulation

- Heat is produced by body mass (volume)
- Surface-to-volume ratio decreases with size
- Heat generated by “volume” is lost at body surface
Metabolic Rate

- Thermoregulatory Problems of Infants
  - Temperature-regulating mechanisms are not fully functional
  - Lose heat quickly (due to small size)
  - Body temperatures are less stable
    - Metabolic rates decline during sleep and rise after awakening
  - Infants cannot shiver
Metabolic Rate

- Infant Thermogenesis Mechanism
  - Infants have brown fat
    - Highly vascularized adipose tissue
    - Adipocytes contain numerous mitochondria found between shoulder blades, around neck, and in upper body
Metabolic Rate

- Function of Brown Fat in Infants
  - Individual adipocytes innervated by sympathetic autonomic fibers stimulate lipolysis in adipocytes
  - Energy released by fatty acid catabolism radiates into surrounding tissues as heat
  - Heat warms blood passing through surrounding vessels and is distributed throughout the body
  - Infant quickly accelerates metabolic heat generation by 100%
Metabolic Rate

- Brown Fat in Adults
  - With increasing age and size
    - Body temperature becomes more stable
    - Importance of brown fat declines
  - Adults have little brown fat
    - *Shivering thermogenesis* is more effective
Metabolic Rate

Thermoregulatory Variations among Adults

- Normal thermal responses vary according to
  - Body weight
  - Weight distribution
  - Relative weights of tissues types
  - Natural cycles
Metabolic Rate

- Adipose Tissue
  - Is an insulator
  - Individuals with more subcutaneous fat
    - Shiver less than thinner people
Metabolic Rate

- Temperature Cycles
  - Daily oscillations in body temperature
    - Temperatures fall 1° to 2°C at night
    - Peak during day or early evening
  - Timing varies by individual
Metabolic Rate

- The Ovulatory Cycle
  - Causes temperature fluctuations
- Pyrexia
  - Is elevated body temperature
  - Usually temporary
Fever

- Is body temperature maintained at greater than 37.2°C (99°F)
- Occurs for many reasons, not always pathological
- In young children, transient fevers can result from exercise in warm weather