CHAPTER 6

Proteins: Crucial Components of All Body Tissues

Chapter Summary

Proteins are large, complex molecules made up of amino acids that are critical components of all body tissues. Amino acids consist of an amine group, an acid group, a hydrogen atom, and a side chain. Of the 20 amino acids in the body, nine are essential to obtain from food. The structure of protein is dictated by DNA, and all protein contains nitrogen. The sequence of amino acids in each individual protein is determined by our genetic makeup. New proteins are synthesized by RNA transcription and translation. The order of amino acids determines the protein's three-dimensional shape, and shape determines function.

Protein turnover involves synthesis of new proteins and degradation of existing proteins, which contributes to the amino acid pool. Denatured proteins lose their function. Essential amino acids must be consumed regularly, and when one is missing or limited, protein synthesis is limited. Eating complementary proteins provides mutual supplementation of all essential amino acids.

Protein digestion occurs mainly in the stomach and small intestine. Once absorbed, amino acids can then be assembled into the proteins required by the body. Protein quality is determined by amino acid content and digestibility; therefore, animal products, soy, and legumes contain the highest-quality protein. Functions are varied and include cell growth, repair, and maintenance. Proteins act as enzymes and hormones and help maintain fluid/electrolyte balance, acid–base balance, and a strong immune system. They transport and store nutrients and supply energy when fat and carbohydrate are limited. The protein RDA for sedentary people is 0.8 grams per kilogram of body weight per day, or 10–35% of total energy intake. High intake may lead to high blood cholesterol and put added stress on the kidneys in individuals who are susceptible to kidney disease. Good sources of protein include meats, dairy products, eggs, legumes, whole grains, and nuts. There are many reasons for choosing some form of vegetarianism, and vegetarian diets can be healthful if they are well planned. Vegans may need to supplement their diet with several nutrients that are found primarily in animal foods, such as vitamins B_{12} and D, riboflavin, iron, calcium, and zinc. Inadequate protein intake can result in protein-energy malnutrition that may take the form of kwashiorkor or marasmus. Other disorders, such as phenylketonuria, sickle cell anemia, and cystic fibrosis are caused by genetic defects that involve protein.

Nutrition Myth or Fact addresses the question: Are current protein recommendations high enough?

Learning Objectives

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

1. Illustrate the structure of an amino acid molecule including its five essential components (p. 212).
2. Differentiate among essential amino acids, nonessential amino acids, and conditionally essential amino acids (pp. 212–214).
3. Explain how amino acids are assembled to form proteins and the relationship between protein shape and function (pp. 214–221).
4. Discuss how proteins are digested and absorbed by the body (pp. 221–223).
5. Describe at least four functions of proteins in the body (pp. 223–227).
6. Calculate an individual's Recommended Dietary Allowance for protein (p. 230).
7. Discuss the relationship between a high-protein diet and heart disease, bone loss, and kidney disease (pp. 231–233).
8. Identify both animal and plant foods that are excellent sources of dietary protein (pp. 233–237).
9. Discuss the health benefits, challenges, and nutritional quality of a balanced and adequate vegetarian diet (pp. 238-241).
10. Describe two disorders related to inadequate protein intake or genetic abnormalities (pp. 241–243).

Key Terms

acidosis
alkalosis
amino acids
antibodies
buffers
chemical score
complementary proteins
complete proteins
conditionally essential amino acids
cystic fibrosis
deamination
denaturation
edema
essential amino acids
gene expression
incomplete proteins
kwashiorkor
limiting amino acid
marasmus
mutual supplementation
neurotransmitters
nonessential amino acids
nucleotide
pepsin
peptide bonds
pH
proteases
protein digestibility corrected amino acid score
protein-energy malnutrition
proteins
sickle cell anemia
transamination
transcription
translation
transport proteins
vegetarianism

Chapter Outline

I. What Are Proteins?

A. Proteins are large, complex molecules with a variety of critical functions in the body.

B. The building blocks of proteins are amino acids.

1. Amino acids are composed of a carbon atom attached to an amine group, an acid group, a hydrogen atom, and a side chain.

a. The side chain makes each amino acid unique.

2. Most of the body's proteins are made from combinations of 20 amino acids.

C. The body can synthesize only some amino acids.

1. There are nine essential amino acids that the body cannot produce and must obtain from food.

2. There are 11 nonessential amino acids that can be made by the body.

a. Nonessential amino acids are made through transamination, the process of transferring the amine group from one amino acid to another in order to manufacture a new amino acid.

3. In some conditions the body cannot produce a nonessential amino acid, making it a conditionally essential amino acid.

a. Conditionally essential amino acids include arginine, cysteine, glutamine, and tyrosine.

Key Terms: proteins, amino acids, essential amino acids, nonessential amino acids, transamination, conditionally essential amino acid

Nutrition Animation: The Building Blocks of Proteins (located in IR-DVD folder)

Figures and Table:

Figure 6.1: Structure of an amino acid.

Figure 6.2: How proteins differ from starch.

Figure 6.3: Transamination

Table 6.1: Amino Acids of the Human Body

II. How Are Proteins Made?

A. Amino acids bond to form a variety of peptides.

1. Amino acids join together by means of a peptide bond.

a. Two amino acids joined together form a dipeptide.

b. Three amino acids joined together form a tripeptide.

c. Four to nine amino acids are referred to as an oligopeptide.

d. Ten or more amino acids bonded together form a polypeptide.

i. Polypeptides fold into complex shapes, giving proteins their unique structure.

B. Genes regulate amino acid binding.

1. A gene is a segment of deoxyribonucleic acid (DNA) that serves as a template for the synthesis of a particular protein.

a. All cells contain a full set of genes, but individual cells only use some of their genes.

b. Gene expression is the process by which cells use genes to make proteins.

2. The building blocks of genes are nucleotides, which are molecules composed of a phosphate group, a pentose sugar called deoxyribose, and one of four nitrogenous bases: adenine (A), guanine (G), cytosine (C), or thymine (T).

3. Genes are chains of nucleotides held together by hydrogen bonds that link their nitrogenous bases.

a. Each base can bond only to its complementary base: A always bonds to T, and G always bonds to C.

2. Proteins are manufactured through transcription and translation.
    a. Through the process of DNA replication, DNA provides the instructions for building every protein in the body.
    b. Messenger RNA transcribes information from DNA and carries the information to the ribosomes.
    c. Messenger and transfer RNA translate information so that new proteins are built.
3. The sequence of amino acids in a protein determines its shape and function.
    a. Genetic abnormalities occur when DNA contains errors in nucleotide sequencing or when mistakes occur in sequencing.
    b. Not all genes are expressed, and each cell does not make every protein, although the DNA for making every protein is contained in every cell nucleus.

C. Protein turnover involves synthesis of new proteins and degradation of existing proteins in response to physiologic needs.

1. Amino acids needed to build new proteins and cells are obtained from the amino acid pool.
2. The amino acid pool includes amino acids from digested food and those released from the breakdown of other foods.
3. Amino acids are also used to produce glucose, fat, and urea.

D. Protein organization determines function.

1. Four levels of protein structure create unique shapes and function.
    a. The primary structure is formed by the sequence of amino acids in the chain.
    b. The amino acids in the chain create the spiral shape, stabilized by hydrogen or sulfur bonds, of the secondary structure.
    c. The three-dimensional, or tertiary structure, determines the function of the protein.
    d. Two or more polypeptides bond to form an even larger protein with a quaternary structure, which may be globular or fibrous.
        i. Globular proteins have entirely different structure and functions than fibrous proteins.

E. Protein denaturation affects shape and function.

1. Proteins lose their shape when exposed to heat or damaging substances.
2. Denatured proteins lose their function.

F. Protein synthesis can be limited by missing amino acids.

1. All essential amino acids must be available for protein synthesis to occur.
2. The amino acid that is missing or in the smallest supply is the limiting amino acid.
3. Without the proper amount of essential amino acids and energy, proteins cannot be made.
4. An incomplete protein does not contain all of the essential amino acids in sufficient amounts to support growth and health.
5. A complete protein contains all nine essential amino acids.

G. Protein synthesis can be enhanced by mutual supplementation.

1. Complementary proteins from food sources can be combined to simulate a complete protein.

2. Complete proteins can be synthesized from a combination of the amino acids in an incomplete protein and those in the pool.
3. Mutual supplementation from food on a daily basis is advisable for vegetarians.

Key Terms: peptide bond, gene expression, nucleotide, transcription, translation, denaturation, limiting amino acid, incomplete proteins, complete proteins, mutual supplementation, complementary proteins

Nutrition Animation: Protein Synthesis (located in IR-DVD folder)

Figures:

Figure 6.4: Amino acid bonding.

Figure 6.5: The double helix of DNA.

Figure 6.6: Protein synthesis

Figure 6.7: Protein turnover involves the synthesis of new proteins and the breakdown of existing proteins.

Figure 6.8: Levels of protein structure.

Figure 6.9: Protein shape determines function.

Figure 6.10: Combining Complementary Foods

III. How Does the Body Break Down Proteins?

A. Stomach acids and enzymes break proteins into short polypeptides.

1. Hydrochloric acid in the stomach begins protein digestion by denaturing the protein.
2. Hydrochloric acid also converts inactive pepsinogen to pepsin, a protein-digesting enzyme.
3. Gastrin controls the production of hydrochloric acid and the secretion of pepsin.
4. Via hydrolysis, pepsin breaks proteins into single amino acids and polypeptides, which then travel into the small intestine.

B. Enzymes in the small intestine break polypeptides into single amino acids.

1. Proteases from the pancreas and small intestine continue the breakdown of polypeptides in the small intestine.
2. Amino acids, dipeptides, and tripeptides are absorbed into the cells of the intestinal wall.
3. Enzymes in the intestinal cells further break down dipeptides and tripeptides into single amino acids.
4. Amino acids are transported to the liver to be converted to glucose or fat, combined to build new proteins, used for energy, or released into the bloodstream and transported to other cells as needed.
5. Single amino acids taken in supplement form on an empty stomach can prevent absorption of other amino acids causing deficiencies.

C. Protein quality is affected by amino acid content and digestibility.

1. A number of methods are used to estimate a food's protein quality including a chemical score.
2. Digestibility can be calculated by using the protein digestibility corrected amino acid score (PDCAAS).
3. Digestibility of a protein is highest in animal products and soy products.

Key Terms: pepsin, proteases, chemical score, protein digestibility corrected amino acid score (PDCAAS)

Nutrition Animations: Protein Absorption; Protein Digestion (located in IR-DVD folder)

Figure:

Figure 6.11: Protein Digestion Overview

IV. Why Do We Need Proteins?

A. Proteins contribute to cell growth, repair, and maintenance.

1. Cells are constantly being broken down, repaired, and replaced.

2. When proteins are broken down, many amino acids are recycled into new proteins.

B. Proteins act as enzymes and hormones.

1. Enzymes are compounds—usually proteins—that speed up chemical reactions without being changed by the chemical reactions themselves.

a. Enzymes can increase the rate at which reactants bond, break apart, or exchange components.

b. Thousands of enzymes facilitate cellular reactions.

2. Some hormones are made of amino acids or peptides.

C. Proteins help maintain fluid and electrolyte balance.

1. Electrolytes are electrically charged atoms (ions) that assist in maintaining fluid balance.

2. Proteins attract fluid.

3. When protein intake is deficient, it can cause edema.

4. Transport proteins in the cell membrane help to maintain the proper balance of sodium and potassium inside and outside the cell.

D. Proteins help maintain acid–base balance.

1. Proteins are excellent buffers and help to maintain a constant blood pH.

2. Acidosis and alkalosis denature proteins, which can result in coma or death.

E. Proteins help maintain a strong immune system.

1. Antibodies are proteins that defend the body against antigens like bacteria, viruses, toxins, and allergens.

2. Each antibody is designed to defend against a specific antigen, which is typically made of protein as well.

3. Immunity is the rapid response of antibodies to antigens that the body remembers from past encounters.

F. Proteins serve as an energy source.

1. In healthy people, protein contributes little to energy needs.

2. When proteins are needed for energy, they are taken from the blood and body tissues.

3. To use proteins for energy, deamination removes the nitrogen so that the remaining carbon, hydrogen, and oxygen can be used to produce glucose and other energy-producing compounds.

4. To protect the body tissues, it is important to eat an adequate amount of fat and carbohydrate to provide energy.

5. Since the body cannot store excess protein, it uses non-nitrogen components for immediate or stored energy.

G. Proteins assist in the transport and storage of nutrients.

1. Proteins carry nutrients through the bloodstream and through cell membranes.

2. Proteins attach to nutrients to create storage forms, as is the case with ferritin which stores iron in the liver.

H. Proteins play many other roles.

1. Amino acids can be used to make neurotransmitters, which transmit messages from one nerve cell to another.

2. Assist in blood clotting.

3. Make up connective tissue.

Key Terms: edema, transport proteins, acidosis, alkalosis, buffers, antibodies, deamination, neurotransmitters

Nutrition Animation: Deamination and Transamination (located in IR-DVD folder)

Figures:

Figure 6.12: The role of proteins in maintaining fluid balance.

Figure 6.13: Transport proteins help maintain electrolyte balance.

Figure 6.14: Urea excretion.

V. How Much Protein Should We Eat?

A. Nitrogen balance is a method used to determine protein needs.

1. Nitrogen balance studies are mostly done in research.

2. People who consume more nitrogen than is excreted are considered to be in positive nitrogen balance.

a. Indicates that the body is retaining or adding protein

b. Occurs during periods of growth, recovery from an illness, or protein deficiency.

3. Negative nitrogen balance occurs when people excrete more nitrogen than they consume.

a. Indicates that the body is losing protein.

b. Occurs during starvation, low-energy diets, during illness, infection, high fever, serious burns or significant blood loss.

4. When nitrogen intake equals nitrogen excretion, nitrogen balance exists.

B. Recommended Dietary Allowance (RDA) for protein varies with lifecycle and lifestyle.

1. The RDA for sedentary people is 0.8 grams per kilogram of body weight per day.

2. The recommended percentage of energy that should come from protein is 10–35% of total energy intake.

3. Protein needs are higher for some groups, such as children, adolescents, pregnant or lactating women, vegetarians, and athletes.

C. Most Americans meet or exceed the RDA for protein.

1. Surveys indicate that Americans eat 16% of their total daily energy intake as protein.

2. People who limit their caloric intake need to pay close attention to their protein intake.

D. Too much dietary protein can be harmful.

1. High protein intake is associated with high cholesterol.

a. Despite conflicting opinions, nutrition experts stress that consuming proteins sources low in saturated fat many help lower risk for cardiovascular disease.

2. The theory that high protein intake contributes to bone loss is still controversial.
3. High protein intake can increase the risk for kidney disease in those who are susceptible.
   a. Healthy individual can consume 2 grams of protein per kilogram body weight with no ill effects.
   b. People who consume excessive protein need to consume adequate fluid to flush urea from the kidneys.

E. A variety of foods are good sources of protein.

1. Good protein sources include meats, dairy products, soy products, legumes, whole grains, and nuts.
2. Legumes provide a variety of nutrients and may help lower cholesterol.
3. Although nuts are high in fat, their consumption has been associated with reduced risk of cardiovascular disease.
4. "New" sources of protein include quorn, quinoa, amaranth, teff, mille, and sorghum.
5. There is little evidence that orally taking amino acid supplements can build muscle or improve strength.

Nutrition Animations: Nitrogen Balance; Fat Synthesis from Excess Protein (located in IR-DVD folder)

Figure and Tables:

Figure 6.15: Nitrogen balance describes the relationship between how much nitrogen (protein) we consume and how much we excrete each day.

Figure 6.16: Maximizing Healthy Protein Intake

Table 6.2: Recommended Protein Intakes

Table 6.3: Protein Content of Commonly Consumed Foods

VI. Can a Vegetarian Diet Provide Adequate Protein?

A. Vegetarianism is the practice of restricting the diet mostly or entirely to foods of plant origin.

B. There are many types of vegetarian diets.

1. Vegetarian diets are varied regarding what types of foods are excluded.
2. The more restrictive the diet, the more challenging it becomes to achieve adequate nutrient intake, including protein.

B. Why do people become vegetarians?

1. Some are vegetarians for religious, ethical, and food-safety reasons.
   a. Some feel it is morally and ethically wrong to consume animals and animal products due to inhumane modern farming practices.
   b. Some are concerned about the safety of animal foods.
2. Some vegetarians are concerned about the effect of the meat industry on the global environment.
3. Some become vegetarians due to demonstrated health benefits.
   a. Vegetarians have a reduced risk for obesity and possibly type 2 diabetes.

b. Vegetarians have lower blood pressure.
c. Vegetarians have reduced risk of heart disease.
d. Vegetarians have fewer digestive problems.
e. Vegetarians have reduced risk of some cancers.
f. Vegetarians have reduced risk of kidney disease, kidney stones, and gallstones.

C. What are the challenges of a vegetarian diet?

1. There is a potential for inadequate intake of certain nutrients.
2. A switch to vegetarianism by female athletes may be a sign of disordered eating.
3. It is important for vegetarians and non-vegetarians to consume a balanced and adequate diet.
4. Appropriate planning can result in a healthful and nutritionally adequate vegetarian diet.

D. Eating tips for vegetarians are available at MyPlate online. This information can help vegetarians achieve the RDA for protein and other nutrients that may be inadequate.

Key Term: vegetarianism

Tables:

Table 6.4: Terms and Definitions of a Vegetarian Diet

Table 6.5: Nutrients of Concern in a Vegan Diet

VII. What Disorders Are Related to Protein Intake or Metabolism?

A. Protein-energy malnutrition can lead to debility and death.

1. Marasmus is a disease that results from grossly inadequate intakes of protein, energy, and other nutrients.
   - **a.** It is most commonly seen in young children living in impoverished conditions.
   - **b.** Consequences of marasmus include muscle wasting, stunted growth and development, deterioration of the intestinal lining, anemia, weakened immune function, fluid electrolyte imbalances, heart failure, and death.
2. Kwashiorkor results from a low-protein diet.
   - **a.** It is typically seen in young children who are weaned from breast milk early and fed mostly cereal.
   - **b.** Consequences of kwashiorkor include weight loss; muscle wasting (with some body fat retention); retarded growth and development; edema; fatty liver; skin sores, and dry brittle hair.
   - **c.** Kwashiorkor can be reversed with adequate protein.
3. Protein-energy malnutrition occurs in developed countries in individuals who experience severe poverty, eating disorders, and some diseases.

B. Many disorders are related to genetic abnormalities.

1. Phenylketonuria is an inherited disease in which a person does not have the ability to break down the amino acid phenylalanine.
   - **a.** Phenylalanine and its metabolic by-products build up in tissues and cause brain damage.
2. Sickle cell anemia is an inherited disorder caused by a change in a single amino acid of the hemoglobin in red blood cells.

3. Cystic fibrosis is an inherited disease that primarily affects the respiratory system and digestive tract.
    a. An abnormal protein prevents the normal passage of chloride into and out of certain cells.
    b. The disease causes breathing difficulties, lung infections, and digestion problems that lead to nutrient deficiencies.

Key Terms: protein-energy malnutrition, marasmus, kwashiorkor, sickle cell anemia, cystic fibrosis

Figures:

Figure 6.17: Two forms of protein-energy malnutrition.

Figure 6.18: A sickled red blood cell.

Activities

1. To illustrate adequate protein intake in terms of food, set up the following example using an average-sized person and ounce-equivalent servings. This is best presented on the board so that students actually see it develop. As you progress through the assignment, you may want to explain what an ounce of grain or meat is in ounce-equivalent servings. Note: This example is set up for non-vegetarians.

    Let's use an average-sized healthy 20-year-old person for our illustration. This person weighs 150 pounds, which is 68 kilograms. An adult needs between 0.8 g/kg and 1.7g/kg protein (non-vegetarian strength athlete). Doing the math, our 20-year-old needs between 54 and 116 g of protein. Using ounce-equivalent servings as a guide for a sedentary 20-year-old female and an extremely active 20-year-old male, we will determine the range of servings for each food group that provides protein and the range of protein contributed by that group.

Food Group	Protein Servings	(approximate g)
Grains	6–10 oz	12–20
Vegetables	2 1/2–4 cups	5–8
Milk	3 cups	24
Meat	5.5–7 oz	38.5–49
Total	79.5–101 g	

    As you can see, this suggests more than enough food to exceed daily protein needs for a sedentary individual, and adequate amount for a normally active person. However, a strong athlete will need to add a small amount of high-protein food to achieve an adequate level of protein intake.

2. Before lecturing on vegetarian diets, ask students to share their experiences and thoughts on vegetarianism. You will have members of the class who have practiced vegetarianism or who are close to someone who does. Ask for insights on reasons for choosing the diet, related health issues, and barriers to practicing vegetarianism. Make a list of beliefs that arise during this discussion. Then work with the class to separate the myth from the truth.

3. Have students work in small groups to plan a menu that meets their RDA for protein. Table 6.3 can help determine the amount of protein in each food. Once the menu is developed, ask students to omit all animal foods and determine if there is still adequate protein in the diet. (As this is a common practice of teens who proclaim themselves

vegetarian, it makes a valid point.) Now have students adapt the menu to meet the protein needs of the vegan. Discuss how variations of the vegetarian diet (pescovegetarian, lacto-ovo-vegetarian, fruitarian, and so on) make it easier or more difficult to consume adequate protein and consume a healthy diet.

4. Instruct students to gather information on high-protein weight-loss diets and products. Have students work in small groups to evaluate the value and safety of these weight-loss methods. Students should note how the cost of these methods compares with the cost of low-fat diets.

5. Bring samples (or have students bring samples) of the most popular protein bars and/or beverages on the market. In addition, bring inexpensive food sources of protein (nuts, soy nuts, tuna, and so on). Have students compare price, quality, amount of protein, additional nutrients, and taste of the samples. Have students rank the samples in terms of value for the amount and quality of protein as well as additional nutrients. This would be a good time to discuss whey and soy protein.

Diet Analysis Activity

6. Using the nutritional assessment previously completed, students should note the following:

a. How many grams of protein do you consume daily?
b. What percentage of your daily Calories comes from protein? Is this percentage within the range recommended in the text?
c. Does your protein intake meet recommendations according to the analysis? If you are an athlete, does it meet your protein requirements according to the text?
d. What three foods that you consumed contained the highest amount of protein? How many grams of protein were in each food?
e. What changes can you make in your diet to more closely meet protein recommendations?

Nutrition Debate Activity

7. Protein and amino acid supplements are very appealing to athletes, and many will not be convinced that food sources of protein are best. Have students research the arguments for and against the use of protein and amino acid supplements in both the popular literature and the professional literature. Divide students into role-play groups of 3 to 5. One or two students take the role of the athlete, one or two take the role of the nutrition expert, and one student observes. The nutrition experts will try to explain the best science behind using food for protein. The athletes will debate the value of supplements from the popular literature point of view. Give students five minutes for the role play. The observer will then lead a discussion on the difficulty of changing this popular perception.

Web Resources

Academy of Nutrition and Dietetics
www.eatright.org

USDA Food and Nutrition Information Center
www.fnic.nal.usda.gov

Centers for Disease Control and Prevention
www.cdc.gov

World Health Organization Nutrition Site
www.who.int/nutrition/en

MEDLINE Plus Health Information
www.nlm.nih.gov/medlineplus

Vegetarian Resource Group
www.vrg.org

MyPlate.gov
www.choosemyplate.gov/tips-vegetarians

Meatless Monday Campaign
www.meatlessmonday.com