Metabolism
Metabolism

• All the biochemical reactions occurring in the body
• Generating, storing, and expending energy
  • ATP
    • Supports body activities
    • Assists in constructing new tissue
Metabolism

- Two types of reactions
  - Catabolism
    - Breakdown of molecules
    - Releases energy
  - Anabolism
    - Synthesis of molecules
    - Requires energy
Energy

- Capacity to do work or put matter into motion
  - Force x distance
- Types of energy:
  - Kinetic
    - Objects are moving
  - Potential
    - Stored (inactive) energy
  - Chemical energy
    - Potential energy stored in bonds of chemical substances
Energy

- Kinetic energy
  - Electromagnetic energy
    - Moving photons from the sun and stars
  - Heat
    - Movement of water or gas molecules
- Potential energy
  - Energy used to increase the level of complexity in an object
Energy

• Chemical energy
  • Moving atoms may collide and form bonds
  • Increased complexity increases stored potential energy
Energy

- Greatest amount of energy in an atom is within nucleus
  - May be used or altered by biological processes
Bonds and Bond Energy

- Chemical energy of a molecule
  - Electron distance from nucleus
    - Moving closer to nucleus = energy released
    - Moving away from nucleus = energy added
  - Electronegativity
    - Ability of an atom to attract an electron to itself
    - Oxygen is very electronegative
Bonds and Bond Energy

• Covalent bonds
• Bond energy
  • Energy required to break bonds
    • High energy molecules
      • Carbohydrates, fats and amino acids
      • C-C and C-H bonds
      • Unstable
      • Logical food sources
  • Low energy bonds
    • Atoms bonded to oxygen
    • C=O
    • Stable
Bonds and Bond Energy

• Bottom line
  • Energy is always released when bonds are formed
  • Amount of energy released is related to final position of bonding electrons
Stages of Metabolism

Processing of nutrients

1. Digestion, absorption and transport to tissues
2. Cellular processing in cytoplasm
   • Synthesis of lipids, proteins, and glycogen, or
   • Catabolism (glycolysis) into intermediates
3. Oxidative (mitochondrial) breakdown of intermediates into CO₂, water, and ATP
**Stage 1** Digestion in GI tract lumen to absorbable forms. Transport via blood to tissue cells.

**Stage 2** Anabolism (incorporation into molecules) and catabolism of nutrients to form intermediates within tissue cells.

**Stage 3** Oxidative breakdown of products of stage 2 in mitochondria of tissue cells. CO₂ is liberated, and H atoms removed are ultimately delivered to molecular oxygen, forming water. Some energy released is used to form ATP.

- Catabolic reactions
- Anabolic reactions
Carbohydrate Metabolism

• Body’s preferred energy source
  • All cells possess enzymes to metabolize it
• Galactose, fructose, and glucose may be directly absorbed
  • Galactose and fructose must be converted to glucose for cellular metabolism
Carbohydrate Metabolism

- Glucose is catabolized in three pathways
  - Glycolysis
  - Krebs cycle
  - Electron transport chain
During glycolysis, each glucose molecule is broken down into two molecules of pyruvic acid in the cytosol. The pyruvic acid then enters the mitochondrial matrix, where the Krebs cycle decomposes it to CO₂. During glycolysis and the Krebs cycle, small amounts of ATP are formed by substrate-level phosphorylation. Energy-rich electrons picked up by coenzymes are transferred to the electron transport chain, built into the cristae membrane. The electron transport chain carries out oxidative phosphorylation, which accounts for most of the ATP generated by cellular respiration.
Carbohydrate Metabolism

- Glycolysis
  - 10-step pathway
  - Anaerobic
  - Occurs in the cytosol
  - Glucose $\rightarrow$ 2 pyruvic acid molecules
Carbohydrate Metabolism

- **Glycolysis**
  - Final products
    - Net gain of 2 ATP
    - 2 pyruvic acid molecules
      - Enter aerobic pathways if $O_2$ is readily available
Figure 24.6 The three major phases of glycolysis.

Glycolysis takes place in the cytosol.
Carbohydrate Metabolism

• Krebs cycle
  • Occurs in mitochondrial matrix
  • Electron (H⁺) carriers are reduced
  • Fueled by pyruvic acid and fatty acids
    • Some amino acids can also form pyruvic acid
  • Also called citric acid cycle
Carbohydrate Metabolism

• Krebs cycle summary
  • Occurs in the presence of oxygen
  • Pyruvic acid molecules enter mitochondrion
    • Catabolized to acetyl CoA
    • Acetyl Co A \rightarrow \text{citric acid}
    • Each citric acid generates
      • 2 CO₂
      • 1 ATP
    • Electrons are transferred to coenzymes which fuel the electron transport system
Figure 24.7 Simplified version of the Krebs (citric acid) cycle.
Carbohydrate Metabolism

- Electron transport chain
- Cytochromes
  - Proteins bound to iron atoms on inner mitochondrial membrane
  - Electrons passed from cytochrome to cytochrome
    - Release energy during transfer
Carbohydrate Metabolism

• Electron transport chain
  • Hydrogen atoms are split into H\(^+\) and electrons
  • Electrons are shuttled along the inner mitochondrial membrane, losing energy at each step
  • Released energy is used to pump H\(^+\) into the intermembrane space
  • Diffusion of H\(^+\) back through membrane is coupled to ATP production system
Intermembrane space

Inner mitochondrial membrane

Mitochondrial matrix

**Electron Transport Chain**
Electrons $e^-$ are transferred from complex to complex and some of their energy is used to pump protons ($H^+$) into the intermembrane space, creating a proton gradient.

**Chemiosmosis**
ATP synthesis is powered by the flow of $H^+$ back across the inner mitochondrial membrane through ATP synthase.
Carbohydrate Metabolism

• Electron transport chain
  • One glucose molecule $\rightarrow$ 32 - 34 ATP
  • Different cells have different totals due to various mechanisms present
  • Oxygen is final electron acceptor and has greatest affinity for hydrogen
  • Cyanide blocks terminal cytochrome which kills the cell
Electrons $e^-$ are transferred from complex to complex and some of their energy is used to pump protons (H$^+$) into the intermembrane space, creating a proton gradient. ATP synthesis is powered by the flow of H$^+$ back across the inner mitochondrial membrane through ATP synthase.
Cellular Respiration

- **Glycolysis**: Glucose → Pyruvic acid
  - Net +2 ATP by substrate-level phosphorylation
- **Krebs cycle**: 2 Acetyl CoA
  - +2 ATP by substrate-level phosphorylation
  - + about 28 ATP by oxidative phosphorylation
- **Electron transport chain and oxidative phosphorylation**:
  - 2 NADH + H+ → 2 NADH + H+ → 6 NADH + H+ → 2 FADH2
  - Electron shuttle across mitochondrial membrane
  - 10 NADH + H+ × 2.5 ATP
  - 2 FADH2 × 1.5 ATP

Maximum ATP yield per glucose: About 32 ATP

Figure 24.12
Cellular Respiration

- Oxidation of glucose

\[
C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2 + \text{heat}
\]

But heat isn’t useful so...

\[
C_6H_{12}O_6 + 6O_2 + 38 \text{ ADP} + 38 \text{ P} \rightarrow 6H_2O + 6CO_2 + 38 \text{ ATP} + \text{less heat}
\]
Anaerobic Metabolism

• Production of ATP in the absence of oxygen
  • Lactic acid fermentation

  glucose $\rightarrow$ $\rightarrow$ $\rightarrow$ 2 pyruvic acid $\rightarrow$ lactic acid
Anaerobic Metabolism

• Muscles during activity
  • At high levels of contractile activity:
    • Bulging muscles compress blood vessels
    • Oxygen delivery is impaired
    • Pyruvic acid is converted into lactic acid
    • Small amounts of ATP can be produced in the absence of oxygen
(b) Anaerobic pathway

Glycolysis and lactic acid formation

**Energy source:** glucose

- **Glucose** (from glycogen breakdown or delivered from blood)

- **Glycolysis in cytosol**

- **Pyruvic acid**

  - 2 net gain

  - Released to blood

- **Lactic acid**

**Oxygen use:** None

**Products:** 2 ATP per glucose, lactic acid

**Duration of energy provision:** 60 seconds, or slightly more
Anaerobic Metabolism

- Lactic acid fermentation problems
  - Relatively small yield of ATP
  - May produce muscle pain
  - Liver can convert lactic acid into pyruvic acid
    - Process requires oxygen
    - Oxygen debt
Efficiency of Aerobic Cellular Respiration

- Calorie
  - Energy to raise the temperature of 1 gram of water by 1°C
  - 1,000 calories = 1 kcal
- 1 mole (180 grams) of glucose releases 686 kcal
- One mole ATP = 7 kcal
  - Glucose catabolism
    - 38 ATP = 278 kcal
    - \(\frac{278}{686} = 40\%\) efficiency
      - 60% lost as heat
- Most human made machines have about 10-30% efficiency
Questions?

• No homework this week!
  • Consider studying for the final... 😊