Nutrition

Metabolism, Energy Balance, and Body Composition

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Chemical Reactions in the Body

• **Metabolism** is the sum total of all chemical reactions that go on in living cells.
• **Anabolism** is the building up of body compounds and requires energy.
• **Catabolism** is the breakdown of body compounds and releases energy.
**ANABOLIC REACTIONS**

- **Glycogen**
  - Uses energy
  - Glucose + Glucose

- **Triglycerides**
  - Uses energy
  - Glycerol + Fatty acids

- **Protein**
  - Uses energy
  - Amino acids + Amino acids

Anabolic reactions include the making of glycogen, triglycerides, and protein; these reactions require differing amounts of energy.

**CATABOLIC REACTIONS**

- **Glycogen**
  - Yields energy
  - Glycogen → Glucose

- **Triglycerides**
  - Yields energy
  - Triglycerides → Glycerol, Fatty acids

- **Protein**
  - Yields energy
  - Protein → Amino acids

Catabolic reactions include the breakdown of glycogen, triglycerides, and protein; the further catabolism of glucose, glycerol, fatty acids, and amino acids releases differing amounts of energy. Much of the energy released is captured in the bonds of adenosine triphosphate (ATP).

**NOTE:** You need not memorize a color code to understand the figures in this chapter, but you may find it helpful to know that blue is used for carbohydrates, yellow for fats, and red for proteins.
The Transfer of Energy in Reactions—ATP

- A high-energy compound called adenosine triphosphate (ATP) is made.
- Coupled reactions are chemical reactions that occur simultaneously.
ATP (Adenosine Triphosphate)

Adenosine + 3 phosphate groups
Transfer of Energy By ATP – A Coupled Reaction

ATP captures and stores energy in the bonds between its phosphate groups.
Chemical Reactions in the Body

- Enzymes and coenzymes are helpers in reactions.
  - Enzymes are protein catalysts that cause chemical reactions.
  - Coenzymes are organic molecules that function as enzyme helpers.
    - Vitamins often serve as co-enzymes
  - Cofactors are organic or inorganic substances that facilitate enzyme action.
Breaking Down Nutrients for Energy

- Glucose
  - Glycolysis: glucose $\leftrightarrow$ pyruvate
  - Pyruvate $\rightarrow$ acetyl CoA (irreversible).

- Acetyl CoA’s Options
  - Synthesize fats when the body has enough ATP
  - Generate ATP when the cell is low in energy
Note that steps from pyruvate to glucose are reversible. The step from pyruvate to Acetyl CoA is irreversible. Fatty acids cannot be converted to glucose.
Breaking Down Nutrients for Energy

- Glycerol and Fatty Acids
  - The conversion of glycerol to pyruvate is easy because they are both three-carbon compounds.
  - Fatty acids-to-acetyl CoA reactions are called fatty acid oxidation.
  - Fatty acids cannot be used to synthesize glucose.
  - Glucose must be available to provide energy to the red blood cells, brain, and nervous system.
Breaking Down Nutrients for Energy

• Amino Acids
  • Amino acids can be converted to acetyl CoA after deamination.
  • Amino Acids-to-Glucose – a fairly good source of glucose when carbohydrate is not available
Amino Acids Enter the Energy Pathway

Most amino acids can be used to synthesize glucose; they are glucogenic.

Some amino acids are converted directly to acetyl CoA; they are ketogenic.

Some amino acids can enter the TCA cycle directly; they are glucogenic.

NOTE: The arrows from pyruvate and the TCA cycle to amino acids are possible only for *nonessential* amino acids; remember, the body cannot make essential amino acids.
Breaking Down Nutrients for Energy

- **Amino Acids**
  - **Deamination** results in two products:
    - Keto acid
    - Ammonia
  - **Transamination** is the transfer of the amino group from an amino acid to a keto acid.
  - Ammonia is converted to urea—a much less toxic compound—in the liver.
  - Urea is excreted through the kidneys to rid the body of unused nitrogen.
Deamination and Synthesis of a Nonessential Amino Acid

The deamination of an amino acid produces ammonia (NH₃) and a keto acid.

Given a source of NH₃, the body can make nonessential amino acids from keto acids.
Transamination and Synthesis of a Nonessential Amino Acid

The body can transfer amino groups (NH₂) from an amino acid to a keto acid, forming a new *nonessential* amino acid and a new keto acid. Transamination reactions require the vitamin B₆ coenzyme.
Urea Synthesis

Ammonia + Carbon dioxide + Ammonia → Water → Urea
Urea Excretion
Breaking Down Nutrients for Energy

In Summary

- Glucose and fatty acids are primarily used for energy, amino acids to a lesser extent.
- Glucose is made from all carbohydrates, most amino acids and the glycerol portion of fat.
- Protein is made from amino acids.
- Glucose can be made into nonessential amino acids if nitrogen is present.
- All energy-yielding nutrients consumed in excess can contribute to fat storage.
The TCA (Krebs) Cycle

NOTE: Knowing that glucose produces pyruvate during glycolysis and that oxaloacetate must be available to start the TCA cycle, you can understand why the complete oxidation of fat requires carbohydrate.

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Electron Transport Chain & ATP Synthesis

**Electron Transport Chain**
Passing electrons from carrier to carrier along the chain releases enough energy to pump hydrogen ions across the membrane.

**ATP Synthesis**
Hydrogen ions flow “downhill”—from an area of high concentration to an area of low concentration—through a special protein complex that powers the synthesis of ATP.

Coenzymes deliver hydrogens and high-energy electrons to the electron transport chain from the TCA cycle. Oxygen accepts the electrons and combines with hydrogens to form water.

Coenzymes: $e^+$

Hydrogens: $H^+$

Oxygen: $O_2$

Water: $H_2O$

ADP: $ADP + P$

ATP: $ADP + P$

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Breaking Down Nutrients for Energy

- The Final Steps of Catabolism
  - The kCalories-per-Gram Secret Revealed
    - Fat provides 9 kcal/gram.
    - Carbohydrate provides 4 kcal/gram.
    - Protein provides 4 kcal/gram.
    - Fat provides more energy because the bonds in fat molecules are easily oxidized and result in more ATP.
The Kcalories-per-Gram Secret Revealed

- The bonds in a fatty acid are mostly between carbon & hydrogen
  - Oxygen can be added to nearly all of them
  - Hydrogen's are released to the electron transport chain
- An oxygen is already bonded to each carbon in glucose leaving less potential for oxidation
  - Fewer hydrogen's are released to the electron transport chain
Energy Balance

- When energy intake exceeds energy output, there is a gain in weight.
- Excess energy can come from protein, fat or carbohydrate.
- Fat is the most efficient in being stored as fat.
Energy Balance

- Feasting—Excess Energy
  - Excess protein is converted to fat but this is inefficient and indirect. Its priority is other roles.
  - Excess carbohydrate is converted to fat but this is inefficient and indirect. Its priority is glycogen stores.
  - Excess fat is efficiently converted to fat.
- The transition from feasting to fasting draws on reserves.
Energy Balance

- Fasting—Inadequate Energy
  - Glucose required for the brain, nervous system, and red blood cells (normally the brain and nerve cells consume about half the total glucose used each day)
  - Glycogen stores are used first but are generally used up within 24 hours.
  - Protein from muscle breakdown can be deaminated to meet glucose needs initially
Energy Balance

- Fasting – Inadequate Energy
  - The Shift to Ketosis
    - Ketones are produced during incomplete breakdown of fat when glucose is not available.
    - Some, not all, brain cells can use ketones for fuel, this slows (doesn’t stop) the breakdown of protein.
  - Ketosis causes a suppression of the appetite.
  - Hormones of fasting slow metabolism to conserve body tissues as long as possible.
<table>
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<th>Broken down in the body to:</th>
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<tr>
<td>Carbohydrate</td>
<td>Glucose</td>
<td>Liver and muscle glycogen stores</td>
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<td>Fat</td>
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<td>Loss of nitrogen in urine (urea)</td>
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**A. When a person overeats (feasting):**
When a person eats in excess of energy needs, the body stores a small amount of glycogen and much larger quantities of fat.

**B. When a person draws on stores (fasting):**
When nutrients from a meal are no longer available to provide energy (about 2 to 3 hours after a meal), the body draws on its glycogen and fat stores for energy.

**C. If the fast continues beyond glycogen depletion:**
As glycogen stores dwindle (after about 24 hours of starvation), the body begins to break down its protein (muscle and lean tissue) to amino acids to synthesize glucose needed for brain and nervous system energy. In addition, the liver converts fats to ketone bodies, which serve as an alternative energy source for the brain, thus slowing the breakdown of body protein.

*The muscles’ stored glycogen provides glucose only for the muscle in which the glycogen is stored.*

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The first step in the formation of ketone bodies is the condensation of two molecules of acetyl CoA and the removal of the CoA to form a compound that is converted to the first ketone body.

This ketone body may lose a molecule of carbon dioxide to become another ketone.

Or, the acetoacetate may add two hydrogens, becoming another ketone body (beta-hydroxybutyrate). See Appendix C for more details.
Energy Balance

• Fasting—Inadequate Energy
  • Symptoms of Starvation
    • Muscle wasting
    • Decreased heart rate, respiratory rate, metabolic rate, and body temperature
    • Impaired vision
    • Organ failure
    • Decreased immunity
    • Depression, anxiety, and food-related dreams
Chemical Reactions in the Body

- During digestion, the energy-yielding nutrients are broken down to monosaccharides, fatty acids, glycerol, and amino acids.
- After absorption, enzymes and coenzymes can use these materials to build more complex compounds.
- They can also be broken down further into energy (ATP), water and carbon dioxide.
Energy Balance

- Body weight is stable when energy consumed is equal to energy expended.
- When energy consumed is greater than expended, weight increases.
- When energy consumed is less than expended, weight decreases.
- One pound of body weight is equal to 3,500 kcalories.
Energy Balance

- **Food Intake**
  - **Appetite** initiates eating through the sight, smell, thought or taste of food.
  - **Hunger** is the feeling that motivates us to eat and is controlled by the hypothalamus.
  - **Satiation** is the feeling of satisfaction and fullness that causes us to stop eating.
  - **Satiety** reminds us not to eat again until the body needs food.
Hunger, Satiation, Satiety

1. **Physiological influences**
   - Empty stomach
   - Gastric contractions
   - Absence of nutrients in small intestine
   - GI hormones
   - Endorphins (the brain’s pleasure chemicals) are triggered by the smell, sight, or taste of foods, enhancing the desire for them

2. **Sensory influences**
   - Thought, sight, smell, sound, taste of food

3. **Cognitive influences**
   - Presence of others, social stimulation
   - Perception of hunger, awareness of fullness
   - Favorite foods, foods with special meanings
   - Time of day
   - Abundance of available food

4. **Postingestive influences**
   (after food enters the digestive tract)
   - Food in stomach triggers stretch receptors
   - Nutrients in small intestine elicit hormones (for example, fat elicits cholecystokinin, which slows gastric emptying)

5. **Postabsorptive influences**
   (after nutrients enter the blood)
   - Nutrients in the blood signal the brain (via nerves and hormones) about their availability, use, and storage
   - As nutrients dwindle, satiety diminishes.
   - Hunger develops

1. **Hunger**
2. **Seek food and start meal**
3. **Keep eating**
4. **Satiation: End meal**
5. **Satiation: Several hours later**

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Energy Balance

• Food Intake
  • Overriding Hunger and Satiety
    • Stress eating is eating in response to arousal.
    • Cognitive influences such as perceptions, memories, intellect, and social interactions
  • Sustaining Hunger and Satiety
    • Protein is the most satiating nutrient.
    • Complex carbohydrates are more satiating than simple carbohydrates.
    • High-fat foods stimulate and entice people to eat more.
For the same size portion, peanuts deliver more than 15 times the calories and 20 times the fat of popcorn.

For the same number of calories, a person can have a few high-fat peanuts or almost 2 cups of high-fiber popcorn. (This comparison used oil-based popcorn; using air-popped popcorn would double the amount of popcorn in this example.)
Energy In: The kCalories Foods Provide

- Food Intake
  - Message Central—The Hypothalamus
    - Integrates messages about energy intake, expenditure, and storage
  - Neuropeptide Y
    - initiates eating,
    - decreases energy expenditure,
    - increases fat storage and
    - causes carbohydrate cravings.
Energy Balance

- Basal metabolic activities
  - differ from person to person and are affected by age, gender, weight, and height.
- Thermic effect of food
  - Estimated at 10% of energy intake
- Physical activity
  - Intensity and duration of physical activity makes a difference.
- Adaptive thermogenesis.
Components of Energy Expenditure

- 30-50% Physical activities
- 10% Thermic effect of food
- 50-65% Basal metabolism
Energy Balance

Components of Energy Expenditure

- Basal Metabolism (basal metabolic rate, BMR)
  - 2/3 of energy expenditure
  - Supports the basic processes of life
  - Resting metabolic rate (RMR) is a measure of energy slightly higher than BMR.
Energy Balance

• Basal Metabolism - Factors affecting BMR
  • Aging slows BMR
  • Height – the taller, the higher the BMR
  • Growth ↑ BMR.
  • Body composition (lean body mass ↑ BMR)
  • Fever and stress ↑ BMR.
  • Environmental temperature – BMR is ↑ with both heat and cold
Energy Balance

- Basal Metabolism - Factors affecting BMR
  - Fasting/starvation & malnutrition slow BMR.
  - Hormones
    - Thyroid hormones can increase or decrease BMR.
    - Premenstrual hormones can increase BMR.
  - Smoking & caffeine increases BMR.
  - Sleep slows BMR.
Energy Balance

- Physical activity
  - Most variable and changeable
  - Voluntary
  - It can be significant in weight loss and weight gain.
  - Duration, frequency and intensity influence energy expenditure.
**Nonexercise Activity Thermogenesis (NEAT)**

- NEAT in the evolution of obesity
  - 150 years ago, 90% of the world’s population lived in agriculture regions
    - They walked to and from work
    - Daily activities were intensively manual
  - With industrialization & urbanization
    - Non-ambulatory mass transit; cars
    - Work is mechanized & less manual
    - We do more sitting on the job and at home

Nonexercise Activity Thermogenesis
NEAT

- NEAT-enhanced living
  - Individualized approaches
    - Finding ways to incorporate more movement into your daily life
  - Environmental re-engineering
    - Re-design the environment to be activity-enticing

Body Weight

- A measurement of the heaviness or mass of a body
- A number of pounds or kilograms as measured on a scale
- Body weight includes the weight of body fat, lean tissue (including water) and bone mass.
Body Composition

- Relative proportions of body fat and lean tissue
- Direct measures of body composition are not possible in living persons
- Indirect measures or assessments of body fat are used in clinical settings
Defining a “Healthy Weight”

- The Criterion of Fashion
  - Society values change over time.
  - Perceived body images
- The Criterion of Health
  - Good health supersedes appearance.
  - Longevity is a criterion.
- Standards that only look at height & weight and do not consider body composition may be misleading
The Declining Weight of Miss America
Defining a “Healthy Weight”

- An appropriate weight for an individual depends on many factors which include:
  - body fat distribution,
  - health history and
  - current state of health.
Assessing Body Weight

• Body Mass Index
  • Body mass index (BMI) measures relative weight for height.
    • Underweight is a BMI below 18.5.
    • Overweight is a BMI above 25.
    • Obese is a BMI above 30.
  • DOES NOT reflect body composition
BMI Values Used to Assess Weight

Key:
- BMI < 18.5 = underweight
- BMI 18.5 to 24.9 = healthy
- BMI 25.0 to 29.9 = overweight
- BMI ≥ 30 = obese
Distribution of Body Weights in US Adults

- Healthy weight (BMI 18.5 – 24.9)
- Overweight (BMI 25 – 29.9)
- Obesity (BMI 30 – 39.9)
- Underweight (BMI < 18.5)
- Extreme obesity (BMI ≥ 40)
Assessing Body Weight

- BMI is used in large clinical studies and epidemiological studies to identify health risks of overweight and obesity
  - In these large studies, BMI appears to be a valid measurement for a “group” of subjects
- BMI should be used cautiously when assessing an individual.
  - It will be appropriate for many, if not most individuals
  - It will not be appropriate for some individuals due to differences in body composition
Body Composition

- Some People Need Less Body Fat
  - Fat for fuel
  - Fat for insulation and protection
  - Fat to assist in nerve impulse transmissions
  - Fat to support normal hormone activity

- Some People Need More Body Fat
  - Thresholds differ among individuals
  - Thresholds differ for each function
Fat Distribution

- Intra-abdominal fat around abdominal organs may be critical.
- Central obesity is excess fat around the trunk of the body.
  - It is also called abdominal fat or upper-body fat.
  - It is associated with increased health risks.
Abdominal Fat

In healthy weight people, some fat is stored around the organs of the abdomen.

In overweight people, excess abdominal fat increases the risks of diseases.
Comparison of “Apple” and “Pear” Body Shapes

Upper-body fat is more common in men than in women and is closely associated with heart disease, stroke, diabetes, hypertension, and some types of cancer.

Lower body fat is more common in women than in men and is not usually associated with chronic diseases.
Assessing “Central Obesity”

- Waist Circumference
  - Practical indicator of fat distribution and abdominal fat
  - ≥ 35 is considered high risk for women.
  - ≥ 40 is considered high risk for men.
Assessing Body Composition

- Other Measures of Body Composition
  - Monitoring changes over time is important.
  - Fatfold measures
  - Hydrodensitometry (underwater weighing)
  - Bioelectrical impedance
  - Air displacement plethysmography
  - Dual energy X-ray absorptiometry (DEXA)
• Health Risks Associated with BMI
Health Risks Associated with Excess Body Weight & Body Fat

- Diabetes
  - Insulin resistance
- Hypertension
- Cardiovascular disease
  - Metabolic Syndrome
- Sleep apnea
- Osteoarthritis

- Some cancers
- Gallbladder disease
- Kidney disease
- Respiratory problems – Pickwickian syndrome
- Complications in pregnancy and surgery
Health Risks Associated with Excess Body Weight & Body Fat

- Obesity and asthma
  - An association exists between obesity and increased prevalence, incidence and severity of asthma
  - Weight loss in obese individuals improves asthma outcomes
  - The mechanism for these observations is not fully known

Health Risks Associated with Excess Body Weight & Body Fat

- Inflammation and the Metabolic Syndrome
  - High blood pressure
  - High blood glucose
  - High blood triglycerides
  - Low HDL cholesterol
  - High waist circumference
Health Risks Associated with Low Body Weight & Inadequate Body Fat

- Lack of energy & nutrient reserves to handle medical stress (disease, illness)
- Menstrual irregularities, infertility, pregnancy complications
- Osteoporosis, bone fractures