Nutrient Role in Bioenergetics

HNF 610: Nutrition & Fitness
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Bioenergetics

- Bioenergetics refers to the flow of energy within a living system.
- Energy is the capacity to do work.
- Aerobic reactions require oxygen.
- Anaerobic reactions do not require oxygen.
Energy and Laws of Thermodynamics

- First law – Energy is neither created nor destroyed, but instead, transforms from one state to another without being used up.
- There are six forms of interchangeable energy states:
  - Chemical
  - Light
  - Electric
  - Mechanical
  - Heat
  - Nuclear
Photosynthesis and Respiration

- During photosynthesis, chlorophyll absorbs radiant energy to synthesize glucose from carbon dioxide and water and releases oxygen.
- Solar energy and photosynthesis power the animal world with food and oxygen.
- Respiration is the reverse of photosynthesis.
Nuclear energy → Radiant energy → Chlorophyll → Glucose (stored energy)

$6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow 6\text{O}_2 + \text{Glucose}$
Biologic Work

- Takes one of three forms:
  - Mechanical work of muscle contraction
  - Chemical work for synthesizing cellular molecules
  - Transport work that concentrates diverse substances in body fluids
Potential Energy and Kinetic Energy

- Potential energy refers to energy associated with a substance’s structure or position.
- Kinetic energy refers to energy of motion.
- Potential energy and kinetic energy constitute the total energy of any system.
- Releasing potential energy transforms it into kinetic energy of motion.
Higher potential energy

Energy changes proportionally to the vertical drop of the water

Potential energy dissipates as water flows downhill

Work results from harnessing potential energy

Lower potential energy
Redox Reactions

- Oxidation–reduction reactions couple:
  - Oxidation = a substance loses electrons
  - Reduction = a substance gains electrons
- Redox reactions power the body’s energy transfer processes.
ATP: The Energy Currency

- Potential energy is extracted from food and conserved within the bonds of ATP.
- Chemical energy is extracted and transferred in ATP to power biologic work.
- Powers all forms of biologic work.
- Potential energy from food is conserved within the bonds of ATP.
Adenosine

Triphosphate

\[ \text{O-P-O \sim P-O \sim P-OH} \]

\[ \text{OH \sim OH \sim OH} \]

High energy bonds

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Phosphocreatine (PCr)

- In addition to ATP, phosphocreatine is another high-energy phosphate compound.
- Releases large amounts of energy when bonds between creatine and phosphate are broken.
- Cells store 4-6 times more PCr than ATP.
- Provide a reservoir of high-energy phosphate bonds.
Phosphorylation

- Refers to energy transfer through phosphate bonds
- Most of the energy for ATP phosphorylation comes from oxidation of carbohydrates, lipids, and proteins.
- Oxidative phosphorylation synthesizes ATP by transferring electrons from NADH and FADH$_2$ to oxygen.
Cellular Oxidation–Reduction Reactions

- Constitute the mechanism for energy metabolism
- Involve the transfer of hydrogen atoms
  - Loss of hydrogen: oxidation
  - Gain of hydrogen: reduction
- Mitochondria contain carrier molecules that remove electrons from hydrogen and pass them to oxygen.
Energy Sources

- Sources for ATP formation include:
  - Glucose derived from liver glycogen
  - Triacylglycerol and glycogen molecules stored within muscle cells
  - Free fatty acids derived from triacylglycerol (in liver and adipocytes) that enter the bloodstream for delivery to active muscle
  - Intramuscular and liver-derived carbon skeletons of amino acids
Energy Release from Carbohydrates

- The primary function of carbohydrates is to supply energy for cellular work.
- The complete breakdown of 1 mole of glucose liberates 689 kCal of energy.
  - Of this, ATP bonds conserve about 261 kCal (38%), with the remainder dissipated as heat.
Glucose Degradation

- Occurs in two stages:
  - 1. Anaerobic: Glucose breaks down relatively rapidly to 2 molecules of pyruvate.
  - 2. Aerobic: Pyruvate degrades further to carbon dioxide and water.
Glycolysis

- Glycogen catabolism
- Substrate-level phosphorylation in glycolysis
- Hydrogen release in glycolysis
- Lactate formation
Citric Acid Cycle

- The second stage of carbohydrate breakdown is known as the citric acid cycle (Krebs cycle).
- Degrades acetyl-CoA substrate to carbon dioxide and hydrogen atoms within the mitochondria.
- The acetyl portion of acetyl-CoA joins with oxaloacetate to form citrate (citric acid).
Net reaction: two pyruvate molecules form 20 hydrogen atoms

\[
2 \text{ pyruvate} + 6 \text{ H}_2\text{O} \rightarrow 6 \text{ CO}_2 + 2 \text{ OH} + 2 \text{ CoA}
\]

- 2 pyruvate molecules: \( \text{CO}_2 : 2 \), \( \text{H} : 4 \)
- 2 acetyl-CoA molecules: \( \text{CO}_2 : 4 \), \( \text{H} : 16 \)

Total: \( \text{CO}_2 : 6 \), \( \text{H} : 20 \)
Energy Release from Fat

- Stored fat represents the body’s most plentiful source of potential energy.
- Energy sources for fat catabolism include:
  - Triacylglycerol stored directly within the muscle fiber
  - Circulating triacylglycerol in lipoprotein complexes
  - Circulating free fatty acids
Adipocytes

- Adipose tissue serves as an active and major supplier of fatty acid molecules.
- Triacylglycerol fat droplets occupy up to 95% of the adipocyte cell’s volume.
- Free fatty acids either form intracellular triacylglycerols or bind with intramuscular proteins and enter the mitochondria for energy metabolism.
Adipose tissue

- Triacylglycerols
  - (50,000 - 100,000 kCal)

Fatty acids
Glycerol

Blood plasma

- Fatty acids
- Albumin

Mitochondrion

- Acetyl-CoA
- Citric acid cycle, Electron transport

Muscle

- Glycogen
  - Intramuscular triacylglycerol
    - (2000 - 3000 kCal)

- FFA
  - Fatty acids

Oxygen (O₂)

ATP energy

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Hormonal Effects

- Epinephrine, norepinephrine, glucagon, and growth hormone augment lipase activation.
- Fat breakdown or synthesis depends on the availability of fatty acid molecules.
- Hormonal release triggered by exercise stimulates adipose tissue lipolysis.
Breakdown of Glycerol and Fatty Acids

- **Glycerol**
  - Provides carbon skeletons for glucose synthesis

- **Fatty acids**
  - Beta (β)-oxidation converts a free fatty acid to multiple acetyl-CoA molecules.
  - Hydrogens released during fatty acid catabolism oxidize through the respiratory chain.
Glucose $\rightarrow$ Triacylglycerol + $3 \text{H}_2\text{O} \rightarrow$ Glycerol + $3 \text{FA}$

3-phosphoglyceraldehyde

$\text{H}_2$

Pyruvate

$\text{H}_2$

Acetyl-CoA

$\beta$-oxidation

Coenzyme A

CoA + Acetyl

H$_2$

Citric acid cycle

ATP

2 CO$_2$

Electron transport chain

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Lipogenesis

- The formation of fat, mostly in the cytoplasm of liver cells
- Occurs when excess glucose or protein is not used immediately to sustain metabolism, so it converts into stored triacylglycerol
- The lipogenic process requires ATP energy and the B vitamins biotin, niacin, and pantothenic acid.
Energy Release from Protein

- Protein plays a role as an energy substrate during endurance activities and heavy trainings.
- Deamination: Nitrogen is removed from the amino acid molecule.
- Transamination: When an amino acid is passed to another compound.
- The remaining carbon skeletons enter metabolic pathways to produce ATP.
Protein and Water

- Protein catabolism facilitates water loss.
- The amine group and other solutes from protein breakdown must be eliminated.
- This requires excretion of “obligatory” water as the waste products of protein catabolism leave the body dissolved in fluid (urine).
The Metabolic Mill

- The citric acid cycle is a vital link between food energy and the chemical energy of ATP.
- The citric acid cycle also provide intermediates that cross the mitochondrial membrane into the cytosol to synthesize bionutrients.