CHAPTER 8

Nutrients Involved in Energy Metabolism

Chapter Summary

The B-vitamins involved in energy metabolism include thiamin, riboflavin, niacin, vitamin B_6, folate, vitamin B_{12}, pantothenic acid, biotin, and choline. Except for folate and B_{12}, the B-vitamins primarily act as coenzymes that assist enzymes in the metabolism of carbohydrates, fats, and amino acids. Food sources of B-vitamins include enriched and whole-grain products, meats, dairy products, and some fruits and vegetables. A deficiency of thiamin can cause beriberi, and a deficiency of niacin can cause pellagra. Megadoses of B-vitamin supplements can be toxic. Choline is a vitamin-like substance that assists with homocysteine metabolism and accelerates the release of the neurotransmitter acetylcholine.

Minerals involved in energy metabolism include iodine, chromium, manganese, and sulfur. Iodine is a trace mineral needed for synthesis of thyroid hormones, which regulate metabolic rate, reproduction, and growth. Chromium is a trace mineral that enhances the ability of insulin to transport glucose from the bloodstream into the cell; it is important for the metabolism of RNA and DNA and support of normal growth and development. Manganese is involved in energy metabolism, the formation of urea, synthesis of bone protein matrix and cartilage, and in protecting our bodies from free radicals as a component of the superoxide dismutase antioxidant system. Sulfur is a major mineral that is a component of the B-vitamins thiamin and biotin and also part of the amino acids methionine and cysteine. Sulfur helps stabilize the three-dimensional shapes of proteins and helps the liver detoxify alcohol and various drugs. Inadequate levels of B-vitamins can reduce an individual's ability to perform physical activity. A diet high in processed foods, sugar, and fat is inadequate in B-vitamins.

Nutrition Myth or Fact addresses the question: Treating premenstrual syndrome with vitamin B_6: Does it work? Is it risky?

Learning Objectives

After studying this chapter, the student should be able to:

1. Describe how B-vitamins act as coenzymes to enhance the activities of enzymes involved in energy metabolism (pp. 306–307).
2. Identify the primary roles of thiamin, riboflavin, and niacin in energy metabolism (pp. 308–314).
3. Identify the deficiency disorders associated with thiamin, riboflavin, and niacin (pp. 308–314).

4. Explain how vitamin B_6, folate, and vitamin B_{12} function in energy metabolism and other body functions (pp. 314–323).
5. Discuss the roles of vitamin B_6, folate, and vitamin B_{12} in homocysteine metabolism and their association with cardiovascular disease (pp. 315-316).
6. Explain why adequate folate intake is especially critical during the first several weeks of pregnancy (pp. 318).
7. Describe the roles of pantothenic acid, biotin, and choline in energy metabolism (pp. 323–326).
8. Discuss the roles of iodine, chromium, manganese, and sulfur in energy metabolism (pp. 326–331).
9. Identify the deficiency disorders associated with poor iodine intake (pp. 327–328).
10. Discuss the effect of poor B-vitamin intake on the ability to perform physical activity (pp. 331–333).

Key Terms

acetylcholine	cretinism	hypothyroidism
ariboflavinosis	goiter	intrinsic factor
atrophic gastritis	homocysteine	pellagra
beriberi	hyperthyroidism	

Chapter Outline

I. How Does the Body Regulate Energy Metabolism?

A. The body requires vitamins and minerals to produce energy.

1. The B-vitamins are particularly important in assisting with energy metabolism.

a. Except for B_{12}, B-vitamins are not stored and are lost through urine; therefore, they must be consumed regularly.

2. The primary role of the six B-vitamins is to act as coenzymes, molecules that combine with an enzyme to activate it.

a. Thiamin, riboflavin, niacin, vitamin B_6, pantothenic acid, and biotin function primarily in energy metabolism.

b. The other two B vitamins—folate and vitamin B_{12}—function secondarily in energy metabolism.

3. Four minerals also function in energy metabolism: iodine, chromium, manganese, and sulfur.

B. Some micronutrients assist with nutrient transport and hormone production.

Figures:

Figure 8.1: The B-vitamins play many important roles in reactions involved in energy metabolism.

Table 8.1: Overview of Nutrients Involved in Energy Metabolism

II. How Do Thiamin, Riboflavin, and Niacin Assist in Energy Metabolism?

A. Thiamin (vitamin B_1) was the first B-vitamin discovered.

1. Dietary thiamin is converted into its coenzyme thiamin diphosphate (TDP) ester.
2. Thiamin is important in a number of energy-producing metabolic pathways.
   a. TDP is critical for the breakdown of glucose for energy.
   b. TDP acts as a coenzyme in the metabolism of the branched-chain amino acids.
   c. TDP assists in producing DNA and RNA.
   d. TDP plays a role in the synthesis of neurotransmitters.
2. The RDA is 1.2 mg per day for men and 1.1 mg per day for women; most Americans consume more than adequate amounts.
3. Good food sources include ham and other pork products, sunflower seeds, beans, oat bran, tuna, whole or enriched cereals grains and meat, and soy products.
4. Excess thiamin is readily cleared from the kidneys, so there is no UL.
5. Thiamin-deficiency disease is called beriberi, which results in muscle wasting and nerve damage.
   a. Beriberi is most common when a population subsists on unenriched processed grains.
   b. Alcohol-related thiamin deficiency is known as Wernicke-Korsakoff syndrome and is seen in heavy drinkers with limited food intake.

B. Riboflavin is vitamin B_2.
1. Riboflavin is an important component of two coenzymes involved in oxidation–reduction reactions within the energy-producing metabolic pathways.
   a. The coenzymes FMN and FAD are involved in the metabolism of carbohydrates, fatty acids, and amino acids.
   b. Riboflavin is part of the coenzyme required by the antioxidant enzyme glutathione peroxidase.
2. The RDA is 1.3 mg per day for men and 1.1 mg per day for women; most Americans consume more than adequate amounts.
3. Good food sources include dairy products, eggs, broccoli, organ meats, enriched bread and grain products, and ready-to-eat cereals.
4. There are no known adverse effects from consuming excess riboflavin.
5. Symptoms of riboflavin deficiency, ariboflavinosis, include sore throat; swelling of mucous membranes in the mouth and throat; dry, scaly lips; purple tongue; and dermatitis.

C. Niacin refers to the compounds nicotinamide and nicotinic acid; it was previously designated as vitamin B_3, a name sometimes still displayed on labels.
1. Niacin is essential in the production of two coenzymes, NAD and NADP, which are required for oxidation–reduction reactions in the catabolism of carbohydrate, protein, and fat.
2. Niacin plays an important role in DNA replication and repair and in cell differentiation.
3. The RDA is 16 mg per day of niacin equivalents for men and 14 mg per day for women; most Americans consume more than adequate amounts.
4. Good food sources include meat, fish, poultry, enriched bread, and cereals.
   a. Not only is niacin more available in meats, it can be synthesized in small amounts from tryptophan.

b. Niacin in cereal grains is bound to other substances, and only about 30% is available for absorption.

5. Excessive niacin supplementation can cause toxicity symptoms, including flushing, liver damage, and glucose intolerance.

6. Pellagra, a condition that causes dermatitis, diarrhea, and dementia, results from niacin deficiency.

Key Terms: beriberi, ariboflavinosis, pellagra

Figures:

Figure 8.2: Examples of some metabolic pathways that require B-vitamins for energy production.

Figure 8.3: Structure of thiamine and thiamine diphosphate (TDP).

Figure 8.4: Common sources of thiamine.

Figure 8.5: Structure of riboflavin and its coenzyme forms.

Figure 8.6: Common food sources of riboflavin.

Figure 8.7: Forms of niacin.

Figure 8.8: Common food sources of niacin.

III. How Do Vitamin B_6, Folate, and Vitamin B_{12} Support Energy Metabolism?

A. Vitamin B_6 (pyridoxine) is actually a group of three related compounds.

1. Vitamin B_6 has many functions.
   - **a.** It is a part of a coenzyme for more than 100 enzymes involved in amino acid metabolism.
   - **b.** It plays a critical role in transamination.
   - **c.** It is a coenzyme involved in the synthesis of neurotransmitters.
   - **d.** It is a coenzyme assisting in carbohydrate metabolism, breaking stored glycogen into glucose.
   - **e.** It is needed for the synthesis of heme, which is needed for the production of hemoglobin.
   - **f.** It plays a role in immune function by maintaining lymphocytes and producing antibodies.
   - **g.** It plays a role in the metabolism of other nutrients, including niacin, folate, and carnitine.
   - **h.** B_6 is important for the metabolism of homocysteine, high levels of which have been associated with increased risk of cardiovascular disease.
2. The RDA is 1.3 mg per day for 19- to 50-year-olds and up to 1.7 mg per day after age 51 for men, and 1.5 mg per day for women.
   - **a.** NHANES III data indicates that adults under age 50 are consuming adequate amounts of B_6.
   - **b.** B_6 requirement increases as protein intake increases, although this is not reflected in the RDAs.
3. Good food sources include meat, fish, poultry, organ meats, enriched cereals, white potatoes, starchy vegetables, bananas, and fortified soy-based meat substitutes.
4. Vitamin B_6 supplements have been used to treat conditions such as premenstrual syndrome and carpal tunnel syndrome.
5. Vitamin B_6 supplementation may result in sensory neuropathy and skin lesions.

6. Alcoholism, some prescription medications, intense physical activity, and some chronic diseases increase the need for vitamin B_6.
7. Symptoms of vitamin B_6 deficiency involve the skin, blood, and nervous system and include anemia, convulsions, depression, and dermatitis.

B. Folate is a generic term used for all the various forms of food folate that demonstrate biologic activity.

1. Folate functions in association with coenzymes that act as acceptors and donors of one-carbon units. These enzymes are critical for DNA synthesis, cell differentiation, and amino acid metabolism that occur within the cytosol, nucleus, and mitochondria of cells.
2. It is a critical nutrient during the first few weeks of pregnancy; it is also essential in the synthesis of new cells.
   - **a.** Neural tube defects are associated with low maternal folate intake.
3. Along with vitamin B_{12}, is needed for the regeneration of methionine from homocysteine.
4. Certain factors alter folate digestion, absorption, and balance.
   - **a.** Folate is absorbed through a carrier-mediated process, but some can cross the mucosal cell membrane by diffusion.
   - **b.** The bioavailability of folate varies, depending on its source.
   - **c.** The amount of food folate is expressed in dietary equivalents (DFE) that can be time consuming to calculate.
   - **d.** Red blood cells are a good measure of folate levels over the past 3 months.
5. The RDA for adult men, and women aged 19 years and older, is 400 µg /day, with 600 µg /day recommended for pregnant women.
6. Food sources include ready-to-eat cereals, bread, and other grain products, liver, spinach, lentils, oatmeal, asparagus, and romaine lettuce.
7. There have been no studies suggesting toxic effects from consuming high amounts in folate in foods; however, toxicity can occur with high amounts of supplemental folate ingestion.
8. Folate deficiency can cause many adverse health effects, including macrocytic anemia, high levels of homocysteine in the blood, and neural tube defects in developing fetuses.

C. Vitamin B_{12} (cobalamin), as with the case of folate, is used somewhat generically to describe a number of compounds.

1. It is a part of coenzymes that assist with DNA synthesis, necessary for the proper formation of red blood cells.
2. It is synthesized almost entirely by bacteria in animals. For this reason, plant sources do not generally contain vitamin B_{12}.
3. Absorption is complex and requires the proteins R-binder, intrinsic factor, and transcobalamin II, and the pancreatic proteolytic enzymes.
4. The body stores vitamin B_{12} in the liver, enabling us to survive for months without the need to consume it in our diet.
   - **a.** It is lost from the system in urine and bile.

4\. The RDA for adults of both genders is 2.4 µg per day.

a. Vegans are advised to consume either vitamin B_{12}-fortified foods, or take a supplement or injections to ensure they maintain adequate blood levels of this nutrient.

5. It is found primarily in dairy products, eggs, meats, and poultry.
6. Atrophic gastritis, a chronic inflammatory condition that results in low HCI secretion, can affect B_{12} levels, and is seen in up to 30% of adults over 50.
7. There are no known adverse effects from consuming excess amounts of vitamin B_{12} from foods; data are not available about the risks of toxicity from supplements.
8. Deficiencies are rare but symptoms usually include those associated with anemia, as well as gastrointestinal and neurologic effects.

Key Terms: homocysteine, intrinsic factor, atrophic gastritis

Figures:

Figure 8.9: Structure of the vitamin B_6 compounds and their interconversions to the phosphorylated forms.

Figure 8.10: The body metabolizes methionine, an essential amino acid, to homocysteine.

Figure 8.11: Common food sources of vitamin B_6.

Figure 8.12: Structure of folate.

Figure 8.13: Common food sources of folate and folic acid.

Figure 8.14: Structure of vitamin B_{12}.

Figure 8.15: Digestion and absorption of vitamin B_{12}.

Figure 8.16: Common food sources of vitamin B_{12}.

IV. What Are the Roles of Pantothenic Acid, Biotin, and Choline in Energy Metabolism?

A. Pantothenic acid is metabolized to two major coenzymes: coenzyme A (CoA) and acyl carrier protein (ACP).

1. Pantothenic acid assists with fatty acid oxidation, ketone metabolism, and the metabolism of carbohydrate and protein.
2. It is required for cholesterol and steroid synthesis and drug detoxification.
3. The AI is 5 mg per day for adults.
4. Food sources include chicken, beef, egg yolk, potatoes, oat cereals, tomato products, whole grains, certain mushrooms, and organ meats.
5. There are no known adverse effects from consuming excess amounts of pantothenic acid; deficiencies are very rare.

B. Biotin is a component of four carboxylase enzymes.

1. Biotin is involved in fatty acid synthesis, gluconeogenesis, and carbohydrate, fat, and protein metabolism.
2. The AI for adults is 30 µg per day.
3. Biotin appears to be widespread in foods.
4. There are no known adverse effects from consuming excess biotin.
5. Biotin deficiencies occur only in those who consume a large number of raw egg whites, and deficiency affects the hair, skin, and nervous system.

C. Choline is a vitamin-like substance important for metabolism, cell membrane integrity, and neurotransmission.

1. **1.** Choline plays an important role in the transport and metabolism of fat and cholesterol and the synthesis of phospholipids.
2. **2.** Choline accelerates the synthesis and release of acetylcholine.
3. **3.** The AI is 550 mg per day for men and 425 mg per day for women;
4. **4.** Choline is widespread in foods, including eggs, milk, liver, soybean oil, salmon, mushrooms, and in lecithin.
5. **5.** Inadequate choline intake can lead to increased fat accumulation in the liver and liver damage.
6. **6.** Excessive supplemental choline intake results in a fishy body odor, vomiting, salivation, sweating, diarrhea, and low blood pressure.

Key Term: acetylcholine

Figures:

Figure 8.17: Structure of coenzymes containing pantothenic acid.

Figure 8.18: Common food sources of pantothenic acid.

Figure 8.19: Structure of biotin.

V. How Do Minerals Help Regulate Energy Metabolism?

A. Iodine, a trace mineral, is needed for synthesis of thyroid hormones.

- **1.** Thyroid hormones regulate many metabolic reactions.
- **2.** The RDA is 150 µg per day, and most Americans consume plenty.
- **3.** Good food sources include saltwater fish, shrimp, seaweed, iodized salt, and products made from iodized salt and dairy products.
- **4.** Excess iodine causes many thyroid-related health problems, including goiter.
- **5.** Deficiency causes goiter, cretinism, hypothyroidism, and a variety of neurological disorders.
- **6.** Because such a large number of people live in areas of iodine deficiency, the World Health Organization has named iodine deficiency as the greatest cause of preventable brain damage and retardation.
- **7.** Hypothyroidism, Graves' disease, is caused by high blood levels of thyroid hormone.

B. Chromium is a trace mineral that plays an important role in carbohydrate metabolism.

- **1.** Chromium enhances the ability of insulin to transport glucose into cells.
- **2.** Chromium plays a role in the metabolism of RNA and DNA, in immune function, and in growth.
- **3.** Chromium supplements are marketed to reduce body fat and increase muscle.
- **4.** The AI is 35 µg per day for men and 25 µg per day for women and decreases slightly after age 50; however, it is difficult to determine whether individuals are consuming enough.
- **5.** Food sources include mushrooms, prunes, dark chocolate, nuts, whole grains, asparagus, brewer's yeast, some beers, red wine, and meats.
- **6.** Because there is little research on excessive chromium supplementation, high doses are not recommended.
- **7.** Although chromium deficiency appears to be rare, it causes a rise in glucose, insulin, and blood lipid levels and brain and nerve damage.

C. Manganese is a trace mineral that functions as a cofactor.

1. **1.** Manganese is involved in energy metabolism, gluconeogenesis, cholesterol synthesis, and urea synthesis.
   2. Manganese assists in synthesis of the protein matrix in bone and cartilage.
   3. Manganese is an integral component of superoxide dismutase, an antioxidant.
   4. The AI is 2.3 mg per day for men and 1.8 mg per day for women and is easily attained from foods.
   5. Good sources of manganese include whole-wheat products, pineapple, pine nuts, okra, spinach, and raspberries.
   6. Manganese toxicity results from inhalation or drinking water high in manganese and causes symptoms similar to Parkinson's disease.
   7. Manganese deficiency is rare.

D. Sulfur, a major mineral, is a component of biotin and thiamin.

- **1.** It is necessary for macronutrient metabolism and helps stabilize the three-dimensional shape of proteins.
- **2.** Sulfur is required by the liver to assist in the detoxification of alcohol and drugs and assists in maintaining acid–base balance.
- **3.** The body obtains ample amounts of sulfur from protein-containing foods.
- **4.** There is no DRI for sulfur, and toxicity or deficiency is unknown.

Key Terms: goiter, cretinism, hypothyroidism, hyperthyroidism

Figures:

Figure 8.20: Thyroid hormones contain iodine.

Figure 8.21: Goiter, or enlargement of the thyroid gland, occurs with both iodine toxicity and deficiency.

Figure 8.22: Common food sources of manganese.

IV. Does B-Vitamin Intake Influence the Body's Capacity for Physical Activity?

A. How do researchers compare vitamin status in active and sedentary populations?

- **1.** They compare exercise performance of those with low B-vitamin status to those with good B-vitamin status.
- **2.** They use metabolic diet studies to determine B-vitamin requirements.
- **3.** They conduct cross-sectional studies comparing the B-vitamin status of trained athletes to sedentary individuals.

B. What evidence links exercise performance and B-vitamin status?

- **1.** Classic studies support the hypothesis that inadequate B-vitamin intake reduces work performance.
- **2.** Studies indicate that as B-vitamin status improves, the ability to perform improves.

Activities

1. Divide the class into small groups. Designate a nutrient discussed in this chapter to each group and ask them to write facts about it on index cards. Recommend that they omit RDA, AI, and UL for the nutrient, as there is no reason to memorize this information. Collect the cards and print the facts on a worksheet. Have students match the correct nutrient to each fact.

2. Assign each student or small group of students either a vitamin or mineral. Students should learn the history of the discovery of the vitamin/mineral and the deficiency or toxicity disease and/or conditions that are related to it. Short presentations using some form of audiovisual can be done as each vitamin/mineral is studied in class or as preparation for an exam.
3. Ask students to bring in package labels or information obtained from the Internet on various "stress formula vitamins." Ask them to note the cost of the product, the vitamins and minerals present, additional ingredients present, and the words used to market the product. Discuss with class members why these vitamins are marketed to increase energy and reduce stress. Knowing that the Federal Trade Commission and the FDA regulate the advertising and packaging of these products, discuss how companies can advertise these products as stress relievers and energy boosters.
4. Either bring labels or have students bring labels from unenriched and enriched grain products and whole-grain products. Compare the nutrient content of the three types of products. Discuss the regulations on enriching and fortifying grain products. Discuss why people may believe they are getting plenty of vitamins from the refined products they are consuming.

Diet Analysis Activities

5. Using the nutritional assessment previously completed, have students note their intake of the following nutrients:
   - **a.** thiamin
   - **b.** riboflavin
   - **c.** niacin
   - **d.** vitamin B_6
6. How does your intake of these nutrients compare with recommendations?
   - **a.** Which foods that you eat are major sources of these nutrients?
   - **b.** If you take supplements, do they affect your intake of B-vitamins positively or negatively?
   - **c.** What changes can you make in your diet to more closely meet recommendations?

Nutrition Debate Activity

7. Have students develop a list of popular perceptions about B-vitamins (such as, they aren't stored, so you will get rid of what you don't need with no harm; beer contains plenty of B-vitamins; sports drinks have B-vitamins to improve performance). This list can be generated by asking fellow students what they know about B-vitamins or by perusing the Internet. Then have them sort the statements into facts and myths. Students can debate in small groups, with several students providing factual information, while the other students resist the factual information using anecdotal information. Either as a debate or a role play, students will be able to visualize how difficult it is to change popular perceptions.

Web Resources

Nutrient Data Laboratory Home Page

ndb.nal.usda.gov

UNICEF: Nutrition
www.unicef.org/nutrition

World Health Organization
www.euro.who.int/en/home

National Institutes of Health and Office of Dietary Supplements
www.ods.od.nih.gov

Linus Pauling Institute
lpi.oregonstate.edu