The word protein comes from the Greek proteios, meaning “of primary importance.” Proteins are essential to every cellular function. Proteins catalyze chemical reactions, are fundamental components of skeletal and muscular tissue, and are vital to immune response. The generation, development, processing, and renewal of protein resources are major human activities.

Although protein is found in plants and animals, Western cultures fulfill most of their protein needs from animal products. As affluence increases in non-Western societies, those societies adopt Western habits, including increasing the amount of beef in their diets, placing greater demands on agriculture to provide grain
for cattle, which will convert it to the preferred beef protein.

Today, agricultural production is facing a challenge from biofuels. In the United States, more and more grain crops are being grown not as food but as biofuel. One may argue that it is inefficient to feed grain to cattle in order to consume beef protein, but at least this process is a nutrition cycle. Corn that is converted into ethanol to fuel an automobile feeds no one. Obtaining enough protein and maintaining an adequate balance of plant and animal protein for the world's population, like protein itself, is clearly of primary importance.

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- Protein Structure
  - What a Scientist Sees: Phenylketonuria

Protein Digestion and Absorption 173

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Meeting Protein Needs 183
- Balancing Protein Intake and Losses
- Recommended Protein Intake
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CHAPTER PLANNER
- Stimulate your interest by reading the opening story and looking at the visual.
- Scan the Learning Objectives in each section:
- Read the text and study all figures and visuals. Answer any questions.

Analyze key features
- Nutrition InSight, p. 170  p. 175  p. 176
- What a Scientist Sees, p. 171
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- Thinking It Through, p. 192
- Stop: Answer the Concept Checks before you go on:

End of chapter
- Review the Summary, Key Terms, and Online Resources.
- Answer the Critical and Creative Thinking Questions.
- Answer What is happening in this picture?
- Complete the Self-Test and check your answers.
When we think of protein, we usually think of a steak, a plate of scrambled eggs, or a glass of milk. These animal foods provide the most concentrated sources of protein in our diet, but plant foods such as grains, nuts, and legumes are also important sources of dietary protein. The proteins found in plants are made up of different combinations of amino acids than proteins found in animals. Because of this difference, most plant proteins are not used as efficiently as animal proteins to build proteins in the human body. Nevertheless, a diet that includes a variety of plant proteins can easily meet most people’s protein needs.

The sources of protein in your diet have an impact not only on the amount of protein and variety of amino acids available to your body but also on what other nutrients you are consuming (Figure 6.1). Animal products provide B vitamins and readily absorbable sources of minerals, such as iron, zinc, and calcium. They are low in fiber, however, and are often high in saturated fat and cholesterol—a nutrient mix that increases the risk of heart disease.

Plant sources of protein provide most, but not all, B vitamins and also supply iron, zinc, and calcium, but often these are in less absorbable forms. Plant foods are generally excellent sources of fiber, phytochemicals, and unsaturated fats—dietary substances that promote health. Recommendations for a healthy diet, including the Dietary Guidelines and MyPlate, suggest that our diets be based on whole-grain products, vegetables, and fruits and include smaller amounts of meats and dairy products. Following these guidelines will provide plenty of protein from a mixture of plant and animal sources.

### CONCEPT CHECK

1. **Which** is higher in protein: an egg or a cup of rice?
2. **What** nutrients are plentiful in meat and milk? in grains and legumes?

### Animal versus plant proteins • Figure 6.1

a. Animal products are high in protein, iron, zinc, and calcium but also add saturated fat and cholesterol to the diet.

b. Plant sources of protein are rich in fiber, phytochemicals, and monounsaturated and polyunsaturated fats.
The Structure of Amino Acids and Proteins

LEARNING OBJECTIVES

1. **Describe** the general structure of an amino acid and of a protein.
2. **Distinguish** between essential and nonessential amino acids.
3. **Discuss** how the order of amino acids in a polypeptide chain affects protein structure.
4. **Explain** how a protein’s structure is related to its function.

What do the proteins in a lamb chop, a kidney bean, and your thigh muscle have in common? They are all constructed of amino acids linked together to form one or more folded, chainlike strands. Twenty amino acids are commonly found in proteins. Each kind of protein contains a different number, combination, and sequence of amino acids. These differences give proteins their specific functions in living organisms and their unique characteristics in foods.

Amino Acid Structure

Each amino acid consists of a carbon atom that is bound to a hydrogen atom; an amino group, which contains nitrogen; an acid group; and a side chain (Figure 6.2a on next page). The nitrogen in amino acids distinguishes protein from carbohydrate and fat; all three contain carbon, hydrogen, and oxygen, but only protein contains nitrogen. The side chains of amino acids vary in size and structure; they give different amino acids their unique properties.

Nine of the amino acids needed by the adult human body must be consumed in the diet because they cannot be made in the body (Figure 6.2b). If the diet is deficient in one or more of these **essential amino acids** (also called **indispensible amino acids**), the body cannot make new proteins without breaking down existing proteins to provide the needed amino acids. The other 11 amino acids that are commonly found in protein are **nonessential, or dispensable, amino acids** because they can be made in the body.

Under certain conditions, some of the nonessential amino acids cannot be synthesized in sufficient amounts to meet the body's needs. These are therefore referred to as **conditionally essential amino acids**. For example, the amino acid tyrosine can be made in the body from the essential amino acid phenylalanine. In individuals who have the inherited disease **phenylketonuria (PKU)**, phenylalanine cannot be converted into tyrosine, so tyrosine is an essential amino acid for these individuals (see What a Scientist Sees on page 171).

Protein Structure

To form proteins, amino acids are linked together by **peptide bonds**, which join the acid group of one amino acid to the amino group of another amino acid (Figure 6.2c). Many amino acids bonded together constitute a **polypeptide**. A protein is made up of one or more polypeptide chains that are folded into three-dimensional shapes. The order and chemical properties of the amino acids in a polypeptide determine its final shape because the folding of the chain occurs in response to forces that attract or repel amino acids from one another or from water (Figure 6.2d). The folded polypeptide chain may constitute the final protein, or it may join with several other folded polypeptide chains to form the final structure of the protein (Figure 6.2e).

The shape of a protein is essential to its function. For example, the elongated shape of the protein collagen, found in connective tissue, helps it give strength to tendons and ligaments. The spherical shape of the protein hemoglobin...
a. The general structure of an amino acid.

Amino group

Hydrogen

Acid group

Side chain, which is unique to each amino acid

b. Twenty amino acids are commonly found in proteins. The table shown here lists them based on whether they are essential or nonessential and indicates those that are conditionally essential.

<table>
<thead>
<tr>
<th>Essential Amino Acids</th>
<th>Nonessential Amino Acids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Histidine</td>
<td>Alanine</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>Arginine*</td>
</tr>
<tr>
<td>Leucine</td>
<td>Asparagine</td>
</tr>
<tr>
<td>Lysine</td>
<td>Aspartic acid</td>
</tr>
<tr>
<td>Methionine</td>
<td>Cysteine*</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>Glutamic acid</td>
</tr>
<tr>
<td>Threonine</td>
<td>Glutamine*</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>Glycine*</td>
</tr>
<tr>
<td>Valine</td>
<td>Proline*</td>
</tr>
<tr>
<td>Serine</td>
<td>Tyrosine*</td>
</tr>
</tbody>
</table>

*Considered conditionally essential by the Institute of Medicine, Food and Nutrition Board

c. Amino acids linked by peptide bonds are called **peptides**. When two amino acids are linked, they form a **dipeptide**; three form a **tripeptide**. Many amino acids bonded together constitute a polypeptide. Polypeptide chains may contain hundreds of amino acids.

d. The order and chemical properties of the amino acids in a polypeptide chain determine how the polypeptide folds and, hence, the three-dimensional shape of the protein.
When the shape of a protein is altered, the protein no longer functions normally. For example, when the enzyme salivary amylase, which is a protein, enters the stomach, the acid causes the structure of the protein to change, and it no longer functions in the digestion of starch. This change in structure is called denaturation, referring to a change from the natural. Proteins in food are often denatured during processing and cooking (Figure 6.3).

Phenylketonuria

This warning on a can of diet soda probably doesn’t mean much unless you have the genetic disease phenylketonuria (PKU). Individuals with PKU must limit their intake of the amino acid phenylalanine. Usually this means limiting their consumption of high-protein foods. When a scientist looks at this label, she recognizes that the artificial sweetener aspartame in this soda is the source of the phenylalanine. The breakdown of aspartame in the digestive tract releases phenylalanine, which cannot be properly metabolized by individuals with PKU. If they consume large amounts of this amino acid, compounds called phenylketones build up in their blood. In infants and young children, phenylketones interfere with brain development, and in pregnant women they cause birth defects in the baby. To prevent this, these individuals must consume a diet that provides just enough phenylalanine to meet the body’s needs but not so much that phenylketones build up in their blood.

Phenylketonuria: Contains phenylalanine

Phenylalanine

Dietary Protein

Phenylketonuria

Aspartame

Normal metabolism

Tyrosine

Reaction blocked

Phenylketone

Toxic to the brain

Think Critically

Why do you think this warning appears on diet soda labels but not on labels for high-protein foods such as meat and milk?

When the shape of a protein is altered, the protein no longer functions normally. For example, when the enzyme salivary amylase, which is a protein, enters the stomach, the acid causes the structure of the protein to change, and it no longer functions in the digestion of starch. This change in structure is called denaturation, referring to a change from the natural. Proteins in food are often denatured during processing and cooking (Figure 6.3).

Concert Check

1. Which chemical elements are found in all amino acids?
2. What determines whether an amino acid must be consumed in the diet?
3. What determines the shape of a protein?
4. How does denaturation affect the function of proteins?
Protein must be broken down into small peptides and amino acids to be absorbed into the mucosal cells.

1. In the mouth, chewing begins the mechanical breakdown of protein.

2. In the stomach, hydrochloric acid and the enzyme pepsin begin the chemical digestion of protein.

3. In the small intestine, protein-digesting enzymes secreted from the pancreas, along with those in the microvilli, break down polypeptides into amino acids, dipeptides, and tripeptides.

4. A variety of transport proteins move the products of protein digestion into the mucosal cell. Some amino acids share the same transport system. In this figure, the larger number of the amino acids shown in purple means that more purple than green amino acids cross the membrane into the cell.

5. Dipeptides and tripeptides can enter the mucosal cell. Once inside, they are broken down into single amino acids.

6. Amino acids pass from the mucosal cell into the blood and travel to the liver, which regulates the distribution of amino acids to the rest of the body.

7. Little dietary protein is lost in the feces.

Ask Yourself

The amino acids shown in purple are absorbed by the same transport system as those shown in green. If you consume a sports drink that is supplemented with the ones shown as green, what will happen to the absorption of the purple ones?

a. Nothing will happen.

b. The larger number of green ones will limit the absorption of the purple ones.

c. The small number of purple ones will be absorbed first.

d. Both will be absorbed equally because the body needs them.
Protein Digestion and Absorption

LEARNING OBJECTIVES

1. Describe the process of protein digestion.
2. Discuss how amino acids are absorbed.

Proteins must be digested before their amino acids can be absorbed into the body (Figure 6.4). The chemical digestion of protein begins in the acid environment of the stomach. Here, hydrochloric acid denatures proteins, opening up their folded structure to make the polypeptide chains more accessible for breakdown by enzymes. Stomach acid also activates the protein-digesting enzyme pepsin, which breaks some of the peptide bonds in the polypeptide chains, leaving shorter polypeptides. Most protein digestion occurs in the small intestine, where polypeptides are broken into even smaller peptides and amino acids by protein-digesting enzymes produced in the pancreas and small intestine. Single amino acids, dipeptides, and tripeptides are absorbed into the mucosal cells of the small intestine.

Amino acids enter your body by crossing from the lumen of the small intestine into the mucosal cells and then into the blood. This process involves one of several energy-requiring amino acid transport systems. Amino acids with similar structures use the same transport system (see Figure 6.4). As a result, amino acids may compete with one another for absorption. If there is an excess of any one of the amino acids sharing a transport system, more of it will be absorbed, slowing the absorption of competing amino acids. This competition for absorption is usually not a problem because foods contain a variety of amino acids, none of which are present in excessive amounts. However, when people consume amino acid supplements, the supplemented amino acid may overwhelm the transport system, reducing the absorption of other amino acids that share the same transport system. For example, weight lifters often take supplements of the amino acid arginine. Because arginine shares a transport system with lysine, large doses of arginine can inhibit the absorption of lysine, upsetting the balance of amino acids in the body.

CONCEPT CHECK

1. Where does the chemical digestion of protein begin?
2. Why might supplementing one amino acid reduce the absorption of other amino acids?

Protein Synthesis and Functions

LEARNING OBJECTIVES

1. Discuss the steps involved in synthesizing proteins.
2. Explain what is meant by the term limiting amino acid.
3. Name four functions of body proteins.
4. Describe the conditions under which the body uses protein to provide energy.

As discussed earlier, proteins are made from amino acids. Amino acids are also used to make other nitrogen-containing molecules, including neurotransmitters; the units that make up DNA and RNA; the skin pigment melanin; the vitamin niacin; creatine phosphate, which is used to fuel muscle contraction; and histamine, which causes blood vessels to dilate. In some situations, amino acids from proteins are also used to provide energy or synthesize glucose or fatty acids.

The amino acids available for these functions come from the proteins consumed in the diet and from the
This causes more ferritin to be synthesized and allows the body to store extra iron in this protein. When the diet is low in iron, the production of ferritin is suppressed so that the body doesn't waste amino acids and energy making large amounts of a protein that it doesn’t need.

**Limiting amino acids** During the synthesis of a protein, a shortage of one amino acid can stop the process. This is similar to an assembly line, where if one part is missing, the line stops; a different part cannot be substituted. If the missing amino acid is a nonessential amino acid, it can be made in the body, and protein synthesis can continue. Most nonessential amino acids are made through a process called **transamination**, which involves transferring the amino group from one amino acid to a carbon-containing molecule to form the needed amino acid (Figure 6.6a). If the missing amino acid is an essential amino acid, the body cannot make the amino acid, but it can break down its own protein to obtain it. If an amino acid cannot be supplied, protein synthesis will stop.

### Amino acid pool • Figure 6.5

Amino acids enter the available pool from the diet and from the breakdown of body proteins. Of the approximately 300 grams of protein synthesized by the body each day, only about 100 g are made from amino acids consumed in the diet. The other 200 g are produced by the recycling of amino acids from protein broken down in the body. Amino acids in the pool can be used to synthesize body proteins and other nitrogen-containing molecules, to provide energy, or to synthesize glucose or fatty acids.

- **Dietary proteins**
- **Protein breakdown**
- **Protein synthesis**
- **Energy**
- **Synthesis of glucose or fatty acids**
- **Synthesis of nonprotein molecules that contain nitrogen**
- **Ask Yourself**

The amino acids in the amino acid pool come from _______ and _______.

---

**green box**

**The amino acids in the amino acid pool come from _______ and _______.**

---

**green box**

**The instructions for making proteins are contained in the nucleus of the cell in stretches of DNA called **genes**. When a protein is needed, the process of protein synthesis begins, and the information contained in the gene is used to make the necessary protein (Figure 6.6).

**Regulating protein synthesis** The types of proteins made and when they are made are carefully regulated by increasing or decreasing **gene expression**. When a gene is expressed, the protein it codes for is made. Not all genes are expressed in all cells or at all times; only the proteins that are needed are made at any given time. This allows the body to save energy and resources. For example, when your diet is high in iron, expression of the gene that codes for the protein ferritin, which stores iron, is increased.

**Ask Yourself**

The amino acids in the amino acid pool come from _______ and _______.
a. Protein is synthesized from amino acids. These protein building blocks come from the diet and from the breakdown of body proteins.

b. The instructions for protein synthesis come from genes. The process of protein synthesis involves transcription and translation.

1. The first step in protein synthesis occurs inside the nucleus. It involves transferring, or transcribing, the blueprint or code for the protein from the DNA gene into a molecule of messenger RNA (mRNA). This process is called transcription.

2. The mRNA takes the genetic information from the nucleus of the cell to structures called ribosomes in the cell fluid, where proteins are made.

3. Transfer RNA reads the genetic code and delivers the needed amino acids to the ribosome to form a polypeptide chain. This process is called translation.

c. The amino acids needed for protein synthesis come from the amino acid pool. If the protein to be made requires more of a particular amino acid than is available, that amino acid limits protein synthesis and is referred to as the limiting amino acid.
provide different combinations of amino acids. The limiting amino acid in a food is the one supplied in the lowest amount relative to the body’s need. For example, lysine is the limiting amino acid in wheat, whereas methionine is the limiting amino acid in beans. When the diet provides adequate amounts of all the essential amino acids needed to synthesize a specific protein, synthesis of the polypeptide chains that make up the protein can be completed.

**Proteins Provide Structure and Regulation**

When you think of the protein in your body, you probably think of muscle, but muscle contains only a few of the many types of proteins found in your body. There are more than 500,000 proteins in the human body, each with a specific function. Some perform important structural roles, and others help regulate specific body processes.

Structural proteins are found in skin, hair, ligaments, and tendons (Figure 6.7a). Proteins also provide structure to individual cells, where they are an integral part of the cell membrane, cell fluid, and organelles. Proteins such as enzymes, which speed up biochemical reactions (Figure 6.7b), and transport proteins that travel in the blood or help materials cross membranes, regulate processes throughout the body (Figure 6.7c).

**Nutrition InSight**

**Protein functions**

- **a.** Collagen, which is the most abundant protein in the body, plays important structural roles. It is the major protein in ligaments, which hold our bones together, and in tendons, which attach muscles to bones, and it forms the protein framework of bones and teeth.

- **b.** Enzymes, such as this one, are protein molecules. Almost all the chemical reactions occurring within the body require the help of enzymes. Each enzyme has a structure or shape that allows it to interact with the specific molecules in the reaction it accelerates. Without enzymes, metabolic reactions would occur too slowly to support life.

- **c.** Proteins help transport materials throughout the body and into and out of cells. The protein hemoglobin, which gives these red blood cells their color, shuttles oxygen to body cells and carries away carbon dioxide.
Proteins are an important part of the body’s defense mechanisms. Skin, which is made up primarily of protein, is the first barrier against infection and injury. Foreign particles such as dirt or bacteria that are on the skin cannot enter the body and can be washed away. If the skin is broken and blood vessels are injured, blood-clotting proteins help prevent too much blood from being lost. If a foreign material does get into the body, antibodies, which are immune system proteins, help destroy it (Figure 6.7d).

Some proteins have contractile properties, which allow muscles to move various parts of the body (Figure 6.7e). Others are hormones, which regulate biological processes.

The hormones insulin, growth hormone, and glucagon are made from amino acids. These protein hormones act rapidly because they affect the activity of proteins that are already present in the cell.

Proteins also help regulate fluid balance (Figure 6.7f) and prevent the level of acidity in body fluids from deviating from the normal range. The chemical reactions of metabolism require a specific level of acidity, or pH, to function properly. Inside the body, pH must be maintained at a relatively neutral level in order to allow metabolic reactions to proceed normally. If the pH changes, these reactions slow or stop. Proteins both within cells and in the blood help prevent large changes in pH.

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Amino acids from dietary or body protein can be used to produce ATP. First, the amino group (NH₃) must be removed through a process called deamination. The remaining compound, composed of carbon, hydrogen, and oxygen, can then be broken down to produce ATP or used to make glucose or fatty acids.

1. The amino group is removed by deamination and converted into the waste product urea. Urea is removed from the blood by the kidneys and excreted in the urine.
2. Deamination of some amino acids results in three-carbon molecules that can be used to synthesize glucose.
3. Deamination of some amino acids results in acetyl-CoA that enters the citric acid cycle.
4. Deamination of some amino acids forms molecules that enter the citric acid cycle directly.
5. The acetyl-CoA derived from the breakdown of amino acids can be used to synthesize fatty acids. This occurs when calories are consumed in excess of needs.
6. In the final step of aerobic metabolism, the energy from the amino acid molecules is trapped and used to produce ATP.

**Ask Yourself**

If you are not eating anything, how can the body supply itself with glucose?
Protein in Health and Disease

LEARNING OBJECTIVES

1. **Distinguish** kwashiorkor from marasmus.
2. **Explain** why protein-energy malnutrition is more common in children than in adults.
3. **Discuss** the potential risks associated with high-protein diets.
4. **Explain** how a dietary protein can trigger a food allergy.

We need to eat protein to stay healthy. If we don’t eat enough of it, less-essential body proteins are broken down, and their amino acids are used to synthesize proteins that are critical for survival. For example, when the diet is deficient in protein, muscle protein is broken down to provide amino acids to make hormones and enzymes for which there is an immediate need. If protein deficiency continues, eventually so much body protein is lost that all life-sustaining functions cannot be supported. In some cases, too much protein or the wrong proteins can also contribute to health problems.

### Protein Deficiency

Protein deficiency is a great concern in the developing world but generally not a problem in economically developed societies, where plant and animal sources of protein are abundant. Usually, protein deficiency occurs along with a general lack of food and other nutrients. The term **protein-energy malnutrition (PEM)** is used to refer to a continuum of

---

**CONCEPT CHECK**

1. **How** does the body know in what order to assemble the amino acids when making a protein?
2. **Why** does protein synthesis stop when the supply of an amino acid is limited?
3. **What** type of protein speeds up chemical reactions?
4. **When** is protein used as an energy source?

---

Protein as a Source of Energy

In addition to all the essential functions performed by body proteins, under some circumstances, proteins can be broken down and their amino acids used to provide energy or synthesize glucose or fatty acids (*Figure 6.8*). When the diet does not provide enough energy to meet the body’s needs, such as during starvation or when consuming a weight-loss diet, body protein is used to provide energy. Because our bodies do not store protein, functional body proteins, such as enzymes and muscle proteins, must be broken down to yield amino acids, which can then be used as fuel or to make glucose. This ensures that cells have a constant energy supply but also robs the body of the functions performed by these proteins.

Amino acids are also used for energy when the amount of protein consumed in the diet is greater than that needed to make body proteins and other molecules. This occurs in most Americans every day because our typical diet contains more protein than we need. The body first uses amino acids from the diet to make body proteins and other nitrogen-containing molecules. Then, because extra amino acids can’t be stored, they are metabolized to provide energy. When your diet includes more calories than you need, amino acids can be converted into fatty acids, which are stored as triglycerides, thus contributing to weight gain.
CHAPTER 6 Proteins and Amino Acids

conditions ranging from pure protein deficiency, called **kwashiorkor**, to an overall energy deficiency, called **marasmus** (Figure 6.9).

Protein deficiency occurs when the diet is very low in protein or when protein needs are high, as they are in young children. Hence, kwashiorkor is typically a disease found in children (Figure 6.9a). The word *kwashiorkor* comes from the Ga tribe of the African Gold

**kwashiorkor** A form of protein-energy malnutrition in which only protein is deficient.

**marasmus** A form of protein-energy malnutrition in which a deficiency of energy in the diet causes severe body wasting.

**Protein-energy malnutrition • Figure 6.9**

a. Kwashiorkor, seen in this child from Haiti, is characterized by a swollen belly, which results from fluid accumulating in the abdomen and fat accumulating in the liver. Growth is impaired, but because energy intake is not necessarily low, the child may not appear extremely thin. The lack of protein also causes poor immune function and an increase in infections, changes in hair color, and impaired nutrient absorption.

b. Marasmus, seen in this Somalian boy, is characterized by depletion of fat stores and wasting of muscle. It has devastating effects on infants because most brain growth takes place in the first year of life; malnutrition in the first year causes decreases in intelligence and learning ability that persist throughout the individual's life.

c. Protein-energy malnutrition is uncommon in the United States and other developed nations, but in developing countries, it is a serious public health problem that results in high infant and child mortality. The highest prevalence is in sub-Saharan Africa and south Asia.

<table>
<thead>
<tr>
<th>% of population undernourished</th>
<th>35%</th>
<th>20–34%</th>
<th>5–19%</th>
<th>2.5–4%</th>
<th>&lt;2.5%</th>
<th>No data</th>
</tr>
</thead>
</table>

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Coast. It means “the disease that the first child gets when a second child is born.” When the new baby is born, the older child is no longer breast-fed. Rather than receiving protein-rich breast milk, the young child is fed a watered-down version of the diet eaten by the rest of the family. This diet is low in protein and often high in fiber and difficult to digest. The child, even if he or she is able to obtain adequate calories from the diet, may not be able to eat a large enough quantity to get adequate protein. Because children are growing, their protein needs per unit of body weight are higher than those of adults, and a deficiency occurs more quickly.

At the other end of the continuum of protein-energy malnutrition is marasmus, meaning “to waste away” (Figure 6.9b). Marasmus is caused by starvation; the diet doesn’t supply enough calories or nutrients to meet the body’s needs. Marasmus may have some of the same symptoms as kwashiorkor, but there are differences. In kwashiorkor, some fat stores are retained because energy intake is adequate. In marasmus, individuals appear emaciated because their stores of body fat have been depleted to provide energy. Although they are most common in children, both marasmus and kwashiorkor can occur in individuals of all ages.

**High-Protein Diets and Health**

The recent popularity of high-protein, low-carbohydrate diets for weight loss (see Chapters 4 and 9) has raised questions about whether consuming too much protein can be harmful. As protein intake increases, so does the production of protein-breakdown products, such as urea, which must be eliminated from the body by the kidneys. To excrete more waste, more water must be lost in the urine. High-protein diets therefore increase water loss. Although not a concern for most people, this can be a problem if the kidneys are not able to concentrate urine, as is the case for infants. Feeding a newborn an infant formula that is too high in protein increases the amount of water lost in the urine and can lead to dehydration. High protein intake may also be detrimental for people with kidney disease; the increased wastes produced with a high-protein diet may speed the progression of renal failure. However, there is no evidence that a high-protein diet will precipitate kidney disease in a person with normal kidney function.

It has also been suggested that the amount and source of protein in the diet affect calcium status and bone health. Adequate protein is essential for healthy bones, but too much protein has been shown to increase the amount of calcium lost in the urine. Some studies suggest that the amount of calcium lost in the urine is greater when protein comes from animal rather than vegetable sources. These findings have contributed to a widely held belief that high-protein diets (especially diets that are high in animal protein) result in bone loss. However, clinical studies do not support the idea that animal protein has a detrimental effect on bone health or that vegetable-based proteins are better for bone health. In fact, when calcium intake is adequate, high-protein diets are associated with greater bone mass and fewer fractures. This is likely the case because in healthy adults, a high protein intake increases intestinal calcium absorption as well as urinary excretion, so the increase in the amount of calcium lost in the urine does not cause an overall loss of body calcium.

The increase in urinary calcium excretion associated with high-protein diets has led to speculation that a high protein intake may increase the risk of kidney stones. Kidney stones are deposits of calcium and other substances in the kidneys and urinary tract. Higher concentrations of calcium and acid in the urine increase the likelihood that the calcium will be deposited, forming these stones. Epidemiological studies suggest that diets that are rich in animal protein and low in fluid contribute to the formation of kidney stones.

The best-documented concern with high-protein diets is related more to the rest of the diet than to the amount of protein consumed. Typically, high-protein diets are also high in animal products; this dietary pattern is high in saturated fat and cholesterol and low in fiber, and it therefore increases the risk of heart disease. These diets are also typically low in grains, vegetables, and fruits, a pattern associated with an increased risk of cancer.

**Proteins and Food Allergies and Intolerances**

When a protein from the diet is absorbed without being completely digested, it can trigger a **food allergy**. The first time the protein is consumed and a piece of it is absorbed intact, it stimulates the immune system. When the same protein is consumed again, the immune system sees it as a foreign substance and mounts an attack, causing an allergic reaction (see Chapter 3). Allergic reactions cause symptoms throughout the body and can be life threatening. The proteins from milk, eggs, peanuts, tree
Food allergy labeling • Figure 6.10

Food labels provide life-saving information for individuals with food allergies. A label must indicate whether the product contains any of the eight major food allergens: milk, eggs, peanuts, tree nuts, fish, shellfish, soy, and wheat. Sometimes these are just included in the ingredient list, but often, as on this label, they are also highlighted at the end of the list in a statement such as “Contains soy ingredients.” Warnings such as “manufactured in a facility that processes peanuts” are included on products that may be cross-contaminated with these allergens.

**Ask Yourself**
If you had an allergy to soy, would this soup be a safe choice?

Gluten intolerance, also called **celiac disease**, celiac sprue, or gluten-sensitive enteropathy, is another form of food intolerance (see Chapter 3). Individuals with celiac disease cannot tolerate gluten, a protein found in wheat, rye, and barley. Celiac disease is an autoimmune disease in which gluten causes the body to attack the villi in the small intestine, causing symptoms such as diarrhea, abdominal bloating and cramps, weight loss, and anemia. Once thought to be a rare childhood disease, it is now known to affect more than 2 million people in the United States. The only treatment is to avoid gluten by eliminating from the diet all products containing wheat, rye, or barley and proteins isolated from these foods.

**CONCEPT CHECK**
1. **Why** do children with marasmus appear more emaciated than those with kwashiorkor?
2. **Why** is kwashiorkor more common in children than in adults?
3. **Who** should be concerned about excessive protein intake?
4. **How** can allergic reactions to food be avoided?

nights, wheat, soy, fish, and shellfish are common causes of food allergies (Figure 6.10).

Not all adverse reactions to proteins and amino acids are due to allergies; some are due to **food intolerances**, also called **food sensitivities**. These reactions do not involve the immune system. The symptoms of a food intolerance can range from minor discomfort, such as the abdominal distress some people feel after eating raw onions, to more severe reactions. For example, some people report having a reaction after consuming monosodium glutamate (MSG). MSG is a flavor enhancer made up of the amino acid glutamic acid bound to sodium. It is used in meat tenderizers and commonly added to Chinese food. Although research has been unable to confirm that MSG ingestion causes any adverse reactions, some people report experiencing a collection of symptoms such as flushed face, tingling or burning sensations, headache, rapid heartbeat, chest pain, and general weakness that are collectively referred to as **MSG symptom complex**, commonly called **Chinese restaurant syndrome**. Sensitive individuals should ask for food to be prepared without added MSG and should check ingredient lists for monosodium glutamate or potassium glutamate before consuming packaged foods.
Meeting Protein Needs

LEARNING OBJECTIVES

1. Describe how protein needs are determined.
2. Explain what is meant by protein quality.
3. Review a diet and replace the animal proteins with complementary plant proteins.
4. Discuss the benefits and risks of vegetarian diets.

In order to stay healthy, you have to eat enough protein to replace the amount you lose every day. Most Americans get plenty of protein, and healthy diets can contain a wide range of intakes from both plant and animal sources. An individual’s protein needs may be increased by growth, injury, and illness, as well as by some types of physical activity.

Balancing Protein Intake and Losses

Current protein intake recommendations are based on nitrogen balance studies. These studies compare the amount of nitrogen consumed with the amount excreted. Studying nitrogen balance allows researchers to evaluate protein balance because most of the nitrogen we consume comes from dietary protein. Most of the nitrogen we lose is excreted in urine. Smaller amounts are lost in feces, skin, sweat, menstrual fluids, hair, and nails. When your body is in nitrogen balance, your nitrogen intake equals your nitrogen losses; in other words, you are consuming enough protein to replace losses. You are not gaining or losing body protein; you are maintaining it at a constant level. Nitrogen balance is negative if you’re losing body protein and positive if the amount of body protein is increasing (Figure 6.11).

Nitrogen balance • Figure 6.11

a. Nitrogen balance
Nitrogen intake = Nitrogen output. This indicates that the amount of protein being synthesized is equal to the amount being broken down, so the total amount of protein in the body is not changing. Healthy adults who consume adequate amounts of protein and are maintaining a constant body weight are in nitrogen balance.

b. Negative nitrogen balance
Nitrogen intake < Nitrogen output. This indicates that more protein is being broken down than is being synthesized so body protein is decreasing. Negative nitrogen balance occurs due to injury or illness as well as when the diet is too low in protein or calories.

c. Positive nitrogen balance
Nitrogen intake > Nitrogen output. This indicates that there is more protein synthesis than degradation so the body is gaining protein. This occurs when the body is growing, during pregnancy, and in individuals who are increasing their muscle mass by lifting weights.

Think Critically

In a healthy adult, what will happen to nitrogen excretion if nitrogen intake increases?
Protein requirements • Figure 6.12

During the first year of life, growth is rapid, so a large amount of protein is required per unit of body weight. As growth rate slows, requirements per unit of body weight decrease, but continue to be greater than adult requirements, until age 19.

![Interpreting Data](image)

Interpreting Data

What is the RDA for a 2-year-old child who weighs 14 kg?

a. 14 g/day
b. 15.4 g/day
c. 11.2 g/day
d. 21 g/day

Recommended Protein Intake

Most of us eat more protein than we need: The typical young adult in the United States consumes about 90 g of protein/day.9 The RDA for protein for adults is 0.8 g/kg of body weight. For a person weighing 70 kg (154 lb), the RDA is 56 g of protein/day. RDAs have also been developed for each of the essential amino acids;2 these are not a concern in typical diet planning but are important when developing solutions for intravenous feeding.

Protein recommendations are expressed per unit of body weight because protein is needed to maintain and repair the body. The more a person weighs, the more protein he or she needs for those purposes. Because children are small, they need less total protein than adults do, but because new protein must be synthesized for growth to occur, protein requirements per unit of body weight are much greater for infants and children than for adults (Figure 6.12). To calculate protein needs per day, multiply weight in kilograms (which equals weight in pounds multiplied by 0.45) by the recommended amount for the individual’s age.

Protein needs are also increased during pregnancy and lactation. Additional protein is needed during pregnancy to support the expansion of maternal blood volume,

Protein needs of athletes • Figure 6.13

a. Endurance athletes need extra protein because some protein is used for energy and to maintain blood glucose during endurance events, such as triathlons and long distance cross country skiing. Endurance athletes may benefit from the daily consumption of 1.2 to 1.4 g/kg of body weight.10

b. Strength athletes, such as weight lifters and body builders, need extra protein because it provides the raw materials needed for muscle growth; 1.2 to 1.7 g/kg/day is recommended.10
the growth of the uterus and breasts, the formation of the placenta, and the growth and development of the fetus. The RDA for pregnant women is 25 g of protein/day higher than the recommendation for nonpregnant women. An extra 25 g/day is also needed during lactation to provide protein for the production of breast milk.

Extreme stresses on the body, such as infections, fevers, burns, or surgery, increase the amount of protein that is broken down. For the body to heal and rebuild, the amount of protein lost must be replaced. The extra amount needed for healing depends on the injury. A severe infection may increase the body’s protein needs by about 30%; a serious burn can increase protein requirements by 200 to 400%.

Although most athletes can meet their protein needs by consuming the RDA of 0.8 g/kg of body weight, extreme endurance athletes and strength athletes benefit from higher protein intakes (Figure 6.13). Athletes often think they need supplements to meet their higher protein needs. However, supplements tend to be an expensive way to increase protein intake. Because athletes

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**Protein and amino acid supplements • Figure 6.14**

Protein and amino acid supplements are rarely needed to meet protein needs. Nonetheless, supplements are marketed to boost total protein intake, to add individual amino acids, and to provide enzyme activity.

Protein supplements are marketed to promote proper immune function, make hair healthy, and stimulate muscle growth, but increasing protein intake above the level required for good health does not protect you from disease, make your hair shine, or give you larger biceps.

Many promises are made about amino acid supplements, from aiding sleep to enhancing athletic performance. There is weak evidence to support some of these, but consuming large amounts of one amino acid may interfere with the absorption of others. Due to insufficient research, no ULs have been set for amino acids.

Supplements of enzymes that function inside body tissues provide no benefits because the enzyme is broken down into amino acids during digestion. Supplements of enzymes that function in the gut, such as lactase for lactose intolerance, retain enzyme activity long enough to breakdown the lactose but are also eventually digested.
typically need to consume more calories to meet their energy needs, they also consume more dietary protein and can easily meet their protein needs through diet alone.

In addition to the RDA, the DRIs include a recommendation for protein intake as a percentage of calories: The Acceptable Macronutrient Distribution Range for protein is 10 to 35% of calories. This range allows for different food preferences and eating patterns. A protein intake in this range will meet protein needs and allow sufficient intakes of other nutrients to promote health. A diet that provides 10% of calories from protein will meet the RDA but is a relatively low-protein diet compared with typical eating patterns in the United States. The upper end of this healthy range—35% of calories—is a relatively high-protein diet, about twice as much protein as the average American eats. This amount of protein is not harmful, but if the diet is this high in protein, it is probably high in animal products, which tend to be high in saturated fat and cholesterol. Therefore, unless protein sources are chosen carefully, a diet that contains 35% protein would tend to include more saturated fat and cholesterol than would a diet with the same number of calories that contains only 10% protein. For example, a 2500-Calorie diet that provides 35% of calories from protein would include the protein equivalent of a 16-oz steak and 2 quarts of milk daily.

Debate Should You Switch to Soy?

The Issue: Many people have switched from cow’s milk to soy milk and chosen to snack on edamame (boiled green soybeans), soy nuts, and soy-based protein bars. Will increasing your intake of soy benefit your health or cause health problems?

Soy is found in many traditional Asian foods, such as tofu and miso, and it is used as a meat substitute in vegetarian hotdogs and chicken nuggets. A high intake of soy has been linked to a lower incidence of heart disease, type 2 diabetes, osteoporosis, and certain types of cancer. This association has contributed to a dramatic rise in the number of available soy products; more than 2700 new foods with soy as an ingredient were introduced between 2000 and 2007. But there has also been concern about the safety of soy for certain segments of the population. So should we be adding tofu to our soups, salads, and stir-fries; spreading soy butter on our toast; and snacking on soy protein bars?

Soy provides high-quality protein—comparable to the protein in eggs and milk. Soy products are also high in healthy polyunsaturated fat, fiber, vitamins, and minerals, and they are low in unhealthy saturated fat. Soy protein is believed to lower blood lipid levels. The FDA has even approved a food label health claim related to soy intake and a lower risk of heart disease. Soy also provides phytochemicals called isoflavones, which have estrogen-like effects. This has led to speculation that consuming soy isoflavones will reduce the symptoms of menopause (including hot flashes), reduce bone loss, and have preventive effects in terms of certain forms of cancer, including breast cancer.

It sounds like we should all switch to soy. However, a more careful look at the research on soy suggests that it may not be as beneficial as initially hoped, and there is now concern that it might not be safe for everyone. A review of the effect of soy on blood cholesterol concluded that it has only a small LDL cholesterol-lowering effect, and this occurs only when large amounts, about 50 g/day, are consumed. But, because soy contains substances that may interfere with thyroid gland function, overconsumption has been accused of contributing to low levels of thyroid hormones in individuals with compromised thyroid function and/or whose iodine intake is marginal. The health effects of those estrogen-like soy isoflavones are also confusing. Clinical trials support a role of isoflavones in the prevention of bone loss, but results are inconsistent. Research has not shown soy to reduce the symptoms of menopause. Isoflavones have been found to promote the growth of breast tumors in animals, and therefore women who have breast cancer are typically advised to avoid soy. In women who do not have breast cancer, soy appears to be protective if it is consumed in moderate amounts throughout life, but switching to soy milk after menopause may have no effect.

So, is soy good for you? Choosing soy products, such as those shown in the photo, will provide plant protein equivalent in quality to animal proteins, and can help you meet your protein needs without much saturated fat. High intakes of soy may help reduce the risk of heart disease. But it is not clear what effect these amounts will have on breast cancer risk or thyroid function. Studies in Asian populations that typically consume soy support its benefits, but there is little evidence that switching to soy will have the same effect as a moderate soy intake throughout life.
Choosing Protein Wisely

To evaluate protein intake, it is important to consider both the amount and the quality of protein in the diet. Protein quality is a measure of how good the protein in a food is at providing the essential amino acids the body needs to synthesize proteins. Because animal amino acid patterns are similar to those of humans, the animal proteins in our diet generally provide a mixture of amino acids that better matches our needs than the amino acid mixtures provided by plant proteins. Animal proteins also tend to be digested more easily than plant proteins; only protein that is digested can contribute amino acids to meet the body’s requirements.\(^\text{11}\) Because they are easily digested and supply essential amino acids in the proper proportions for human use, foods of animal origin are generally sources of high-quality protein, or complete dietary protein. When your diet contains high-quality protein, you don’t have to eat as much total protein to meet your needs.

Compared to animal proteins, plant proteins are usually more difficult to digest and are lower in one or more of the essential amino acids. They are therefore generally referred to as incomplete dietary protein. Exceptions include quinoa and soy protein, which are both high-quality plant proteins (see Debate: Should You Switch to Soy?).

Think critically: An intake of about 50 g of soy protein per day has been shown to lower blood cholesterol in some people. Based on the protein content of foods in the table, is this a reasonable way for Americans to lower cholesterol? Why or why not?

### Good sources of soy

<table>
<thead>
<tr>
<th>Food</th>
<th>Serving</th>
<th>Protein (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soy milk, regular</td>
<td>1 cup</td>
<td>7</td>
</tr>
<tr>
<td>Tofu, regular</td>
<td>1 oz</td>
<td>2.5</td>
</tr>
<tr>
<td>Miso</td>
<td>1 Tbsp</td>
<td>2</td>
</tr>
<tr>
<td>Tempeh</td>
<td>1 Tbsp</td>
<td>2</td>
</tr>
<tr>
<td>Roasted soybeans</td>
<td>1/4 cup</td>
<td>15</td>
</tr>
<tr>
<td>Soybean sprouts</td>
<td>1 cup</td>
<td>9</td>
</tr>
<tr>
<td>Texturized soy protein (TSP)</td>
<td>1 oz</td>
<td>14</td>
</tr>
<tr>
<td>Veggie hotdog</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Soy veggie burger</td>
<td>3 oz</td>
<td>12</td>
</tr>
<tr>
<td>Tofutti frozen dessert, regular</td>
<td>1/2 cup</td>
<td>2</td>
</tr>
<tr>
<td>Soy flour, regular</td>
<td>1 Tbsp</td>
<td>2</td>
</tr>
<tr>
<td>Soy butter</td>
<td>2 Tbsp</td>
<td>7</td>
</tr>
</tbody>
</table>

Soy milk is a substitute for cow’s milk.

Soy flour can be incorporated into baked goods.

Soy butter is similar to peanut butter and can be spread on crackers and sandwiches.

Tofu, also known as bean curd, is added to soups, salads, and stir-fries.

Texturized soy protein (TSP), also known as texturized vegetable protein (TVP), is formed into chunks, woven or spun into fibers, or otherwise shaped and flavored to produce vegetarian versions of burgers, hotdogs, meatballs, and chicken.
Complementary proteins If you get your protein from a single source and that source is an incomplete protein, it will be difficult to meet your body’s protein needs. However, combining proteins that are limited in different amino acids can supply a complete mixture of essential amino acids. For example, legumes are limited in methionine but high in lysine. When legumes are consumed with grains, which are high in methionine and low in lysine, the combination provides all the needed amino acids (Figure 6.15). Vegetarian diets rely on this technique, called **protein complementation**, to meet protein needs. By eating plant proteins that have complementary amino acid patterns, a person can meet his or her essential amino acid requirements without consuming any animal proteins.

**Protein complementation • Figure 6.15**

a. The amino acids that are most often limited in plant proteins are lysine (lys), methionine (met), and cysteine (cys). As a general rule, legumes are deficient in methionine and cysteine but high in lysine. Grains, nuts, and seeds are deficient in lysine but high in methionine and cysteine.

Grains, nuts, or seeds + Legumes = Complete protein

b. Many of the food combinations consumed in traditional diets take advantage of complementary plant proteins, such as lentils and rice or chickpeas and rice in India, rice and beans in Mexico and South America, hummus (chickpeas and sesame seeds) in the Middle East, and bread and peanut butter (peanuts are a legume) in the United States. Complementary proteins do not have to be consumed in the same meal, so eating an assortment of plant foods throughout the day can provide enough of all the essential amino acids.18
Meeting Protein Needs

Choosing healthy protein sources • Figure 6.16

The protein group and the dairy group provide the most concentrated sources of protein. Nuts, dry beans, and peas are the most concentrated sources of plant protein. When you eat dry beans or peas, you can count them in either the vegetables group or the protein group. There is very little protein in fruits.

MyPlate and Dietary Guidelines recommendations

MyPlate and the Dietary Guidelines include recommendations regarding both animal and plant sources of protein to meet your need for protein and essential amino acids (Figure 6.16). The MyPlate food groups that provide the most protein per serving are the dairy and protein groups; 1 cup of milk provides about 8 g of protein, 1 ounce of meat about 7 g, 1/2 cup of beans 7 to 10 g. Each serving from the grains group and the vegetables group provides 2 to 4 g, so choosing the recommended number of servings from these groups will provide a significant proportion of your protein needs. To assure an overall healthy diet, the 2010 Dietary Guidelines recommend that we choose a variety of protein foods, including seafood, lean meat and poultry, eggs, beans, soy products, and unsalted nuts and seeds. They recommend increasing consumption of seafood and low-fat or fat-free dairy products and replacing protein foods that are high

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in solid fats with those that are lower in solid fats and calories (see What Should I Eat?).

**Vegetarian Diets**

In many parts of the world, diets based on plant proteins, called **vegetarian diets**, have evolved mostly out of necessity because animal sources of protein are limited, either physically or economically, in those areas. Animals require more land and resources to raise and are more expensive to purchase than are plants. The developing world relies primarily on plant foods to meet protein needs. For example, in rural Mexico, most of the protein in the diet comes from beans, rice, and tortillas (corn), and in India, protein comes from lentils and rice. As a population’s economic prosperity rises, the proportion of animal foods in its diet typically increases, but in developed countries, people eat vegetarian diets for a variety of reasons other than economics, such as health, religion, personal ethics, or environmental awareness. **Vegan diets** eliminate all animal products, but there are other types of vegetarian diets that are less restrictive (Table 6.1).

### Benefits of vegetarian diets

A vegetarian diet can be a healthy, low-cost alternative to the traditional American meat-and-potatoes diet. Vegetarians have been shown to have lower body weight relative to height and a reduced incidence of obesity and of other chronic diseases, such as diabetes, cardiovascular disease, high

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**Table 6.1** Types of vegetarian diets

<table>
<thead>
<tr>
<th>Diet</th>
<th>What it excludes and includes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semivegetarian</td>
<td>Excludes red meat but may include fish and poultry, as well as dairy products and eggs</td>
</tr>
<tr>
<td>Pescatarian</td>
<td>Excludes all animal flesh except fish</td>
</tr>
<tr>
<td>Lacto-ovo vegetarian</td>
<td>Excludes all animal flesh but does include eggs and dairy products such as milk and cheese</td>
</tr>
<tr>
<td>Lacto vegetarian</td>
<td>Excludes animal flesh and eggs but does include dairy products</td>
</tr>
<tr>
<td>Vegan</td>
<td>Excludes all food of animal origin</td>
</tr>
</tbody>
</table>

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Meeting nutrient needs with a vegan diet

Table 6.2

<table>
<thead>
<tr>
<th>Nutrient at risk</th>
<th>Sources in vegan diets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein</td>
<td>Soy-based products, legumes, seeds, nuts, grains, and vegetables</td>
</tr>
<tr>
<td>Vitamin B₁₂</td>
<td>Products fortified with vitamin B₁₂, such as soy beverages, rice milk, and breakfast cereals; fortified nutritional yeast; dietary supplements</td>
</tr>
<tr>
<td>Calcium</td>
<td>Tofu processed with calcium; broccoli, kale, bok choy, and legumes; products fortified with calcium, such as soy beverages, rice milk, grain products, and orange juice</td>
</tr>
<tr>
<td>Vitamin D</td>
<td>Sunshine; products fortified with vitamin D, such as soy beverages, rice milk, breakfast cereals, and margarine</td>
</tr>
<tr>
<td>Iron</td>
<td>Legumes, tofu, dark green leafy vegetables, dried fruit, whole grains, iron-fortified grain products (absorption is improved when iron-containing foods are consumed with vitamin C found in citrus fruit, tomatoes, strawberries, and dark green vegetables)</td>
</tr>
<tr>
<td>Zinc</td>
<td>Whole grains, wheat germ, legumes, nuts, tofu, and fortified breakfast cereals</td>
</tr>
<tr>
<td>Iodine</td>
<td>Iodized salt, sea vegetables (seaweed), and foods grown near the sea</td>
</tr>
<tr>
<td>Omega-3 fatty acids</td>
<td>Canola oil, flaxseed and flaxseed oil, soybean oil, walnuts, and sea vegetables (seaweed), which provide fatty acids that can be used to synthesize EPA and DHA; DHA-rich microalgae</td>
</tr>
</tbody>
</table>

blood pressure, and some types of cancer. The lower body weight of vegetarians is a result of lower energy intake, primarily due to higher intake of fiber, which makes the diet more filling. The reductions in the risk of other chronic diseases may be due to lower body weight and to the fact that these diets are lower in saturated fat and cholesterol, which increase disease risk. Or it could be that vegetarian diets are higher in whole grains, legumes, nuts, vegetables, and fruits, which add fiber, vitamins, minerals, antioxidants, and phytochemicals—substances that have been shown to lower disease risk. It is likely that the total dietary pattern, rather than a single factor, is responsible for the health-promoting effects of vegetarian diets.

In addition to reducing disease risks, diets that rely more heavily on plant protein than on animal protein are more economical. For example, a vegetarian stir-fry over rice costs about half as much as a meal of steak and potatoes. Yet both meals provide a significant portion of the day’s protein requirement. A small steak, a baked potato with sour cream, and a tossed salad provides about 50 g of protein, whereas a dish of rice with tofu and vegetables provides about 30 g.

Risks of vegetarian diets Despite the health and economic benefits of vegetarian diets, a poorly planned vegetarian diet can cause nutrient deficiencies. Protein deficiency is a risk when vegan diets that contain little high-quality protein are consumed by small children or by adults with increased protein needs, such as pregnant women and those recovering from illness or injury. Most people can easily meet their protein needs with lacto and lacto-ovo vegetarian diets. These diets contain high-quality animal proteins from eggs or milk, which complement the limiting amino acids in the plant proteins.

Vitamin and mineral deficiencies are a greater concern for vegetarians than is protein deficiency. Of primary concern to vegans is vitamin B₁₂. Because this B vitamin is found almost exclusively in animal products, vegans must take vitamin B₁₂ supplements or consume foods fortified with vitamin B₁₂ to meet their needs for this nutrient. Another nutrient of concern is calcium. Dairy products are the major source of calcium in the North American diet, so diets that eliminate these foods must rely on plant sources of calcium. Likewise, because much of the dietary vitamin D comes from fortified milk, this vitamin must be made in the body from exposure to sunlight or consumed in other sources. Iron and zinc may be deficient in vegetarian diets because they exclude red meat, which is an excellent source of these minerals, and iron and zinc are poorly absorbed from plant sources. Because dairy products are low in iron and zinc, lacto-ovo and lacto vegetarians as well as vegans are at risk for deficiencies of these minerals. Vegan diets may also be low in iodine and the omega-3 fatty acids EPA and DHA (see Chapter 5).
Simon is 26 years old and weighs 154 pounds. A year ago, he decided to stop eating meat because he thought it would make his diet healthier. Now that he is studying nutrition, he has become concerned that his vegetarian diet may not be as healthy as he thought. First, he wants to see if he meets his protein needs.

**What is the RDA for protein for someone of Simon’s age and weight?**

Your answer:

Simon records his food intake for one day and then uses iProfile to assess his nutrient intake. He is pleased to discover that his diet provides 66 g of protein, which exceeds his RDA, but he is shocked to discover that his diet is high in saturated fat.

**This is a photo of Simon’s typical lunch. Why is it high in saturated fat?**

Your answer:

Vegetarian diets are often deficient in calcium, vitamin D, zinc, and iron. Which of these are likely low in Simon’s diet?

Your answer:

What could Simon have for dinner that would provide less saturated fat and more of the nutrients that are lacking in his diet?

Your answer:

To reduce his saturated fat intake, Simon wants to try a vegan lunch. Suggest a vegan sandwich Simon could have that makes use of complementary plant proteins.

Your answer:

(Check your answers in Appendix J.)
Planned vegetarian diets Well-planned vegetarian diets, including vegan diets, can meet nutrient needs at all stages of the life cycle, from infancy, childhood, and adolescence to early, middle, and late adulthood, and during pregnancy and lactation (See Thinking It Through). One way to plan a healthy vegetarian diet is to modify the selections from MyPlate. The food choices and recommended amounts from the grains, vegetables, and fruits groups should stay the same for vegetarians. Including 1 cup of dark green and colorful vegetables daily will help meet iron and calcium needs. The dairy group and the protein group include foods of animal origin. Vegetarians who consume eggs and milk can still choose these foods. Those who avoid all animal foods can choose dry beans, nuts and seeds, and soy products from the protein group. Fortified soy milk and protein-enriched rice milk can be substituted for dairy foods. To obtain adequate vitamin B12, vegans must take supplements or use products fortified with vitamin B12. Obtaining plenty of omega-3 fatty acids from foods such as canola oil, nuts, and flaxseed ensures adequate synthesis of the long-chain omega-3 fatty acids DHA and EPA.

CONCEPT CHECK

1. What circumstances result in a positive nitrogen balance?
2. Why is the quality of animal protein generally considered to be higher than that of plant protein?
3. What could you serve with rice to increase the overall protein quality of the meal?
4. Why are vegans at risk for vitamin B12 deficiency?
3 Protein Digestion and Absorption 173

- Digestion breaks dietary protein into small peptides and amino acids that can be absorbed. Because amino acids that share the same transport system, such as those pictured here in green and purple, compete for absorption, an excess of one can inhibit the absorption of another.

4 Protein Synthesis and Functions 173

- Amino acids are used to synthesize proteins and other nitrogen-containing molecules. Genes located in the nucleus of the cell code for the order of amino acids in the polypeptide chains that make up proteins. Regulatory mechanisms ensure that proteins are made only when they are needed. For a protein to be synthesized, all the amino acids it contains must be available. The essential amino acid present in shortest supply relative to need, depicted here as amino acid A (orange), is called the limiting amino acid.

- In the body, protein molecules form structures, regulate body functions, transport molecules through the blood and in and out of cells, function in the immune system, and aid in muscle contraction, fluid balance, and acid balance.

- When the diet is deficient in energy or when the diet contains more protein than needed, amino acids are used as an energy source and to synthesize glucose or fatty acids. Before amino acids can be used for these purposes, the amino group must be removed via deamination.
Meeting Protein Needs 183

• Protein requirements are determined by looking at nitrogen balance, the amount of nitrogen consumed as dietary protein compared with the amount excreted as protein waste products.

• For healthy adults, the RDA for protein is 0.8 g/kg of body weight. Growth, pregnancy, lactation, illness, injury, and certain types of physical exercise increase requirements. Recommendations for a healthy diet are to ingest 10 to 35% of calories from protein.

• Animal proteins are considered high-quality proteins because their amino acid composition matches that needed to synthesize body proteins. Most plant proteins are limited in one or more of the essential amino acids needed to make body protein; therefore, they are considered incomplete proteins. The protein quality of plant sources can be increased through protein complementation. As illustrated here, it combines proteins with different limiting amino acids to supply enough of all the essential amino acids.

Protein complementation • Figure 6.15b

Protein in Health and Disease 179

• Protein-energy malnutrition (PEM) is a health concern primarily in developing countries. Kwashiorkor, shown here, occurs when the protein content of the diet is deficient but energy is adequate. It is most common in children. Marasmus occurs when total energy intake is deficient.

Protein-energy malnutrition • Figure 6.9a

• High-protein diets increase the production of urea and other waste products that must be excreted in the urine and therefore can increase water losses. High protein intakes increase urinary calcium losses, but when calcium intake is adequate, high-protein diets are associated with greater bone mass and fewer fractures. Diets high in animal proteins and low in fluid are associated with an increased risk of kidney stones. High-protein diets can be high in saturated fat and cholesterol.

• If proteins are absorbed without being completely digested, they can trigger an immune system reaction, resulting in a food allergy. Some amino acids and proteins can also cause food intolerances.

• Compared with meat-based diets, vegetarian diets are lower in saturated fat and cholesterol and higher in fiber, certain vitamins and minerals, antioxidants, and phytochemicals. People consuming vegan diets must plan their diets carefully to meet their needs for vitamin B₁₂, calcium, vitamin D, iron, zinc, and omega-3 fatty acids.
Key Terms
- amino acid pool 174
- amino acid 168
- celiac disease 182
- conditionally essential amino acid 169
- deamination 178
- denaturation 171
- dipeptide 170
- edema 177
- essential, or indispensable, amino acid 169
- food allergy 181
- food intolerance or food sensitivity 182
- gene 174
- gene expression 174
- high-quality protein or complete dietary protein 187
- hydrolyzed protein or protein hydrolysate 182
- incomplete dietary protein 187
- kwashiorkor 180
- leucine 168
- limiting amino acid 174
- marasmus 180
- monosodium glutamate (MSG) 182
- MSG symptom complex or Chinese restaurant syndrome 182
- nitrogen balance 183
- nonessential, or dispensable, amino acid 169
- peptide bond 169
- peptide 170
- phenylketonuria (PKU) 169
- polypeptide 169
- protein complementation 188
- protein quality 187
- protein-energy malnutrition (PEM) 179
- transamination 174
- transcription 175
- translation 175
- tripeptide 170
- urea 178
- vegan diet 190
- vegetarian diet 190

Online Resources
- For more information on choosing a healthy vegetarian diet, go to www.choosemyplate.gov/tipsresources/vegetarian_diets.html.
- For more information on vegetarian diets for children, go to www.pcrm.org/health/veginfo/vegetarian_kids.html.
- For more information on the health effects of high-protein diets, go to www.americanheart.org/presenter.jhtml?identifier=11234.
- For more information on food allergies, go to www.webmd.com/allergies/foods-allergy-intolerance.
- For more information on protein needs of athletes, go to www.aces.edu/pubs/docs/H/HE-0748/.
- Visit your WileyPLUS site for videos, animations, podcasts, self-study, and other media that will aid you in studying and understanding this chapter.

Critical and Creative Thinking Questions
1. Syed is a body builder. He is concerned about his protein intake. If Syed weighs 200 pounds and consumes about 3600 Calories/day, 15% of which comes from protein, will his diet supply enough protein to meet the recommendation for strength athletes of 1.2 to 1.7 g of protein/kilogram of body weight per day? What if he consumed only 2500 Calories/day?

2. Make a vegetarian meal plan for yourself for one day. Use iProfile to make sure it meets your calorie and protein needs. Then plan a day that includes meat. Go to the grocery store and calculate how much each day’s meals will cost. Use this information to explain the economic benefits or pitfalls of these two eating plans.

3. For each food in column A, select one or more in column B that could be combined with it to provide a meal of high-quality protein.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>Tofu</td>
</tr>
<tr>
<td>Wheat bread</td>
<td>Peanut butter</td>
</tr>
<tr>
<td>Corn tortilla</td>
<td>Cheese</td>
</tr>
<tr>
<td>Pasta</td>
<td>Kidney beans</td>
</tr>
<tr>
<td>Tofu</td>
<td>Cashews</td>
</tr>
<tr>
<td>Peanut butter</td>
<td>Corn tortilla</td>
</tr>
<tr>
<td>Corn bread</td>
<td>Wheat bread</td>
</tr>
<tr>
<td>Soybeans</td>
<td>Chickpeas</td>
</tr>
<tr>
<td>Black-eyed peas</td>
<td>Chicken</td>
</tr>
</tbody>
</table>
4. Children with the genetic disease phenylketonuria must consume a low-phenylalanine diet to prevent the accumulation of damaging phenylketones. Why not just eliminate the essential amino acid phenylalanine from the diet altogether?

5. Jack consumes about 120 g of protein/day. Of this, about 30 g is broken down and used to make ATP, and 30 g is used to synthesize body fat. What does this tell you about Jack’s protein and energy intake?

6. Fluid accumulates in the bellies of children with kwashiorkor. Use your understanding of how protein helps regulate fluid balance to explain why this occurs.

7. The graph shows the amount of animal protein and saturated fat in four different diets. Based on the data here, what is the relationship between the two? How might the animal protein choices in a diet affect this relationship—for example, if a skinless chicken breast replaced a cheeseburger?

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**What is happening in this picture?**

Sickle cell anemia is an inherited disease caused by an abnormality in the gene for the protein hemoglobin. It causes red blood cells to take on a sickle shape.

**Think Critically**

1. Sickle cell hemoglobin differs from normal hemoglobin by one amino acid. Why might this difference change the shape of the hemoglobin?
2. Do you think sickle-shaped red blood cells can travel easily through narrow capillaries?
3. How might this disorder affect the ability to get oxygen to the body’s cells?
Self-Test

(Check your answers in Appendix K.)

1. Which part of this amino acid will differ, depending on the particular amino acid?

2. Amino acids that cannot be made by the adult human body in sufficient amounts are called ____________.
   a. essential amino acids
   b. complete proteins
   c. incomplete amino acids
   d. hydrolyzed proteins
   e. nonessential amino acids

3. Based on the diagram, which letters label the parts of the digestive tract where chemical digestion of protein occurs?

4. Which one of the following is made from amino acids?
   a. triglycerides
   b. glycogen
   c. lecithin
   d. cholesterol
   e. enzymes

5. Which of the following letters best labels transcription?

6. __________ is the process of transferring an amino group from an amino acid to another molecule to form a second amino acid.
   a. Deamination
   b. Transamination
   c. Denaturation
   d. Hydrogenation

7. The amino acid colored __________ would be considered the most limiting for the synthesis of this specific protein?
   a. yellow
   b. green
   c. orange
   d. red
   e. blue
8. Which of the following groups requires the least protein per kilogram of body weight?
  a. adult men  
  b. pregnant women  
  c. infants  
  d. young children

9. What element is found in amino acids but not in glucose and triglycerides?
  a. carbon  
  b. nitrogen  
  c. phosphorous  
  d. oxygen  
  e. hydrogen

10. Which of the following is least likely to be low in a vegan diet?
    a. calcium  
    b. vitamin D  
    c. iron  
    d. fiber  
    e. vitamin B₁₂

11. Which of the following values for nitrogen intake and output are most likely to belong to a healthy 9-year-old boy?
    a. nitrogen in = 14 g, nitrogen out = 16 g  
    b. nitrogen in = 15 g, nitrogen out = 15 g  
    c. nitrogen in = 14 g, nitrogen out = 10 g  
    d. nitrogen in = 20 g, nitrogen out = 22 g

12. When extra protein is consumed, it is stored in the muscle for later use.
    a. true  
    b. false

13. When amino acids are broken down to generate energy or synthesize glucose, the amino group must be removed. What waste product is generated from it?
    a. ketones  
    b. urea  
    c. free fatty acids  
    d. carbon dioxide  
    e. oxygen

14. Which of the following is not a good example of protein complementation?
    a. sunflower seeds and peanuts  
    b. rice and beans  
    c. chickpeas and sesame seeds  
    d. corn and rice  
    e. lentils and rice

15. Which one of the following statements about children with kwashiorkor is false?
    a. Their fat stores are completely depleted.  
    b. They are more susceptible to infections than healthy children.  
    c. They have swollen bellies.  
    d. They have hair color changes.  
    e. They do not grow well.

THE PLANNER

Review your Chapter Planner on the chapter opener and check off your completed work.