# 5

# Proteins


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## Learning Objectives

1. Describe amino acids and how the structure of a protein affects its function.
2. Distinguish between indispensable, conditionally indispensable, and dispensable amino acids.
3. Describe the digestion, absorption, transport, and metabolism of amino acids.
4. Describe when and how the body uses protein to fuel exercise.
5. State protein recommendations for athletes and the effects of high and low protein and/or energy intakes on training, performance, and health.
6. Identify sources of dietary protein.
7. Assess an athlete's dietary protein intake.
8. Evaluate dietary supplements containing amino acids and proteins, such as whey and casein, for safety and effectiveness.

## Pre-Test Assessing Current Knowledge of Proteins

Read the following statements and decide if each is true or false.

1. Skeletal muscle is the primary site for protein metabolism and is the tissue that regulates protein breakdown and synthesis throughout the body.
2. In prolonged endurance exercise, approximately 3 to 5 percent of the total energy used is provided by amino acids.
3. To increase skeletal muscle mass, the body must be in positive nitrogen balance, which requires an adequate amount of protein and energy (calories).
4. The daily recommended protein intake for strength athletes is 2.0 to 3.0 grams per kilogram body weight, twice that recommended for endurance athletes.
5. Strength athletes usually need protein supplements because it is difficult to obtain a sufficient amount of protein from food alone.

**Since the days of the ancient Olympiads,** **protein** has held a special place in the athlete's diet. Protein is critical to growth and development, including growth of muscle tissue, so its place as an important nutrient has been earned. But its role can be overstated if it is elevated above other nutrients. No one nutrient, by itself, ensures proper nutrition. Protein functions optimally only when **energy** intake from carbohydrate and fat is sufficient.

A primary function of protein is to build and maintain tissues. To increase muscle mass, an athlete must engage in resistance exercise, consume a sufficient amount of energy (kcal), and be in positive nitrogen (protein) balance. Because so much emphasis is put on protein and muscle growth, it can easily be forgotten that protein is also the basis of **enzymes** and many **hormones,** and of structural, transport, and immune system proteins. Although it is not the primary function of protein, the **amino acids** that make up protein can be used to provide energy. In prolonged endurance exercise, amino acids are an important energy source even though carbohydrates and fats supply the majority of the energy.

The basic component of all proteins is the amino acid, a nitrogen-containing compound. Proteins found in food are broken down into amino acids through the processes of digestion and absorption. Once absorbed, the amino acids are transported to the liver, which plays a major role in amino acid metabolism. Body proteins are constantly being manufactured and broken down. Dietary protein and degraded body proteins provide a steady stream of amino acids for protein synthesis. In a prolonged starvation state the body's ability to maintain nitrogen balance is compromised and muscle tissue will be sacrificed to ensure survival.

Proteins are found in both plant and animal foods. Although they differ in quality (i.e., amount and type of amino acids), in industrialized countries it is easy to consume an adequate amount of protein with sufficient quality. The amount of protein recommended for athletes is usually higher than for nonathletes, although protein consumption typically exceeds recommendations in both athletes and nonathletes when energy (kcal) intake is adequate. Timing of protein intake is important, especially during the postexercise (recovery) period.

Athletes have numerous protein-containing foods to choose from as well as a range of protein supplements. Protein supplements are generally manufactured using food proteins such as milk or soy, and protein supplements have not been proven more or less effective than protein-containing foods. Protein supplements are safe for healthy adults. Supplements of individual amino acids (e.g., glutamine, **branched chain amino acids**) under certain conditions (e.g., endurance running) have shown some promise, but more research is needed to confirm effectiveness.

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Proteins are found in both plant and animal foods.

## Proteins

Proteins are made up of amino acids, which contain carbon, hydrogen, oxygen, and nitrogen. It is the nitrogen that distinguishes them from the composition of carbohydrates, fats, and alcohol, which are made up of only carbon, hydrogen, and oxygen. To understand their functions one must understand the structures of proteins. The basic structural component is an amino acid.

### AMINO ACIDS

An amino acid is a chemical compound that contains an $NH_2$ (i.e., amino) group and a COOH (i.e., carboxyl) group of atoms. The basic structure of an amino acid is shown in Figure 5.1. The nitrogen content of an amino acid is approximately 16 percent. There are a total of 20 different amino acids that will be used by the body to make various proteins. Amino acids may have side chains (e.g., glycine, leucine), acid groups (e.g., glutamine), basic groups (e.g., lysine), or rings (e.g., tryptophan). Some contain sulfur (e.g., cysteine, methionine). These differences in amino acid structure play critical roles in the functions of the proteins created. Important features of the 20 amino acids are shown in Table 5.1.

### INDISPENSABLE AND DISPENSABLE AMINO ACIDS

Of the 20 amino acids needed by healthy adults, nine are considered **indispensable** because the body cannot manufacture them. The remaining 11 amino acids are termed **dispensable** because they can be manufactured in the liver. Six of these 11 amino acids are referred to as **conditionally indispensable**, because during periods of stress the body cannot manufacture a sufficient amount. Illness, injury, and prolonged endurance exercise are examples of physiologically stressful conditions. In the past, the terms ***essential*** and ***nonessential*** were used to describe indispensable and dispensable amino acids, respectively. *Nonessential* is a misleading term because it implies that such amino acids are not needed. In fact, they are needed but the body has the ability to manufacture them if they are not consumed directly from food. Indispensable and dispensable are now the preferred terminology when describing amino acids.

In the United States and other countries where a variety of food, including protein-containing food, is widely available, few healthy adults are at risk for amino acid deficiencies. They consume an adequate amount of protein daily and receive ample amounts of all the indispensable amino acids. Those at risk for low protein intake include those with **eating disorders** and **disordered eating,** the frail elderly, and people with liver or kidney disease.

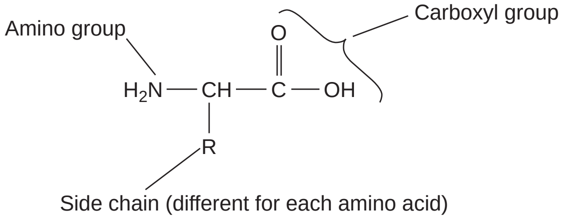


**Figure 5.1** The Basic Structure of an Amino Acid

### PROTEIN QUALITY

**Protein quality** is determined based on the amounts and types of amino acids and the extent to which the amino acids are absorbed. Protein quality is a critical issue in human growth and development. In countries where protein foods are abundant, sufficient protein quality is a near certainty, an assumption that should not be made in countries where protein foods are limited.

Humans must obtain through diet all of the indispensable amino acids, which are found in lower concentrations in plant proteins than in animal proteins. Animal proteins are termed **complete proteins** because they contain all the indispensable amino acids in the

**Protein:** Amino acids linked by peptide bonds.

**Energy:** The capacity to perform work.

**Enzyme:** A protein-containing compound that catalyzes biochemical reactions.

**Hormone:** A compound that has a regulatory effect.

**Amino acid:** The basic component of all proteins.

**Branched chain amino acid (BCAA):** One of three amino acids (leucine, isoleucine, and valine) that has a side chain that is branched.

**Indispensable amino acid:** Amino acid that must be provided by the diet because the body cannot manufacture it.

**Dispensable amino acid:** Amino acid that the body can manufacture.

**Conditionally indispensable amino acid:** Under normal conditions, an amino acid that can be manufactured by the body in sufficient amounts, but under physiologically stressful conditions an insufficient amount may be produced.

**Essential amino acid (EAA)**: See indispensable amino acid.

**Nonessential amino acid:** See dispensable amino acid.

**Eating disorder:** Substantial deviation from normal eating, which meets established diagnostic criteria.

**Disordered eating:** A deviation from normal eating.

**Protein quality:** The amounts and types of amino acids contained in a protein and their ability to support growth and development.

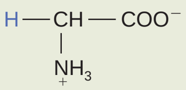
**Complete protein:** Protein that contains all the indispensable amino acids in the proper concentrations and proportions to each other to prevent amino acid deficiencies and to support growth.

**Table 5.1** Summary of the 20 Indispensable and Dispensable Amino Acids

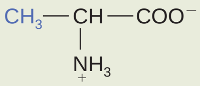
| Amino Acid | Figure Number | Classification | Glucogenic | Ketogenic | Miscellaneous |
|---|---|---|---|---|---|
| Alanine (Ala) | 2 | Dispensable | Yes | No | Can be produced in the muscle from pyruvate but must be transported to the liver for conversion to pyruvate to produce glucose. An important glucose-generating pathway during starvation |
| Arginine (Arg) | 14 | Conditionally indispensable | Yes | No | |
| Asparagine (Asn) | 12 | Dispensable | Yes | No | |
| Aspartic acid (Asp) | 10 | Dispensable | Yes | No | One of the two amino acids that make up the structure of the artificial sweetener aspartame |
| Cysteine (Cys) | 8 | Conditionally indispensable | Yes | No | |
| Glutamic acid (Glu) | 11 | Dispensable | Yes | No | |
| Glutamine (Gln) | 13 | Conditionally indispensable | Yes | No | Represents about half of all the amino acids in the amino acid pool; possible role as a countermeasure for the immunological stress of endurance exercise |
| Glycine (Gly) | 1 | Conditionally indispensable | Yes | No | |
| Histidine (His) | 16 | Indispensable | Yes | No | |
| Isoleucine (Ile) | 5 | Indispensable | Yes | Yes | Branched chain amino acid; muscle can use as an energy source during prolonged endurance exercise when muscle glycogen stores are low |
| Leucine (Leu) | 4 | Indispensable | No | Yes | Branched chain amino acid; muscle can use as an energy source during prolonged endurance exercise when muscle glycogen stores are low |
| Lysine (Lys) | 15 | Indispensable | No | Yes | |
| Methionine (Met) | 9 | Indispensable | Yes | No | |
| Phenylalanine (Phe) | 17 | Indispensable | Yes | Yes | One of the two amino acids that make up the structure of the artificial sweetener aspartame |
| Proline (Pro) | 20 | Conditionally indispensable | Yes | No | |
| Serine (Ser) | 6 | Dispensable | Yes | No | |
| Threonine (Thr) | 7 | Indispensable | Yes | Yes | |
| Tryptophan (Trp) | 19 | Indispensable | Yes | Yes | |
| Tyrosine (Typ) | 18 | Conditionally indispensable | Yes | Yes | |
| Valine (Val) | 3 | Indispensable | Yes | No | Branched chain amino acid; muscle can use as an energy source during prolonged endurance exercise when muscle glycogen stores are low |

**Table 5.1** Summary of the 20 Indispensable and Dispensable Amino Acids (continued)

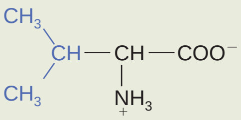
1. Glycine (Gly)



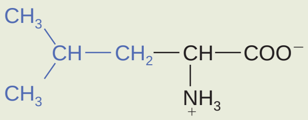
2. Alanine (Ala)



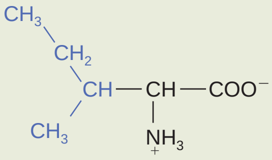
3. Valine (Val)



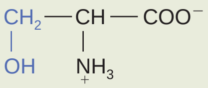
4. Leucine (Leu)



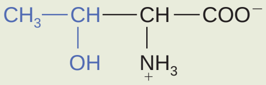
5. Isoleucine (Ile)



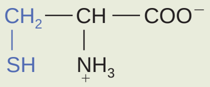
6. Serine (Ser)



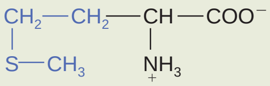
7. Threonine (Thr)



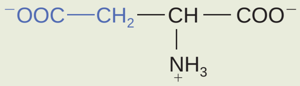
8. Cysteine (Cys)



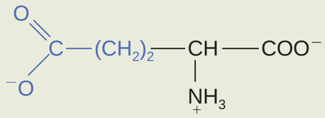
9. Methionine (Met)



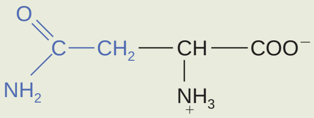
10. Aspartic acid (Asp)



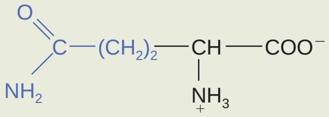
11. Glutamic acid (Glu)



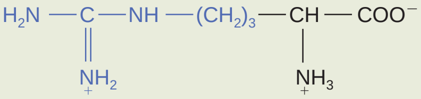
12. Asparagine (Asn)



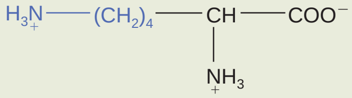
13. Glutamine (Gln)



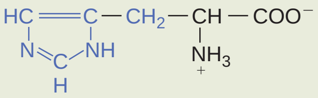
14. Arginine (Arg)



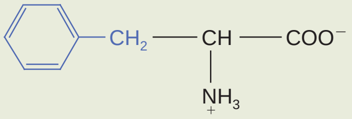
15. Lysine (Lys)



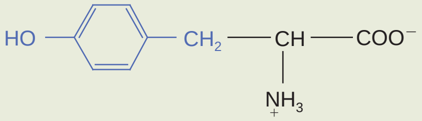
16. Histidine (His)



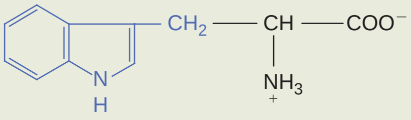
17. Phenylalanine (Phe)



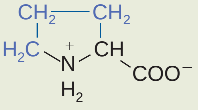
18. Tyrosine (Tyr)



19. Tryptophan (Trp)



20. Proline (Pro)



proper amounts and proportions to each other to prevent amino acid deficiencies and to support growth. In contrast, plant proteins may lack one or more of the indispensable amino acids or the proper concentrations and are termed **incomplete proteins.** The indispensable amino acids that are of greatest concern are lysine, threonine, and the sulfur-containing amino acids, cysteine and methionine. If the intake of these specific amino acids is limited, then protein deficiencies could occur.

It is possible to pair different plant proteins with each other and bring the total concentration of all the indispensable amino acids to an adequate level. This is the concept of **complementary proteins** or combining two incomplete proteins. When consumed together (i.e., during the same day), the complementary proteins can be nutritionally equal to a complete (animal) protein. This concept is more fully illustrated when vegetarian diets are discussed later in the chapter.

## BASIC STRUCTURE OF POLYPEPTIDES

**Peptide** refers to two or more amino acids that are combined. Specifically, **dipeptide** refers to two amino acids, **tripeptide** to three amino acids, and **polypeptide** to four or more amino acids. Most proteins are polypeptides and are made up of many amino acids, often numbering in the hundreds or thousands. *Protein* and *polypeptide* are terms that are used interchangeably. *Dipeptide* and *tripeptide* are terms that are typically used when discussing digestion and absorption.

Polypeptides are synthesized on ribosomes, organelles found in large numbers in the cytoplasm of cells. The primary structure of the protein is determined at its creation based on information contained in DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). The RNA acts like a blueprint for the type, number, and sequence of amino acids to be included in a particular polypeptide. The differences in amino acids influence the bonding abilities of the polypeptide, which affect the shape of the protein. For example, proteins can be straight, coiled, or folded based on the type, number, and sequence of amino acids in the polypeptide. The primary structure of the polypeptide determines how a protein functions.

The secondary structure of the polypeptide is a result of weak bonding of amino acids that are located close to each other. These weak bonds give more rigidity and stability to the protein, an important characteristic for structural proteins such as collagen. The tertiary (third) level of structure is a result of interactions of amino acids that are located far away from each other. These interactions, if present, cause the polypeptide to form a loop. The loop results in a clustering of certain amino acids, which then function in a particular way. For example, a cluster of amino acids may have a positive or negative charge and accept or repel other compounds, such as water. Quaternary (fourth) level structure involves more than one polypeptide, typically two or four. Because of their quaternary structure, these proteins can interact with other molecules. Insulin, which interacts with glucose, is an example of a compound made up of two polypeptides.

## FUNCTIONS OF POLYPEPTIDES

As explained above, the structure of the protein determines its function. Body proteins are often classified in five major categories: enzymes, hormones, structural proteins, transport proteins, and immune system proteins.

Enzymes are polypeptides that are necessary to catalyze reactions. It is the structure of the enzyme, particularly the quaternary structure, which allows the protein-based enzyme to interact with other compounds. The unique structure of each enzyme interacts with its substrate much like a key fits into and opens a specific lock. The purpose of enzymes is to regulate the speed of chemical reactions (refer to the more detailed description of enzymes in Chapter 2).

Hormones are compounds that act as chemical messengers to regulate metabolic reactions. Many hormones are protein based, although some hormones are made from cholesterol (e.g., steroid hormones). Insulin, glucagon, and human growth hormone are just three examples of the hundreds of hormones made from amino acids. Insulin is a relatively small polypeptide, made up of only 51 amino acids, yet it is one of the body's most essential hormones. Part of the polypeptide chain folds back on itself (due to its secondary structure) and the two protein chains that make up its quaternary structure are linked by disulfide bonds. Because insulin is small, it can move through the blood quickly and the folded chain and the disulfide bonds give it great stability.

Structural proteins include the proteins of muscle and connective tissue (e.g., actin, myosin, and collagen), as well as proteins found in skin, hair, and nails. Structural proteins can be constructed into long polypeptide strands, similar to a long chain. These strands can be twisted and folded into a wide variety of three-dimensional shapes (secondary structure). Elements of the constituent amino acids in the polypeptide chains, such as sulfide groups, may be brought close together by the twisting and folding and may form interconnected bonds (tertiary structure). The secondary and tertiary structures of the polypeptide are responsible for the differences in rigidity and the durability of these polypeptides.

Examples of transport proteins include lipoproteins (lipid carriers) and hemoglobin, which carries oxygen and carbon dioxide in the blood. Without its particular quaternary structure, hemoglobin would not be as efficient. Four polypeptide chains are bonded in such a way that they can work in concert and can change shape slightly when necessary. This structure allows hemoglobin to be flexible and capable of changing its ability to bind and release oxygen. For example, hemoglobin needs a high affinity to bind oxygen in the lungs and carry it throughout the body, but it must reduce its affinity for oxygen so oxygen can be released for use by the tissues.

The immune system is a protein-based system that protects the body from the invasion of foreign particles, including viruses and bacteria. One immune system response is the activation of lymphocytes, cells that produce antibodies. All antibodies are compounds that are made of polypeptide chains (usually four) in the shape of a Y. The antibody fits the virus or bacteria like a key in a lock, aiding in their destruction. The shape of the "key" is due to disulfide bonds and the sequence of the amino acids.

All of the compounds described above are proteins, but none of these compounds are provided directly from proteins found in foods. Enzymes, hormones, and the other protein-based compounds are manufactured in the body from indispensable and dispensable amino acids. To understand how food proteins become body proteins one must know how amino acids found in food are digested, absorbed, transported, and metabolized.

## Digestion, Absorption, and Transportation of Protein

Digestion begins as soon as proteins found in food arrive in the stomach. Absorption takes place primarily in the **jejunum** and **ileum** (i.e., middle and lower small intestine) by several mechanisms. Once absorbed, the amino acids will be transported to the liver, which acts as a clearinghouse. After a meal the majority of the amino acids absorbed will remain in the liver for metabolism, while the remainder will circulate in the blood and be transported to other parts of the body.

### DIGESTION OF PROTEINS

Protein digestion begins when a food protein comes in contact with the gastric juice of the stomach. The hydrochloric acid (HCl) in the gastric juice begins to **denature** (change the structure of) the protein. At the same time, the HCl activates pepsin, an enzyme that will break down the polypeptides into smaller units. Pepsin prefers to break the bonds of certain amino acids, such as leucine and tryptophan. This initial stage of digestion generally breaks down very large polypeptides into smaller units, but these smaller units are still very large amino acid chains.

As the denatured and partially digested polypeptides move from the stomach to the small intestine, a number of digestive enzymes are activated. Some of these are found in pancreatic juice, which is secreted from the pancreas into the small intestine. Other digestive enzymes are released from the cells of the brush border that line the gastrointestinal tract. Similar to pepsin, these enzymes prefer to break the bonds of specific amino acids. For example, some enzymes break down amino acids with rings while other enzymes break down amino acids with side chains.

Due to the action of the various enzymes, the large polypeptides that entered from the stomach are broken down into small polypeptides (usually no more than six amino acids), tripeptides, dipeptides, and free amino acids. The cells of the gastrointestinal tract can normally absorb nothing larger than a tripeptide, so the small polypeptides are broken down further by brush border enzymes.

### ABSORPTION OF PROTEINS

Absorption takes place primarily in the jejunum and the ileum. Two-thirds of the amino acids absorbed are in the form of dipeptides or tripeptides, while one-third are individual amino acids. Absorption takes place in a variety of ways but one of the most common is the use of a carrier that moves these compounds across the cell membrane. There are a number of different carriers and each has an affinity for certain amino acids. Some of the carriers require sodium to load the amino acids. Not surprisingly, indispensable amino acids are absorbed more rapidly than dispensable amino acids.

Since proteins must be broken down into dipeptides, tripeptides, and free amino acids to be absorbed, protein supplements may be sold as "predigested." The predigestion is a result of exposing the food proteins in the supplement to enzymatic action during the manufacturing process. Due to a lack of scientific studies, it

**Incomplete protein:** Protein that lacks one or more of the indispensable amino acids in the proper amounts and proportions to each other to prevent amino acid deficiencies and to support growth.

**Complementary proteins:** The pairing of two incomplete proteins to provide sufficient quantity and quality of amino acids.

**Peptide:** Two or more amino acids linked by peptide bonds.

**Dipeptide:** Two amino acids linked by peptide bonds.

**Tripeptide:** Three amino acids linked by peptide bonds.

**Polypeptide:** Four or more amino acids linked by peptide bonds; often contain hundreds of amino acids.

**Jejunum:** The middle portion of the small intestine.

**Ileum:** The lowest portion of the small intestine.

**Denature:** To change the chemical structure of a protein by chemical or mechanical means.

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A wide array of protein supplements is available. Some are sold as "predigested."

is not known if supplements containing predigested dipeptides and tripeptides are absorbed faster or differently than food proteins broken down into dipeptides and tripeptides by digestive enzymes. It is known that free amino acids do compete with each other for absorption because of carrier competition. If some free amino acids are found in higher concentrations than others, it is possible that they would be preferentially absorbed over the amino acids found in lower concentrations (Gropper, Smith, and Groff, 2005). Well-designed research studies are needed in this area.

Protein from food provides about two-thirds of the amino acids absorbed from the small intestine. These amino acids are described as being **exogenous** (from outside the body). The other one-third of the amino acids is **endogenous** (from inside the body). Endogenous proteins include mucosal cells shed into the gastrointestinal tract and gastrointestinal secretions that contain enzymes and other protein-based compounds. These endogenous proteins are broken down and absorbed in a manner similar to proteins originally derived from food, although they are often absorbed lower in the gastrointestinal tract, including the colon. This is the body's way of recycling amino acids, but not all of them can be reclaimed. Those that are not absorbed are excreted in fecal material, which represents one way that nitrogen is lost from the body and is one reason why dietary protein must be consumed daily. Once amino acids are absorbed, the body does not distinguish between the amino acids originally obtained from food and those from endogenous sources.

Once inside the mucosal cells, any dipeptides and tripeptides are broken down into free amino acids by cellular enzymes. Some of the amino acids will not leave the intestinal cells because they will be used to make cellular proteins. Those that are not incorporated into cellular proteins will be released into the blood via the **portal** (liver) **vein.**

### TRANSPORTATION OF PROTEINS

The liver serves as a clearinghouse for the amino acids by monitoring the supply of amino acids and dictating which amino acids will be transported to which tissues. Exceptions to this are the branched chain amino acids (BCAA)—leucine, isoleucine, and valine. The liver has very low levels of the enzyme BCAA transferase, which is needed to transfer these amino acids to tissues. Therefore, the branched chain amino acids leave the liver, circulate in the **plasma,** and are taken up by skeletal muscle cells, which have high levels of the enzyme that the liver lacks. BCAA transferase is also found in the heart, kidneys, and adipose tissue.

After a protein-containing meal, 50 to 65 percent of the amino acids absorbed will be found in the liver. The remainder of the amino acids absorbed will be immediately released as free amino acids into the blood and lymph and become part of the **amino acid pool,** which is shown in Figure 5.2. The concentration of amino acids in the blood is increased for several hours after a protein-containing meal is consumed.

The amino acid pool refers to free amino acids that are circulating in the blood or in the fluid found within or between cells. Half of the amino acid pool is found in or near skeletal muscle tissue while the remainder is distributed throughout the body. Some of the amino acids in the amino acid pool have recently been absorbed from the gastrointestinal tract, but most come from a different source—the breakdown of body tissues, including muscle tissue. The amino acid pool undergoes constant change but on average contains about 150 g of amino acids, of which ~80 g is glutamine. There are more dispensable amino acids in the pool than indispensable amino acids. The amino acid pool is always in flux as a result of food intake, exercise, and the breaking down or building of tissues, especially muscle. This constant flux is referred to as **protein turnover.** It is thought that a relatively large amount of energy (~20 percent of resting metabolism) is expended each day on synthesizing and degrading proteins.

## Metabolism of Proteins (Amino Acids)

The liver is a major site for amino acid metabolism. The liver monitors the body's amino acid needs and responds accordingly with anabolic or catabolic processes. **Anabolic** is defined as building complex molecules from simple molecules. An example is the synthesis of a protein. **Catabolic** is the breakdown of complex molecules into simple ones. The use of protein for energy is a catabolic process, as the protein must be broken down into its amino acid components, some of which are then metabolized for energy. The liver plays the primary role in amino acid metabolism but it functions

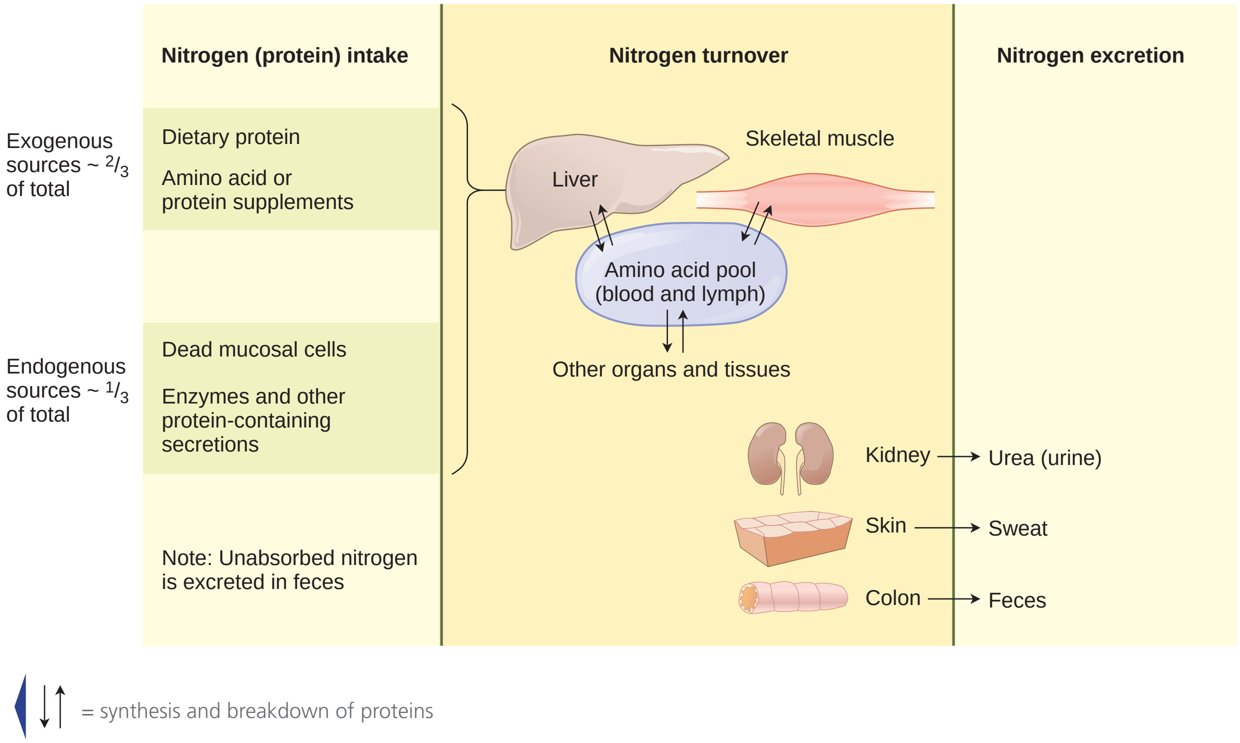
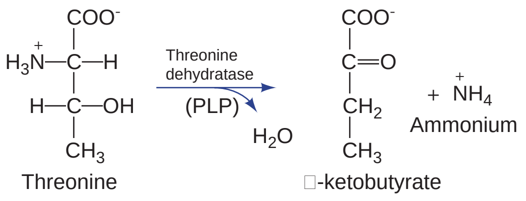


**Figure 5.2** Nitrogen Intake, Turnover, and Excretion

The amino acid pool is a reservoir of amino acids. It is always in flux as dietary protein is consumed, body proteins are broken down and synthesized, and nitrogen is excreted in urine, sweat, and feces.



PLP = pyroxidoxal phosphate (Vitamin $B_6$ containing enzyme)

**Figure 5.3** An Example of Deamination

The amino acid threonine is deaminated to form α-ketobutyrate (an α-keto acid).

Transamination involves the transfer of an amino group to another carbon skeleton, whereby an amino acid is formed. Transamination allows the liver to manufacture dispensible amino acids from indispensable amino acids. Deamination and transamination are regulated in concert with other tissues, such as skeletal muscle and kidneys.

What is the fate of the amino acids absorbed from the gastrointestinal tract and transported to the liver? The liver uses approximately 20 percent of these amino acids to make proteins and other nitrogen-containing compounds. The liver catabolizes (breaks down) the majority of the amino acids delivered from the gastrointestinal tract. Two important metabolic processes are **deamination** and **transamination.** Deamination refers to the removal of the amino group from the amino acid (see Figure 5.3). When the amino group is removed, the remaining compound is an **alpha-keto acid (α-keto acid),** frequently referred to as the **carbon skeleton.**

**Exogenous:** Originating from outside of the body.

**Endogenous:** Originating from within the body.

**Portal vein:** A vein that carries blood to the liver; usually refers to the vein from the intestines to the liver.

**Plasma:** Fluid component of blood; does not include cells.

**Amino acid pool:** The amino acids circulating in the plasma or in the fluid found within or between cells.

**Protein turnover:** The constant change in body proteins as a result of protein synthesis and breakdown.

**Anabolism:** Metabolic processes involving the synthesis of simple molecules into complex molecules.

**Catabolism:** Metabolic processes involving the breakdown of complex molecules into simpler molecules.

**Deamination:** The removal of an amino group.

**Transamination:** The transfer of an amino group.

**Alpha-keto acid (α-keto acid)**: The chemical compound that is a result of the deamination (i.e., nitrogen removal) of amino acids.

**Carbon skeleton:** The carbon-containing structure that remains after an amino acid has been deaminated (i.e., nitrogen removed).

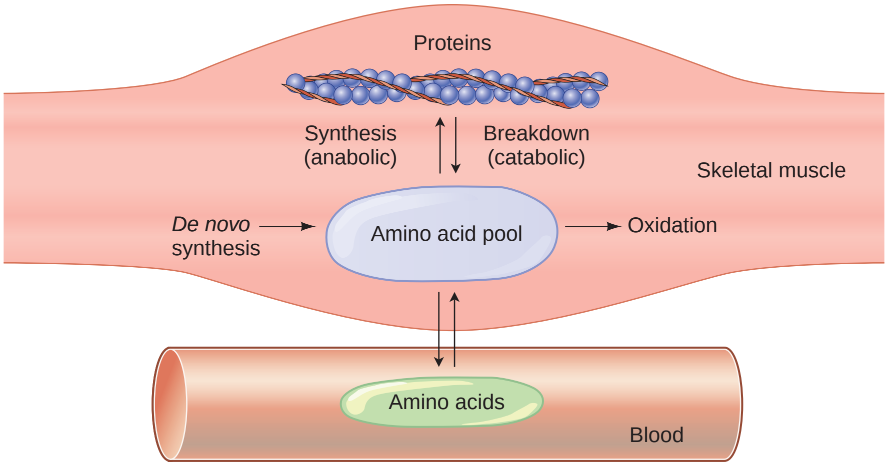


**Figure 5.4** Skeletal Muscle Protein Turnover

A general depiction of muscle protein turnover (synthesis and breakdown). The amino acid pool in muscle tissue is derived from amino acids taken up from the blood, those synthesized in the muscle (de novo synthesis), or those from the breakdown of muscle protein. Amino acids from this pool can be used to synthesize muscle proteins, metabolized for energy via oxidative phosphorylation, or released into the blood for distribution to other tissues in the body.

by enzymes and are part of an intricate system that the liver uses to monitor and respond to the body's amino acid and protein needs.

Amino acids absorbed from food that do not remain in the liver become part of the amino acid pool. The amino acids in the pool are also involved in both anabolic and catabolic processes. For example, the synthesis of skeletal muscle protein is an anabolic process that uses amino acids from the pool to synthesize new proteins. When skeletal muscle proteins are degraded, a catabolic process, the amino acids are returned to the amino acid pool.

## PROTEIN ANABOLISM

One of the major functions of the liver is protein anabolism. Some amino acids will be incorporated into liver enzymes. Others will be used to make **plasma proteins.** For example, the liver manufactures albumin, a protein that circulates in the blood and helps to transport nutrients to tissues. Many of the proteins made in the liver are synthesized and released in response to infection or injury. As mentioned earlier, the liver continually monitors the body's amino acid and protein needs and responds to changing conditions.

In addition to protein synthesis, the liver uses amino acids to manufacture compounds such as creatine. Recall from Chapter 3 that creatine can be obtained directly from the diet (e.g., beef, fish) and/or synthesized from the amino acids arginine, glycine, and methionine. The creatine synthesis process begins in the kidney but is completed in the liver.

Of particular interest to athletes is the synthesis and breakdown of skeletal muscle proteins. Figure 5.4 illustrates protein turnover. An anabolic state occurs when the synthesis of proteins is greater than their breakdown. In the anabolic state, amino acids from the amino acid pool are incorporated into the synthesis of proteins. How does this anabolic process occur? The process of protein synthesis occurs by the stimulation of a specific gene within a cell, which then sets into motion a series of complex steps resulting in the assembly of a specific protein.

A gene is a section of DNA in a chromosome of a cell that contains specific information to control hereditary characteristics. When stimulated, genes "express" these characteristics, usually through the synthesis of specific proteins. For example, the mechanical stress of force production by muscle that occurs as a result of strength training stimulates the genes that regulate the synthesis of actin and myosin. The target genes are signaled in a variety of ways beginning with the first step of the process, transcription. In transcription, the code for making each specific protein is copied to RNA. The next step is translation, during which RNA passes on the directions for manufacturing the protein to the ribosomes, cell organelles that assemble the amino acids from the amino acid pool into the correct sequence for that specific protein.

A simple analogy for this series of steps is the process of designing and building a house. The architect creates and keeps an original, detailed set of drawings and plans for the house. The architect does not build the house, however; this task is usually the responsibility of a building contractor. The contractor takes a copy of the architectural plans to the construction site and gives specific instructions to the construction workers to build the house as it appears in the plans. The original architectural plan is the gene (the specific DNA sequence in the cell), the "working copy" of the house construction plan is the RNA, and the construction site of cell protein synthesis is the ribosomes.

There are many factors that influence muscle protein synthesis and degradation, including genetics, exercise, nutrition, hormones, injury, and disease. The synthesis of muscle protein is strongly influenced by exercise, specifically strength training. The mechanical force that is developed by muscle during strength training stimulates both protein synthesis and protein breakdown. Protein synthesis is stimulated to a greater degree because one of the adaptations of skeletal muscle in response to strength training over time is **hypertrophy,** an increase in the amount of muscle tissue. The greatest increase is in **myofibrillar proteins,** the proteins that make up the force-producing elements of the muscle.

Feeding also promotes an anabolic state in the muscle, particularly if the meal contains adequate amino acids. Insulin has an important role in this anabolic process by stimulating protein synthesis and acting to inhibit protein degradation. Athletes have long known that strength training stimulates muscle growth and have recently begun to explore the manipulation of protein intake in conjunction with their strength training to optimize protein synthesis (see Timing of Protein Intake). Unfortunately, it is difficult to study optimal protein synthesis in athletes.

## PROTEIN CATABOLISM

Amino acids that are not used for building proteins are catabolized. In other words, excess amino acids are not "stored" for future use in the same way that carbohydrates and fats are stored. Carbohydrate can be stored in liver or muscle as glycogen and fat can be stored in adipocytes (fat cells) and at a later time removed easily from storage and used as energy. In contrast, the so-called "storage" site for protein is skeletal muscle. Under relatively extreme circumstances, protein can be removed from the skeletal muscle, but the removal of a large amount of amino acids has a very negative effect on the muscle's ability to function.

Amino acids can provide energy. In fact, the source of approximately half of the ATP used by the liver comes from amino acids. When the amino group is transferred or removed, the carbon skeleton (alpha-keto acid) can be oxidized to produce energy (i.e., ATP). Although it is commonly written that amino acids are oxidized for energy, this is technically incorrect because the nitrogen is not oxidized. The term "oxidation of amino acids" is understood to mean that after the nitrogen is removed, the carbon skeleton of the amino acid is oxidized for energy and the nitrogen goes through the urea cycle in the liver.

Similar to carbohydrate, protein yields approximately 4 kcal/g. Energy is best supplied for exercise by carbohydrate and fat rather than protein. Sufficient caloric intake in the form of carbohydrate and fat is referred to as having a **protein-sparing effect.** In other words, the carbohydrate and fat provide the energy that the body needs and the protein is "spared" from this function. The protein is available for other important functions that can only be provided by protein. When people consume sufficient energy, all the important protein-related functions can be met and, in fact, some of the protein consumed *will* be metabolized for energy. Problems can result if caloric intake is too low and some protein *must* be used to meet energy needs.

The metabolic pathways for producing energy from protein are not reviewed in detail here; however, the catabolism of amino acids to provide ATP is summarized. Under aerobic conditions the carbon skeleton of an amino acid can be used in the Krebs cycle. As shown in Figure 5.5, amino acids have different entry points into the Krebs cycle, which is based on the structure of each amino acid. Some amino acids, such as alanine and glycine, can be converted to pyruvate. Others, such as leucine, are converted to acetyl Co-A. Additional pathways include the conversion of various amino acids to intermediate compounds of the Krebs cycle.

Six amino acids are most commonly broken down in muscle cells to yield energy—the branched chain amino acids (leucine, isoleucine, and valine), aspartate, asparagine, and glutamate. The breakdown of muscle, or **proteolysis,** is stimulated by the stress hormone **cortisol,** which is secreted by the adrenal glands. When the body is stressed, one response is the oxidation of amino acids. Endurance exercise represents an **acute** (short-term) stress so the use of amino acids for energy is not unexpected.

Endurance exercise results in an increased oxidation of leucine. At the beginning of an endurance exercise task there is usually sufficient carbohydrate stored as muscle glycogen, so little of the energy needed comes from amino acids initially. But as muscle glycogen stores decline substantially, the muscle uses some amino acids, particularly leucine, for energy. This metabolic response is influenced by the carbohydrate content of the athlete's diet. When the athlete has been consuming a low-carbohydrate diet

**Plasma protein:** Any polypeptide that circulates in the fluid portion of the blood or lymph, (e.g., albumin).

**Hypertrophy:** An increase in size due to enlargement, not an increase in number; in relation to muscle refers to an increase in the size of a muscle due to an increase in the size of individual muscle cells rather than an increase in the total number of muscle cells.

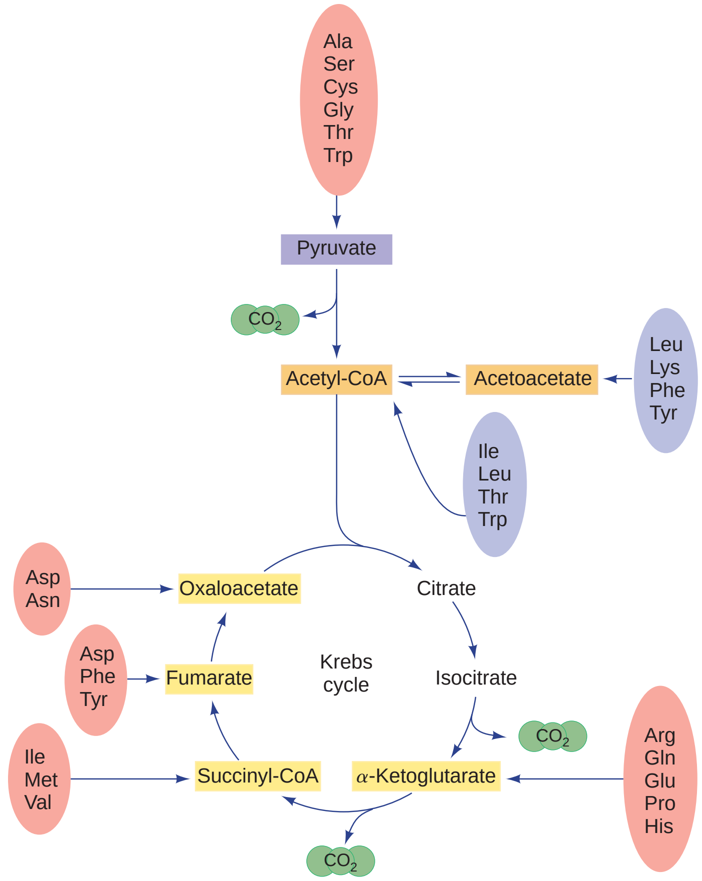
**Myofibrillar proteins:** The strandlike proteins that make up the force-producing elements of skeletal muscle, specifically the contractile proteins actin and myosin.

**Protein-sparing effect:** The consumption of sufficient kilocalories in the form of carbohydrate and fat, which protects protein from being used as energy before other protein-related functions are met.

**Proteolysis:** The breakdown of proteins into amino acids.

**Cortisol:** A glucocorticoid hormone that is secreted by the adrenal cortex that stimulates protein and fat breakdown and counters the effects of insulin.

**Acute**: Short-term.



Ala = alanine
Arg = arginine
Asn = asparagine
Asp = aspartic acid
Cys = cysteine
Glu = glutamic acid
Gln = glutamine
Gly = glycine
His = histidine
Ile = isoleucine
Leu = leucine
Lys = lysine
Met = methionine
Phe = phenylalanine
Pro = proline
Ser = serine
Thr = threonine
Trp = tryptophan
Tyr = tyrosine
Val = valine

**Figure 5.5** Amino Acids Used for ATP Production

The structure of the amino acid determines the entry point into the Krebs cycle.

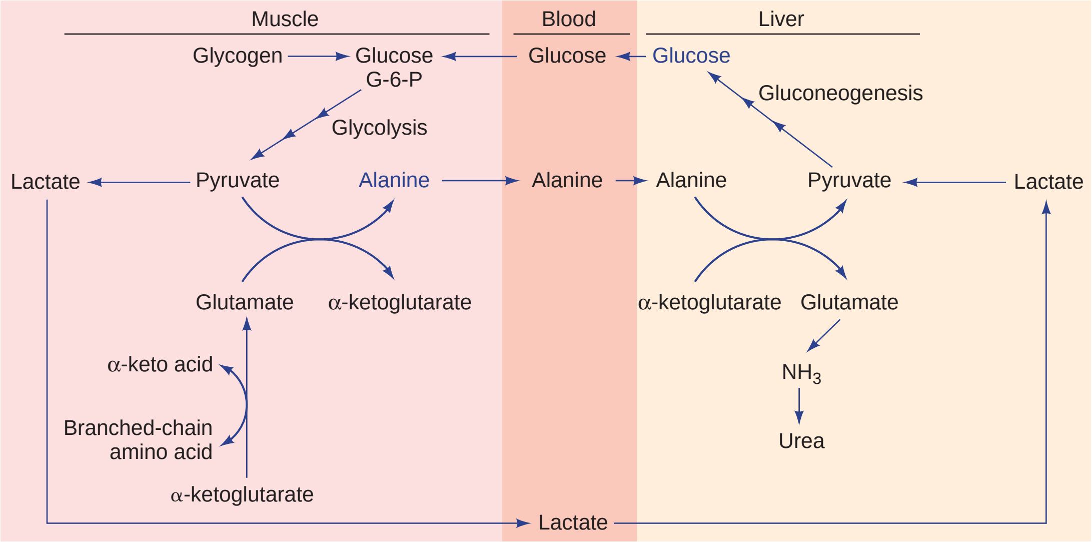
and is carbohydrate depleted, the oxidation of leucine is increased, while a high-carbohydrate diet and near-maximal muscle glycogen stores decrease the need for leucine oxidation (McKenzie et al., 2000).

As a percentage of the total energy used, that which comes from amino acids is small, about 3 to 5 percent. However, under the stress of endurance exercise, amino acids can represent an important energy source. For this reason, endurance athletes have explored the use of BCAA supplements, which will be discussed later in this chapter.

A discussion of protein catabolism would not be complete without mention of the ammonia ($NH_3$) or ammonium ions ($NH^+_4$) that are produced as a result of the catabolism of amino acids. Ammonia, which is toxic to the body, must be converted to urea, a related compound that can be safely transported in the blood to the kidneys where it is excreted in urine. The conversion of ammonia to urea takes place in the liver, so

Sandra Mu/Getty Images

Prolonged endurance exercise results in increased protein metabolism, particularly in the later stages of a triathlon.



G-6-P = glucose-6-phosphate
$NH_3$ = ammonia

**Figure 5.6** Glucose-Alanine Cycle

Muscle produces pyruvate as a result of using the glycolysis or glycogenolysis energy pathway. This pyruvate can be converted to alanine, which is then released into the blood and taken up by the liver. The liver can then convert the alanine to pyruvate for use in gluconeogenesis to produce glucose. The newly formed glucose can be released into the blood for distribution throughout the body and use by a variety of tissues.

ammonia that is a result of amino acid catabolism in the liver can readily enter the urea cycle. Ammonia is also produced in the muscle as a result of the breakdown of adenosine monophosphate (AMP), which produces a compound that can be oxidized in the Krebs cycle for energy. This ammonia must be transported in the blood to the liver for conversion to urea. Urea contains nitrogen, so a small amount of nitrogen is lost every day via the urine. This loss of nitrogen is one reason that dietary protein must be consumed daily.

In addition to the oxidation of amino acids to produce ATP, a second major metabolic use of protein during exercise is for **gluconeogenesis** (i.e., the production of glucose from a noncarbohydrate source). The glucose-alanine cycle illustrates how amino acids can be used to generate glucose (see Figure 5.6). Exercising muscle may use carbohydrate (glucose and/or glycogen) for metabolism and in this process some of the pyruvate produced by **glycolysis** is converted (via transamination) to the amino acid alanine. Alanine is not used by the muscle, but is released into the blood where it travels to the liver. In the liver, alanine (as well as other amino acids) can be converted to pyruvate to produce glucose, a process known as gluconeogenesis. The newly formed glucose can then be released into the blood where it circulates and is taken up and used by a variety of tissues (e.g., brain, kidney, muscle). Eighteen of the 20 amino acids can be converted into glucose (only leucine and lysine cannot) and this primarily takes place in the liver. Although various amino acids can provide the carbon skeleton for gluconeogenesis, during exercise lactate is most likely the major source.

**Effects of Training on Protein Usage.** The effect of exercise training on the use of protein as a fuel source is not well established. Based on adaptations of other metabolic energy systems to the **chronic** stress of exercise, it is logical to assume that protein metabolism would be enhanced after exercise training, particularly endurance exercise training. The level of transaminase enzymes in muscle can increase two-fold, and studies with animal models show an increased ability to oxidize BCAA during exercise. However, evidence in humans (McKenzie et al., 2000) suggests that the amount of amino acid oxidation, specifically leucine, is actually reduced at both the same absolute and relative exercise intensity after endurance exercise training. The endurance exercise training apparently enhances fat oxidation to such a degree that the body does not need to rely as much on protein metabolism, giving further evidence that protein is not the body's preferred fuel source.

**Gluconeogenesis:** The manufacture of glucose by the liver from other compounds such as lactate, protein, and fat. Gluco = glucose, neo = new, genesis = beginning.

**Glycolysis:** A series of linked chemical reactions that break down glucose for energy to replace ATP.

**Chronic:** Always present or recurring; long-term.

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Athletes must be in positive nitrogen balance to increase skeletal muscle mass. Negative nitrogen balance, as a result of starvation, leads to substantially reduced skeletal muscle mass.

## PROTEIN BALANCE AND TURNOVER

The body is in a constant state of protein turnover. In other words, every day the body simultaneously degrades and synthesizes proteins. It is estimated that 1 to 2 percent of the total protein in the body is degraded each day (i.e., proteins are broken down to the amino acids that formed them). The source of most of the degraded protein is skeletal muscle, and these amino acids become part of the amino acid pool. About 80 percent of the amino acids that result from protein degradation are resynthesized into new proteins. However, at least 20 percent of the amino acids are not made into new proteins and are broken down to yield nitrogen, which must be excreted in the urine or feces, and carbon skeletons, which are used for energy. Approximately 5 to 7 g of nitrogen, which is equivalent to 30 to 40 g of protein, is excreted via the urine each day. This fact alone makes it obvious that humans need to consume protein in their diets each day.

The term protein turnover is used to compare protein synthesis with protein degradation. In a growth state, protein synthesis outpaces protein degradation. In a starvation state, protein degradation outpaces protein synthesis. Each protein in the body has its own turnover rate. Some turn over very quickly, in a matter of minutes, while others take several months to turn over.

Protein metabolism is never static; rather, it is always changing. One way to measure and describe the changes is to determine **nitrogen balance.** Nitrogen balance is the difference between total nitrogen (protein) intake and total nitrogen loss (via the urine and feces), usually determined over several weeks. When intake is equal to loss, a state of nitrogen balance exists. When intake is greater than loss, a person is in positive nitrogen balance. Conversely, when loss is greater than intake, a state of negative nitrogen balance is present.

Under normal conditions most adults are in nitrogen balance. Their intake of nitrogen is in equilibrium with their nitrogen losses. There is also equilibrium in their protein turnover. In other words, the amount of protein being synthesized is equal to the amount of protein being degraded. On average, the adult body turns over about 320 g of protein a day. Those adults who want to be in a growth state must achieve positive nitrogen balance. Adult growth states include pregnancy and substantial increases in skeletal muscle mass, which is a goal for many athletes, particularly strength athletes. To achieve positive nitrogen balance both energy and protein intake must be sufficient. More details about increasing skeletal muscle mass can be found in Chapter 11.

Negative nitrogen balance is not desirable. Examples of conditions in which negative nitrogen balance occurs include starvation and semistarvation states (e.g., eating disorders such as anorexia athletica) and disease states such as fast-growing cancers.

Protein turnover and nitrogen balance are not the same, but they are related. In a growth state, the body is in positive nitrogen balance. Protein synthesis is also outpacing protein degradation. Although the exact mechanisms for regulating balance and turnover are not entirely known, the amino acid pool does play a role (Gropper, Smith, and Groff, 2005). Unfortunately, protein turnover and nitrogen balance are difficult to study in humans.

In addition to the amino acid pool, the body has a **labile protein reserve.** This reserve of amino acids is found in liver and other organs **(visceral tissues).** Labile refers to something that readily or frequently undergoes change. The labile protein reserve allows the body to respond to very short-term changes in protein intake. For example, if on a given day a person consumed little food and little protein (e.g., fasting), then the body can immediately tap the labile protein reserve and provide


AP Photo/Eduardo Verdugo

AP Photo/Elaine Thompson

Both strength/power and endurance athletes need adequate protein daily.

amino acids to the amino acid pool. Having the ability to quickly use liver and other visceral tissue proteins as a source of amino acids allows the body to protect the skeletal muscle from being used as an amino acid source for short-term emergencies (Institute of Medicine, 2002).

When faced with semistarvation or starvation the body adapts by decreasing the rate of protein synthesis and increasing protein degradation. The rate of protein synthesis is decreased overall by at least 30 percent and to a greater degree in skeletal muscle than in other tissues. This is another example of the negative impact that insufficient energy intake has on protein metabolism. Under starvation conditions the hormonal balance also changes. Food is not being consumed, so little insulin is being produced and the muscle and fat cells become resistant to the insulin that is present. Without the influence of insulin, protein synthesis is further reduced because insulin promotes the uptake of amino acids by the muscle cells. The **hormonal milieu** in this case favors the breakdown of muscle protein to provide amino acids such as alanine, which can be used to make glucose. Earlier it was mentioned that visceral tissues (i.e., liver and other organs) protect the skeletal muscle from being used as an amino acid source for short-term emergencies. During prolonged starvation the situation is reversed and the amino acids in skeletal muscle are used to protect the visceral tissues. The reason for this change is that visceral tissue proteins turn over very quickly and these visceral proteins are critical for the body's survival. Skeletal muscle is sacrificed in long-term and extreme starvation states.

## INTEGRATION OF METABOLIC PATHWAYS

Carbohydrate, protein, and fat metabolism are complicated, so each is usually explained individually. However, all metabolic pathways are integrated and the liver plays a major role in metabolizing carbohydrate, protein, and fat and regulating their metabolism. Substrate utilization will depend, in part, on whether the body is in a fed (absorptive) state or a postabsorptive state, the two states humans experience under normal conditions. Other conditions, such as fasting or long-term starvation, force the body to reprioritize its metabolic processes. Table 5.2 shows the metabolic pathways favored under various conditions.

The fed state refers to the three to four hours after a meal is eaten, and for this discussion assumes that a mixture of carbohydrate, protein, and fat is consumed and that the individual is nonobese. Insulin is the hormone that primarily affects substrate metabolism at this time. In general, as a result of insulin, the liver and muscle cells take up glucose, synthesize glycogen, and produce energy (i.e., glycolysis). Additionally, fatty acids are synthesized in the liver and stored in adipose tissue and protein synthesis is increased.

Other metabolic pathways are favored in the postabsorptive state, which begins about three to four hours after eating and may last as long as 12 to 18 hours. The liver provides glucose to the blood by breaking down liver glycogen. Some glucose is also produced from noncarbohydrate sources (i.e., gluconeogenesis). Fatty acids are released from adipose cells and are used by both the liver and muscle to produce ATP. Glucagon, a counter-regulatory hormone to insulin, stimulates

**Nitrogen balance:** When total nitrogen (protein) intake is in equilibrium with total nitrogen loss.

**Labile protein reserve:** Proteins in the liver and other organs that can be broken down quickly to provide amino acids.

**Visceral tissue:** Tissue of the major organs, such as the liver.

**Hormonal milieu:** The hormonal environment.

**Table 5.2** Metabolic Pathways Favored Under Normal and Starvation Conditions

| | Liver | Muscle | Adipose Tissue | Central Nervous System (CNS) |
|---|---|---|---|---|
| Fed (absorptive) state | Glucose used as energy, stored as glycogen, and converted to fatty acids if energy intake is greater than expenditure; Amino acids metabolized; Fatty acids transported to adipose tissue for storage as triglycerides | Glucose used for energy or stored as glycogen | Fatty acids are stored as triglycerides (3 fatty acids + glycerol) | Glucose from food used to provide energy |
| Postabsorptive state | Glycogen broken down to provide glucose; Manufacture of glucose from lactate and alanine (provided by muscle) and glycerol (provided by the breakdown of fat from adipose tissue) begins | Glucose used for energy, some glycogen storage continues; Lactate and alanine released to liver to make glucose; Fatty acid uptake (provided by the breakdown of fat from adipose tissue) for use as energy | Triglycerides are broken down to provide fatty acids to muscle and liver; Glycerol to liver to be used for glucose | Glucose comes predominantly from liver glycogen |
| Fasting (18 to 48 hours without food) | Liver glycogen is depleted; glucose made from lactate and amino acids provided by muscle; Red blood cells also provide some lactate | Muscle protein degraded to provide amino acids to liver; Lactate to liver for glucose synthesis | Same as above | Glucose provided by the liver (from lactate and amino acids) |
| Starvation (>48 hours without food) | Liver continues to manufacture glucose, predominantly from glycerol (from adipose tissue) to prevent muscle from providing amino acids and lactate; Fatty acids broken down to produce ketones (for use by CNS and muscle) | Muscle depends predominantly on fatty acids and ketones for energy | Triglycerides are broken down to provide fatty acids to muscle and liver; Glycerol to liver to be used for glucose | CNS depends primarily on ketones produced by the liver for energy |

protein degradation in skeletal muscle, although it also stimulates the synthesis of liver proteins.

Fasting, a lack of food intake for 18 to 48 hours, forces the body to adapt its energy systems to an uncommon and threatening circumstance. Glycogen is nearly depleted in the liver, and gluconeogenesis must be increased. This forces the liver to use more amino acids as a source to produce glucose. Recall that 18 of the 20 amino acids are glucogenic, meaning that they are biochemically capable of being used to manufacture glucose. Some of these amino acids are in muscle cells and the fasting state increases the rate at which skeletal muscle is broken down. Degrading muscle proteins results in a mixture of amino acids being released; however, one of the most prominent is alanine. Alanine and lactate, also present in muscle cells, and glycerol, obtained from the breakdown of fatty acids stored in adipose tissue, will be transported to the liver for the manufacture of glucose.

Long-term starvation (lack of food intake for >48 hours) poses a clear threat to the body and more metabolic adjustments are made. Amino acids must be protected from being used for glucose so that they can be available for the synthesis of vital compounds such as the plasma proteins and enzymes. To meet its glucose needs the body depends on glycerol (released from adipose tissue) to manufacture glucose. The brain uses some of the glucose produced but because the amount is small, it will use ketones predominantly for energy under starvation conditions (it cannot use fatty acids for fuel). Fatty acids become the primary fuel source for skeletal muscle and liver. All these adaptations are made to prevent or delay the breakdown of body proteins.

Although this explanation is very brief, it does point out how the body shifts its metabolic pathways in response to various conditions and the role that the liver plays. Consuming a sufficient amount of energy from dietary carbohydrate and fat sources is an important influence on protein metabolism. Fasting and starvation are obviously not desirable conditions for the athlete.

**What's the point?** The body is in a constant state of protein turnover—anabolism (synthesis) and catabolism (breakdown), processes that are highly influenced by the liver and total caloric (energy) intake. Skeletal muscle proteins are synthesized using amino acids from the amino acid pool. Conversely, skeletal muscle can be broken down to provide amino acids back to the pool.

## Protein Recommendations for Athletes

Many years of research has led to well-established protein recommendations for nonathletes. There is a general consensus on the amount of protein needed by strength, endurance, and ultraendurance athletes, although controversies still exist and more research on highly trained athletes is needed. There are many obstacles to studying protein balance, turnover, need, and timing in athletes.

### RECOMMENDED TOTAL DAILY PROTEIN INTAKE FOR ATHLETES AND NONATHLETES

The Dietary Reference Intake (DRI) for adults is 0.8 g of protein/kg body weight daily (Institute of Medicine, 2002). Recommendations for protein intake for athletes usually fall between 1.0 and 2.0 grams of protein/kg body weight/day (g/kg/d). These recommendations make two assumptions: 1) energy intake is adequate and 2) the quality of the protein is good. In the United States and other developed countries, protein quality is usually not a concern. However, it cannot be assumed that energy intake is adequate for all athletes.

Although 1.0 to 2.0 g/kg/d is the general protein guideline, more specific recommendations are made depending on the predominant type of training (i.e., endurance, ultraendurance, or strength). It is typically recommended that endurance athletes consume 1.2 to 1.4 g/kg of protein daily while the recommendation for strength athletes is 1.6 to 1.7 g/kg of protein daily (American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine, 2000). Recreational athletes may need the same or just slightly more protein than nonathletes (0.8 to 1.0 g/kg/d) and ultraendurance athletes may need much more depending on the training mesocycle (up to 2.0 g/kg/d) (Seebohar, 2006). General protein recommendations are shown in Table 5.3.

**Table 5.3** General Protein Recommendations Based on Activity

| Level of Activity | Recommended Daily Protein Intake |
|---|---|
| Sedentary adults | 0.8 g/kg |
| Active adults (e.g., recreational athletes not in training) | 0.8 to 1.0 g/kg |
| Endurance athletes | 1.2 to 1.4 g/kg |
| Ultraendurance athletes | 1.2 to 2.0 g/kg |
| Strength athletes | 1.6 to 1.7 g/kg |

**Legend:** g/kg = grams per kilogram body weight

While these ranges are good guidelines, they may need to be adjusted slightly depending upon the individual athlete's specific circumstances. Similar to carbohydrate and fat recommendations, protein intake may need to change as the training cycles change. For example, a strength athlete may consume 1.5 g/kg/d during training periods when the goal is muscle mass maintenance but increase protein intake slightly when the goal is to increase muscle mass. Many athletes engage in both endurance and strength training to various degrees over the course of a year's training, and increasing or decreasing the amount of protein in their diets to match their training goals is appropriate.

The need for protein is influenced by energy intake. As a rule of thumb, when energy intake is deficient, protein intake should be increased. The extent of the increase will depend on whether the deficits are long- or short-term, but a general recommendation is to increase protein intake by ~15 percent. For an athlete whose usual protein intake is 1.2 g/kg as part of a diet that provides sufficient energy, it is prudent to increase protein intake to 1.4 g/kg when energy intake is deficient (e.g., "dieting"). Low protein intake when coupled with low energy intake over time will eventually affect the body's "stores" of protein (i.e., muscle mass), training, performance and, ultimately, the ability to engage in physical activity.

**Expressing Protein Recommendations as a Relative Amount.** All of the protein recommendations for athletes mentioned so far have been expressed on a gram per kilogram body weight basis (g/kg). In other words, protein recommendations are stated as an absolute amount. Sometimes recommendations are stated as a percent of total energy intake (e.g., 15 percent of total calories as protein), which is a relative amount. This relative method is problematic for athletes for two reasons: 1) athletes may not be consuming an adequate amount of energy and 2) protein requirements increase when energy intake is deficient. The Spotlight on Enrichment: Protein Intake feature discusses how percentages based on total energy intake are distorted when caloric intake is low.

Nutrient recommendations are often expressed as a percentage of calories because it is easier for consumers to understand. The typical American does not know his or her weight in kilograms, so a recommendation to consume 0.8 g of protein per kilogram body weight is not seen as being very practical. The Acceptable Macronutrient Distribution Range (AMDR) for protein for adults is 10 to 35 percent of energy. This recommendation was developed for the general population and assumes that energy intake is adequate and that physical activity is low. The lower end of this recommended range (10 percent) corresponds to the 0.8 g of protein per kilogram body weight recommended for adults (Institute of Medicine, 2002).

Percentage guidelines for protein intake for athletes usually range from 10 to 30 percent of total caloric intake. For endurance athletes, an intake of 10 to 15 percent of total calories from protein is typical because carbohydrate intake is relatively high (60 to 70 percent). The remaining kilocalories, 15 to 30 percent of total caloric intake, will likely be provided by fat. In some cases, alcohol may be a source of a small percentage of total caloric intake.

Guidelines for percentage of protein intake for strength athletes often range from 15 to 20 percent of total calories. These percentages take into account that carbohydrate intake must be sufficient (~50 to 60 percent of total caloric intake). Given these guidelines, fat intake would range from 20 to 35 percent of total calories, although a small percentage may be provided by alcohol. Other configurations have been suggested, such as the 40–30–30 diet (40 percent carbohydrate and 30 percent each protein and fat), which is discussed in Chapter 12. Although percentage of total calorie guidelines can be useful for athletes consuming sufficient calories, it is recommended that athletes use recommendations based on g/kg because such figures will not be distorted by low caloric intake.

**Recommended Protein Intake for Vegetarian Athletes.** Vegetarians do not consume the flesh of animals (e.g., meat, fish or poultry), but may consume animal products (e.g., eggs, milk, cheese). **Vegans** do not consume any product derived from animals. There have been no studies examining the amount of protein required by vegetarian athletes. A common recommendation for physically active vegetarians is to consume 10 percent more than the nonvegetarian athlete. Thus, general protein guidelines for vegetarian athletes are in the range of 1.1 to 2.2 g/kg/d. This 10 percent figure is an adjustment for the lower digestibility of plant proteins when compared to animal proteins. Consuming this amount of protein is not difficult if energy intake is sufficient. Vegans tend to have lower protein intakes than nonvegans. It is recommended that vegan athletes emphasize more protein-rich vegetarian foods (e.g., beans, legumes, soy milk, tofu) than vegetarian foods that are relatively low in protein (e.g., fruits, vegetables) (Larson-Meyer, 2006). More information about vegetarianism can be found in the section entitled, Vegetarian Diets.

## TIMING OF PROTEIN INTAKE

Obtaining an adequate amount of protein each day is fundamentally important, but athletes should not overlook the importance of the timing of protein intake throughout the day, especially after exercise. Consuming protein prior to resistance exercise has not been as well studied (see Spotlight on Enrichment: Other Protein Timing Issues for Athletes).

**Protein Consumption after Exercise.** The acute effect of exercise is to put the body into a catabolic state, breaking down certain tissues to provide the energy to sustain the exercise. For example, muscle glycogen is broken

### SPOTLIGHT ON ENRICHMENT

### Protein Intake Expressed as a Percentage of Total Calories Can Be Deceiving

Dietary analysis programs often calculate protein intake as a percentage of total energy intake. When caloric intake is adequate, protein intake is considered adequate if at least 10 percent of total caloric intake is provided by protein. However, if total caloric intake is too low, then protein intake may be too low. For example, a 50-kg (110-lb) woman needs at least 40 grams of protein daily (0.8 g/kg/d × 50 kg). If she were sedentary, she would need approximately 1,500 kcal per day (30 kcal/kg × 50 kg). Forty grams of protein is 160 kcal (40 g × 4 kcal/g) and would be approximately 10 to 11 percent of her total caloric intake (160 kcal ÷ 1,500 kcal). Because her calorie intake was adequate, the percentage of calories provided by protein represents an amount of protein that is adequate.

This is not the case if her caloric intake is too low. If her caloric intake were 1,200 kcal and protein provided 11 percent of her intake, the amount of protein she consumed would only be 33 g (1,200 kcal × 0.11 = 132 kcal from protein; 132 kcal ÷ 4 kcal/g = 33 g). When calculated on a g/kg basis, her protein intake would be only 0.66 g/kg (33 g ÷ 50 kg), less than the 0.8 g/kg recommended. Percentages get distorted when caloric intake is very low, so expressing protein on a gram per kilogram basis is recommended.

down to provide glucose, stored fats are broken down to mobilize fatty acids, and muscle proteins are broken down to provide amino acids that can be used as energy (e.g., leucine). An important recovery strategy for athletes is to reverse the catabolic state, and put the body in an energy and hormonal state that favors recovery and long-term tissue growth. Athletes interested in stimulating muscle growth have attempted to do this by consuming amino acids, protein, and/or carbohydrate and protein foods or beverages relatively soon after exercise.

The first one to two hours after exercise is sometimes referred to as the "anabolic window." This is the time period when it is important to reverse the catabolic state and promote a hormonal and nutritional state that favors replacement of energy stores and the synthesis of protein rather than its breakdown. As discussed in Chapter 4, the hours immediately after exercise are the most important for initiating optimal glycogen replacement. A similar "window" exists for restoration of protein.

Taking advantage of the favorable postexercise anabolic environment requires proper nutritional intake, although the details are still under investigation. Levenhagen and colleagues (2002) demonstrated that a supplement containing 10 g of protein from casein along with 8 g of carbohydrate and 3 g of lipid (fat) consumed immediately after exercise increased whole-body protein synthesis as well as protein synthesis in the leg, the muscles that were tested. This study also found that the carbohydrate/lipid mixture without protein and the placebo resulted in a net loss of whole-body and leg protein. Other studies have shown that amino acids ingested as whey or as indispensable and dispensable amino acids, both singly and in combination, promote protein synthesis after exercise. The amount of amino acids used in these studies was relatively small and larger amounts do not seem to be necessary or more effective because such levels would exceed the saturation point of the amino acid pool (Borsheim, Aarsland, and Wolfe, 2004; Miller et al., 2003; Borsheim et al., 2002; Tipton et al., 2002).

These research studies used beverages or amino acid infusions, but there is no reason to assume that protein foods that contain the same indispensable amino acids (e.g., milk, chicken, fish) would be less effective. Stated on a g/kg basis, ~0.1 g/kg of indispensable amino acids are recommended after exercise. A more practical recommendation is to include a beverage with some protein or food that contains animal protein immediately following exercise. For example, 8 ounces of low-fat chocolate milk contains 8 g of protein (Gibala and Howarth, 2006).

As described in Chapter 4, carbohydrate, especially high glycemic carbohydrate, consumed immediately after exercise is beneficial because it helps restore muscle glycogen. The carbohydrate also stimulates the release of insulin. Although its primary role is cellular glucose uptake, insulin also increases amino acid uptake into muscle and inhibits the process of muscle degradation. Athletes often consume a protein-carbohydrate drink (e.g., a specially formulated sports beverage or milk) after exercise. Food containing carbohydrate and protein (e.g., fruit-in-the-bottom yogurt) after exercise would likely be beneficial, too. The important point is to provide the body with the nutrients it needs immediately after exercise to begin resynthesis of tissue that has been catabolized during exercise. In this respect, consumption of both carbohydrate and protein (both of

**Vegan:** One who does not eat food of animal origin.

## SPOTLIGHT ON ENRICHMENT

### Other Protein Timing Issues for Athletes

There is general scientific agreement that protein (and carbohydrate) intake immediately after training is beneficial. An area receiving more attention is the intake of protein, alone or with carbohydrate, prior to resistance exercise. Trained athletes, particularly strength athletes, are looking for ways to maximize muscle protein synthesis and reduce breakdown. Consuming protein does temporarily elevate blood amino acid concentrations, and it is theorized that this condition may stimulate the synthesis of muscle protein. At least one study has shown this to be the case (Hulmi et al., 2005). Carbohydrate stimulates insulin release, which is known to influence amino acid uptake into muscle so the presence of carbohydrate may also have a beneficial effect. More research is needed to draw definitive conclusions.

Athletes trying to maximize muscle mass often ask about the amount of protein that should be consumed at one time. Some athletes have been told that no more than 30 g of protein can be absorbed from the gastrointestinal tract at once and that they should consume small amounts of protein throughout the day for maximum protein absorption. There is no scientific evidence to support or refute this figure. The maximum amount of protein that can be absorbed or should be taken to enhance absorption in trained athletes is not known at this time.

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Both bodybuilders and football players spend many hours lifting weights during training, but their performance demands are very different.

which also provide energy) shortly after exercise ends is advantageous.

## INTAKE OF PROTEIN ABOVE RECOMMENDED LEVELS AND THE EFFECTS ON TRAINING, PERFORMANCE, AND HEALTH

Bodybuilders are known for their high intake of dietary protein via both food and supplements. Surveys suggest that many bodybuilders consume more than 2.0 g/kg/d (Poortmans and Dellalieux, 2000). At 220 pounds (100 kg) a 2.0 g/kg daily intake would be 200 g of protein. Because weight in pounds is the familiar unit of measure in the United States, strength athletes are sometimes told that their protein intake should be 1 gram per pound, which is the equivalent of 2.2 g/kg. "Hardcore" male bodybuilders who openly discuss anabolic steroid use on Internet discussion groups typically suggest that protein intake should be approximately 3.0 to 3.5 g/kg/d when anabolic steroids are used. Based on this range, an athlete weighing 220 pounds (100 kg) might consume between 300 and 350 g of protein daily. There is no scientific evidence to support or refute this recommendation because it is not ethical to conduct such studies.

It is important to understand that the goals of a bodybuilder are different from those of other strength athletes and these goals influence their protein intake. Bodybuilders are judged on muscle size, definition, and proportion (the development of all muscle groups). They are also judged on stage presence, which includes posing and charisma, as well as overall appearance. They are not judged on muscle strength or power, attributes that are important to most strength athletes because they enhance performance. One of the bodybuilder's goals is to achieve the maximum *amount* of muscle mass that is genetically possible, while strength and power athletes have a goal of maximum muscle effectiveness, regardless of size. Both a bodybuilder and a linebacker on a football team will spend many hours training in the gym, but the performance demands of their sports are very different (Lambert, Frank, and Evans, 2004).

The recommended protein intake for strength-trained athletes is based on maintaining a positive nitrogen balance. Resistance exercise results in a decrease in nitrogen excretion, which is one reason protein recommendations for strength athletes are 1.6 to 1.7 g/kg/d and only slightly higher than that for endurance athletes. But bodybuilders are looking to not only be in positive nitrogen balance but to take in the amount of protein that correlates with *maximum* muscle protein synthesis. Such an amount has not yet been determined through scientific studies, so many bodybuilders (and some other strength athletes such as football players) may take large amounts of protein in hopes of achieving maximum levels of muscle mass. The looming question for those consuming large amounts of protein daily is: Are such high levels of protein intake safe?

**Short-Term Effects.** In the past, caution was raised regarding high-protein diets (typically defined as greater than 2.0 g/kg/d), especially for those athletes who took protein supplements. It was thought that excessive protein would stress healthy kidneys and liver in the short-term. This does not seem to be the case for those with normal kidney function. A seven-day study of bodybuilders and other well-trained athletes detected no short-term harmful effects on renal function with protein intakes up to 2.8 g/kg/d (Poortmanns and Dellalieux, 2000). All of the athletes in this study were healthy and had normal kidney and liver function. Athletes should be aware that they could experience problems with high-protein diets if they have latent (hidden) or known kidney or liver conditions. Any athlete consuming large amounts of protein should monitor their health and contact a physician if problems appear.

Athletes should also be aware of the potential training and performance problems that can be caused by excessive amounts of protein (≥2.5 grams of protein/kg body weight/d). The primary concerns are dehydration, low carbohydrate intake, and excessive caloric intake. Protein supplements make it easy to consume a lot of protein, but all of these concerns could also be associated with an excess of dietary protein.

Large amounts of protein can result in dehydration because additional water is needed to metabolize protein. Athletes who consume large amounts of protein should be aware of the need for adequate fluid intake. Urea, one of the by-products of protein metabolism, must be eliminated from the body by the kidneys via the urine. Urea is an osmotically active compound that draws more water into the collecting tubules of the kidneys, increasing the volume of the urine and resulting in the loss of water from the body. Water and fluid balance will be discussed further in Chapter 7.

Consuming large amounts of protein may come at the expense of the inclusion of enough carbohydrate foods. If protein *replaces* adequate carbohydrate intake, then the athlete will be consuming a high-protein, low-carbohydrate diet. This could result in lower muscle glycogen stores after several days of demanding training. If protein intake consistently *exceeds* usual intake, then caloric intake may be too high and body fat may increase over time. Maintaining macronutrient and energy balance is important.

**Long-Term Effects.** High-protein diets consumed by healthy individuals have manageable short-term effects, but what about the long-term effects? Concern has been expressed about the increased urinary excretion of calcium that accompanies high-protein diets. When protein is metabolized, acid is produced. To neutralize the acid, the body draws calcium carbonate from bones. The carbonate neutralizes the acid and the calcium is excreted in the urine. Studies of athletes and nonathletes have shown that excessive amounts of protein can result in increased urinary calcium excretion (Kerstetter, O'Brien, and Insogna, 2003; Heaney, 1993).

Concerns have also been raised about an association between long-term intake of high-protein diets (defined as >1.5 g/kg/d in many medical studies) and two medical conditions, osteoporosis and renal (kidney) disease. Long-term high protein intake, especially protein from animal sources, which contain amino acids with a high sulfur content, does increase the amount of calcium excreted in the urine. Most (~80 percent) of the increase in excreted calcium is a result of an increase in calcium absorption from the intestine. The remaining 20 percent increase is currently unexplained but bone could be the source. Therefore, the long-term effects (if any) of high-protein diets on bone metabolism and the potential for osteoporosis are not clear (Kerstetter, O'Brien, and Insogna, 2003). There is some medical evidence that lifelong high-protein consumption may affect the life span of the kidney and accelerate the progression of renal disease (Lentine and Wrone, 2004). More research is needed to clarify the long-term health effects of a high-protein intake.

**The Internet Café**

**Where do I find reliable information about protein, exercise, and health?**

Athletes who search for information about protein on the Internet will often be directed to commercial sites that are selling protein supplements or high-protein weight loss diets. Unbiased information about protein needs for athletes is lacking. Some university or medical-related sites give general information about protein, such as that found at Harvard School of Public Health **(www.hsph.harvard.edu/nutritionsource/protein.html).**

More information about vegetarianism can be found at The Vegetarian Resource Group, **www.vrg.org,** a nonprofit organization dedicated to educating the public about vegetarianism.

## ENERGY RESTRICTION AND PROTEIN INTAKE IN ATHLETES

The amount of protein required is related to energy intake. Under normal conditions, an adequate energy intake from either carbohydrate or fat spares amino acids from being used for energy and helps maintain nitrogen balance. Athletes need to be in nitrogen balance to maintain muscle mass and need to be in positive nitrogen balance to increase muscle mass.

Adjustments to protein intake will need to be made when energy intake is deficient. There is much evidence that high-protein, low-energy diets can achieve positive nitrogen balance in rats. However, amino acid metabolism in rats is different from that of humans. Unfortunately, the body of literature in humans is small and not well defined (Millward, 2004 and 2001). Nevertheless, it is also recommended that when humans are energy deficient they should increase protein intake in an effort to maintain nitrogen balance.

The amount of protein needed depends on the magnitude of the energy deficit and whether it is acute or chronic. The most serious situations are those athletes who self-impose starvation and are not receiving treatment for their eating disorders. In these cases the energy deficits are substantial and sustained over several months or years. Some athletes maintain small chronic energy deficits and their pattern of eating is one of restricting calories. In other cases, such as those who need to obtain a particular weight to qualify (e.g., wrestlers, lightweight

Robert Cianflone/Getty Images

Some athletes have eating patterns that result in small daily energy (kcal) deficits that occur over long periods of time.

rowers, kick boxers), the energy deficits may be substantial and rapid. Each situation is discussed below.

**Long-Term, Substantial Energy Deficits.** When a chronic energy deficit is present, more protein is needed than when energy intake is sufficient. Nitrogen balance cannot be maintained if energy and protein intakes are too low. Studies of athletes with anorexia nervosa report low intakes of both energy and protein. In one study, the mean daily protein intake of athletes with anorexia nervosa was 0.7 g/kg body weight (range 0.5 to 1.0 g/kg/d) (Sundgot-Borgen, 1993). Athletes with eating disorders are struggling with psychological issues that interfere with the consumption of food and will need intense counseling from well-trained practitioners. Among the nutritional goals will be appropriate energy and protein intakes.

A study of female athletes with subclinical eating disorders (i.e., the presence of some but not all the features of an eating disorder) reported that the mean daily energy intake was 1,989 kcal, or approximately 500 kcal/d less than estimated energy expenditure. Some athletes were consuming fewer than 1,700 kcal daily. Mean daily protein intake was 1.2 g/kg (Beals and Manore, 2000 and 1998). These athletes could benefit from nutritional counseling that addresses disordered eating behaviors, determines appropriate energy intake, and evaluates protein intake in light of chronic energy restriction (See Chapter 13).

**Long-Term, Small Energy Deficits.** Distance runners and female gymnasts and figure skaters are examples of athletes who commonly have small, but long-term energy deficits. They differ from those in their sports who have eating disorders because caloric intake is restricted to a lesser degree, body image is accurate, and they do not have an excessive fear of weight gain. They do, however, want a body that is well matched for their sport. In the case of runners, they desire a lightweight body with a sufficient amount of muscle mass, and in the case of gymnasts and figure skaters, a strong but aesthetically pleasing body. These athletes try to achieve this by maintaining a low percentage of body fat without losing muscle mass.

One survey of female endurance and aesthetic sport athletes who did not have eating disorders reported an average daily consumption of approximately 2,400 kcal or about 100 kcal per day less than their estimated energy expenditure. Their average protein intake was approximately 1.5 g/kg (Beals and Manore, 1998). In other words, these athletes tended to slightly undereat and consume slightly more protein than that recommended for endurance athletes (i.e., 1.2 to 1.4 g/kg/d). Such a diet could be nutritionally sound as long as carbohydrate intake is sufficient and a variety of nutrient-dense foods are consumed.

**Intermediate-Term, Small-to-Medium Energy Deficits.** Many athletes periodically want to lose body fat and will reduce caloric intake for a short time (a few weeks to a few months) to achieve fat loss. Some studies have shown that high-protein diets produce greater weight loss than low-fat diets. The current evidence suggests that weight loss diets for the general (sedentary) population should be reduced in calories and total energy intake should be distributed as 35 to 50 percent carbohydrate, 25 to 30 percent protein, and 25 to 35 percent fat (Schoeller and Buchholz, 2005). However, subjects of these studies were not athletes and substantially reducing carbohydrate intake will likely be detrimental to an athlete's training.

To achieve weight loss, athletes reduce caloric intake and usually alter the macronutrient balance of their current diets by increasing protein intake, reducing carbohydrate intake slightly (but still consuming enough for adequate glycogen resynthesis), substantially reducing fat intake, and eliminating alcohol. The increase in protein is thought to blunt the reduction in resting energy expenditure (REE), which usually accompanies energy restriction (i.e., "dieting"). Protein also increases the thermic effect of food (TEF), although the influence on overall energy balance is likely to be small. Recall from Chapter 2 that both REE and TEF are on the "energy out" side of the energy balance equation, and these effects may result in a slightly greater weight loss when compared to weight loss diets with less protein (Luscombe et al., 2002). A high-protein, low-calorie diet is often recommended to athletes who desire to lose weight as body fat. Although this recommendation may be prudent, scientific studies of effectiveness in athletes are lacking.

**Short-Term, Substantial-Energy Deficits.** When energy deficits are large and short-term, such as when an athlete is "making weight," the goals are to lose body weight through fat and water loss but maintain as much muscle protein as possible. This is difficult to accomplish. Under starvation conditions, the loss of weight comes from several components, including water, glycogen, protein, and fat. In the first 10 days of fasting/starvation, only about one-third of the body weight lost is lost as body fat (Brownell, Steen, and Wilmore, 1987). Six to 16 percent is lost from protein stores. This type of severe energy restriction raises serious concerns about hydration status, the potential for heat illness, maintenance of muscle mass, ability to exercise due to depleted glycogen stores, hypoglycemia, and declines in resting metabolic rate.

## EFFECTS OF AN INADEQUATE PROTEIN AND ENERGY INTAKE ON TRAINING, PERFORMANCE, AND HEALTH

Studies have shown that athletes who consume an inadequate amount of protein also usually consume an inadequate amount of energy (kcal), so the problems they face are numerous. The lack of protein is an especially important problem because of its critical role in building and maintaining muscle mass and supporting the immune system.

Protein synthesis and degradation is a constant process and there must be a balance between protein intake and protein loss. The primary problem with consuming a chronically low protein, low-energy diet (i.e., a semi-starvation state) is that protein balance cannot be maintained. The body has few intermediate-term options if dietary protein is not available over a period of weeks and months. It must reduce the synthesis of some body proteins and degrade muscle protein, thus returning the body to balance but at a lower functional level. Protein balance will be achieved but at the expense of training, performance, and health. Severe starvation leads to the loss of homeostasis, general weakness, and, ultimately, death.

The immune system is highly dependent on protein because of the rapid turnover of immune system cells and the number of immune-related proteins (e.g., immunoglobulins, which act like antibodies). Low protein intake usually accompanies low energy intake and low nutrient intake, all of which can negatively affect the immune system. While low protein intake and immune system function have not been studied directly in athletes, studies of people who restrict energy severely (i.e., "dieters") have shown that some immune mechanisms are impaired. These studies are interpreted to mean that a low protein intake is detrimental to the functionality of the immune system (Gleeson, Nieman, and Pedersen, 2004).

**What's the point?** Protein recommendations for athletes generally range from 1.0 to 2.0 g/kg/d, depending on the athlete's training and body composition goals. Many athletes consume a sufficient amount of protein daily. Athletes who consume low-protein, low-energy diets could experience negative effects on performance, body composition, and health. When caloric intake is restricted, protein needs are higher. The effects of long-term, excessively high protein diets have not been well studied.

# Translating Daily Protein Recommendations to Food Choices

## FOOD PROTEINS

Proteins are found in both animal and plant foods. Meat, fish, and poultry are familiar protein-containing foods. Eggs, milk, and milk products also contain protein. Beans, legumes, nuts, and seeds are popular plant protein sources. Grains and vegetables contain smaller amounts than other protein-containing foods, but because these

## THE EXPERTS IN. . .

### Protein and Exercise

Some of the experts in the field of protein and exercise conduct their research at Canadian universities. The work of Peter W.R. Lemon, Ph.D., and colleagues helped to determine daily protein requirements in trained athletes. Mark Tarnopolsky, Ph.D., has published numerous articles on the metabolism of amino acids and protein turnover. Martin J. Gibala, Ph.D., conducts research focusing on the regulation of energy provision in skeletal muscle and the cellular adaptations that are made in amino acid metabolism during exercise. He also conducts applied research to determine the role of exercise and dietary interventions on athletic performance. While researchers from across the globe contribute to the body of scientific knowledge of protein and exercise, scientists from Canada have a long history of doing so.

**Table 5.4** Protein Content of Selected Foods

| Food | Amount | Protein (g) |
|---|---|---|
| Meat (lean ground beef) | 3 oz | 21 |
| Chicken (roasted breast) | 3 oz | 26 |
| Fish (halibut) | 3 oz | 23 |
| Egg | 1 large | 6 |
| Milk | 8 oz | 9 |
| Cheese | 1 oz | 7 |
| Beans (dried) | ½ cup cooked | 8 |
| Lentils | ½ cup cooked | 9 |
| Peanuts | ¼ cup | 10 |
| Almonds | ¼ cup | 8 |
| Sunflower seeds | 1 oz | 6 |
| Rice (white) | ½ cup cooked | 2 |
| Rice (brown) | ½ cup cooked | 2.5 |
| Spaghetti noodles | ½ cup cooked | 3.5 |
| Potato (baked) | 1 large (~7 oz) | 5 |
| Sweet potato | ½ cup cooked | 1 |
| Bread (white) | 1 slice | 2 |
| Bread (whole wheat) | 1 slice | 2.5–3 |

**Legend:** g = gram; oz = ounce

foods may be eaten in large quantities, they often contribute a reasonable amount to total daily protein intake. The protein content of various foods is listed in Table 5.4.

Each **macronutrient** (e.g., carbohydrate, protein, fat) must be considered individually, but in reality most foods contain a mixture of macronutrients, and thus protein foods may not be chosen solely for the amount of protein contained. Table 5.5 groups protein-containing foods based on their fat and carbohydrate contents. For example, athletes who are looking for protein without much fat or carbohydrate could choose egg whites or very lean cuts of meat, fish, or poultry. Those athletes who want both proteins and carbohydrates but wish to limit fat intake could choose beans, legumes, and nonfat dairy products. Nuts provide heart-healthy fats as well as proteins and carbohydrates. As Table 5.5 illustrates, there are many choices.

**Macronutrient:** Nutrient needed in relatively large amounts. The term includes energy, carbohydrates, proteins, fats, cholesterol, and fiber but frequently refers to carbohydrates, proteins, and fats.

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The majority of athletes consume sufficient protein.


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Beans and corn tortillas provide complementary proteins in this vegetarian meal.

## PROTEIN INTAKE BY ATHLETES

Table 5.6 on page 160 summarizes the average daily protein and energy intakes of various athletes. The majority of athletes consume sufficient protein. Low protein intake is most common in females who restrict energy and in males who compete in weight-restricted sports. Bodybuilders, weight lifters, and other strength athletes are most likely to consume large amounts of protein. Many athletes consume an appropriate level of protein (Nogueira and Da Costa, 2004; Onywera et al., 2004; Jonnalagadda, Ziegler, and Nelson, 2004; Paschoal and Amancio, 2004; Leydon and Wall, 2002; Mullins et al., 2001; Poortmans and Dellalieux, 2000).

## VEGETARIAN DIETS

Vegetarians do not eat meat, fish, or poultry but many do consume some animal proteins. For example, milk, cheese, and eggs may make up a substantial part of a

**Table 5.5** Protein, Fat, and Carbohydrate Content of Selected Foods

| Food | Amount | Protein (g) | Fat (g) | Carbohydrate (g) | Energy (kcal) |
|---|---|---|---|---|---|
| Egg whites | ¼ cup | 6 | 0 | 1 | 30 |
| Chicken (white meat, roasted) | 3 oz | 26 | 3 | 0 | 140 |
| Turkey (white meat, roasted) | 3 oz | 25.5 | 0.5 | 0 | 115 |
| Fish (cod, halibut or roughy) | 3 oz | 19 | 0.5 | 0 | 89 |
| Tuna (fresh or water packed) | 3 oz | 23 | 0.5 | 0 | 106 |
| Meat (flank steak) | 3 oz | 30 | 8 | 0 | 199 |
| T-bone steak | 3 oz | 21 | 16.5 | 0 | 238 |
| Chicken (dark meat, roasted) | 3 oz | 23 | 8 | 0 | 174 |
| Turkey (dark meat, roasted) | 3 oz | 24 | 6 | 0 | 159 |
| Pork (tenderloin, roasted) | 3 oz | 24 | 4 | 0 | 139 |
| Veal (lean) | 3 oz | 27 | 6 | 0 | 167 |
| Fish (oily such as salmon) | 3 oz | 20 | 4 | 0 | 118 |
| Tuna (oil packed, drained) | 3 oz | 25 | 7 | 0 | 168 |
| Milk (whole, 3.3%) | 8 oz | 8 | 8 | 11 | 146 |
| Milk (reduced fat, 2%) | 8 oz | 8 | 5 | 11 | 122 |
| Milk (low-fat, 1%) | 8 oz | 8 | 2 | 12 | 102 |
| Milk (nonfat) | 8 oz | 8 | Trace | 12 | 83 |
| Yogurt (low-fat, fruit in the bottom) | 8 oz | 6 | 1.5 | 31 | 160 |
| Yogurt (nonfat, artificially sweetened) | 8 oz | 11 | Trace | 19 | 122 |
| Cheese (cheddar) | 1 oz | 7 | 9 | 0 | 114 |
| Cheese (fat-free) | 1 slice | 4 | 0 | 3 | 30 |
| Beans | ½ cup cooked | 8 | 0.5 | 24 | 129 |
| Lentils | ½ cup cooked | 9 | Trace | 20 | 115 |
| Peanuts (oil roasted) | ¼ cup | 10 | 19 | 7 | 221 |
| Almonds (dry roasted) | ¼ cup | 8 | 18 | 7 | 206 |
| Sunflower seeds (dry roasted) | ¼ cup | 6 | 16 | 8 | 186 |
| Sunflower seeds (oil roasted) | ¼cup | 6 | 17 | 4 | 178 |
| Rice (white) | ½ cup cooked | 2 | Trace | 22 | 103 |
| Rice (brown) | ½ cup cooked | 2.5 | ~1 | 22 | 108 |
| Spaghetti noodles | ½ cup cooked | 3.5 | 0.5 | 19.5 | 95 |
| Potato (baked) | 1 large (~7 oz) | 5 | Trace | 43 | 188 |
| Sweet potato | ½ cup cooked | 1 | Trace | 12 | 51 |
| Bread (white) | 1 slice (25 g) | 2 | 0.8 | 13 | 67 |
| Bread (whole wheat) | 1 slice (44 g) | 2.5–3 | ~2.5 | 21.5 | ~119 |

**Legend:** g = gram; oz = ounce; kcal = kilocalorie vegetarian's diet. When animal foods are included, the likelihood is high that the diet will provide protein of sufficient quality. When no animal proteins are consumed, vegetarians should assess protein quality and be aware of the concept of complementary proteins.

Plant proteins (i.e., incomplete proteins) may either lack one or more of the indispensable amino acids or the proper concentrations of these amino acids. Of greatest concern are lysine, threonine, and the sulfur-containing amino acids cysteine and methionine. Legumes such as lentils and beans are low in methionine and cysteine. However, grains, nuts, and seeds are high in these sulfur-containing amino acids. Grains lack lysine but legumes have high levels. Vegetables lack threonine but grains have adequate amounts.

Consuming two plant proteins, each with a relatively high amount of the amino acid that the other lacks, can result in an adequate intake of all of the indispensable amino acids. This is the concept of complementary proteins. Beans and rice, lentils and rice, corn

## SPOTLIGHT ON A REAL ATHLETE

### Lucas, a Cross Country Runner

As in the previous chapter, a 24-hour dietary intake is analyzed for Lucas, a collegiate cross country runner (see Figure 5.7). Recall that due to the demands of his training, Lucas needs approximately 3,400 kcal (~54 kcal/kg) daily. His need for carbohydrate during the preseason mesocycle that emphasizes longer distance runs (75 to 80 miles a week) is estimated to be 8 g/kg/d. The guideline for protein for endurance athletes is approximately 1.2 to 1.4 g/kg/d and may be as high as 2.0 g/kg/d for ultraendurance athletes during some phases of their training. In Lucas' case he would like to consume approximately 1.5 g/kg/d.

According to the dietary analysis, Lucas consumed 3,333 kcal and 532 g of carbohydrate (8.5 g/kg/d). These amounts are very close to his goals. Lucas' protein intake was 124 g or ~2 g/kg/d (15 percent of total caloric intake). He exceeded his goal for protein but he does not consume an excessive amount. In fact, his intake reflects that of many Americans and is in line with guidelines for ultraendurance athletes. His total energy intake was adequate and he met his goal for total carbohydrate intake. He consumed high-quality protein both as animal protein (e.g., cheese and milk) and complementary proteins (e.g., black beans and rice). His macronutrient and energy intakes are balanced. From a performance perspective, the quantity and quality of Lucas' protein intake was appropriate.

### Marcus, a Running Back (American Football)

Now consider the diet of a strength athlete such as a college football player. Marcus is a 6-ft (183-cm), 200-lb (91-kg) running back. Marcus' goals for the three months prior to fall

| Nutrient | DRI | Intake | 0% | 50% | 100% |
|---|---|---|---|---|---|
| **Energy** | | | | | |
| Kilocalories | 3365 kcal | 3332.8 kcal | | | 99% |
| Carbohydrate | 379–547 g | 532.15 g | | | |
| Fat, total | 75–131 g | 93.86 g | | | |
| Protein | 84–294 g | 124.09 g | | | |

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| | Goal* | Actual | % Goal |
|---|---|---|---|
| Grains | 10 oz. eq. | 11.8 oz. eq. | 118% |
| Vegetables | 4 cup eq. | 1.2 cup eq. | 30% |
| Fruits | 2.5 cup eq. | 1.7 cup eq. | 68% |
| Milk | 3 cup eq. | 5.4 cup eq. | 180% |
| Meat & Beans | 7 oz. eq. | 8.8 oz. eq. | 126% |
| Discretionary | 648 | 1152 | 178% |

*Your results are based on a 3200 calorie pattern, the maximum caloric intake used by MyPyramid.

**Figure 5.7** Dietary Analysis of 24-Hour Diet of a Male Collegiate Cross Country Runner and beans, and peanut butter and bread consumed at the same meal or within the same day are examples of complementary proteins. Many cultures have a long history of combining plant proteins in traditional dishes or meals that result in the consumption of complementary proteins. New Orleans is famous for its red beans and rice, Mexican cuisine features corn tortillas and pinto beans, and Asian dishes often include stir-fried tofu (made from soy beans) and rice. An important issue for vegans is that they consume a variety of plant proteins to ensure that they consume all the indispensable amino acids in the proper quantities. Many vegans include soy protein isolate in their diets because it is usually considered comparable in quality to animal protein. Adequate energy intake is also important.

## PROTEIN SUPPLEMENTS

Protein supplements are popular among athletes with higher than average protein needs, particularly

practice include increasing body weight (as muscle mass) by 10 lb (4.5 kg), increasing muscle strength, and maintaining aerobic fitness. To achieve this he has developed a training plan that predominately consists of strength training along with some speed and agility drills. For the hypertrophy or muscle-building phase, Marcus emphasizes an increased volume of strength training. To accomplish this, he works out four to six days a week in the weight room with multiple sets of each exercise. As he gets closer to fall practice, he will reduce the number of repetitions but increase the resistance of each exercise to transition into a strength and power development phase. To support training, it is estimated that he needs approximately 4,000 kcal (44 kcal/kg), 600 g carbohydrate (6.6 g/kg), 155 g protein (1.7 g/kg), and 110 g of fat (1.2 g/kg) daily.

Marcus can easily meet his energy and nutrient needs as shown in Figure 5.8. The composition of the diet shown is very close to the recommended guidelines, although these guidelines are just estimates and athletes' diets are not expected to match them exactly. His protein intake (2.0 g/kg/d) is slightly higher than recommended (1.7 g/kg/d) because his carbohydrate intake is slightly lower (6.5 g/kg/d versus 6.6 g/kg/d). Marcus' diet as shown will provide the nutrients he needs to support his training and includes foods that are easy to prepare and readily available at the grocery store.

**Breakfast:** 2 cups oatmeal with ½ cup nonfat milk, ¼ cup raisins, one honey-wheat English muffin with 1 tablespoon each margarine and jelly, 8 ounces orange juice.

**Lunch:** 2 sandwiches, each including 2 slices of whole wheat bread, 3 ounces lean turkey, 1 slice Swiss cheese, sliced tomato, lettuce, mustard, and 1 tablespoon light mayonnaise; 1 apple, 8 ounces nonfat milk.

**Dinner:** 6 ounces grilled halibut, 1 large baked potato with ¼ cup fat-free sour cream, 1½ cups broccoli, 5 Fig Newtons, 1 cup frozen yogurt.

**Snacks:** 8 ounces reduced-fat chocolate milk (postexercise), 2 bananas, 1 peanut butter Powerbar.

**Energy:** 4,009 kcal (44 kcal/kg)

**Carbohydrate:** 589 g (6.5 g/kg or ~59% of total caloric intake)

**Protein:** 185 g (2.0 g/kg or ~18% of total caloric intake)

**Fat:** 112 g (1.2 g/kg or ~25% of total caloric intake)

**Figure 5.8** Sample Diet for a Strength Athlete

**Legend:** kcal = kilocalorie; g=gram; g/kg=grams per kilogram body weight

**Table 5.6** Average Daily Protein and Energy Intakes of Athletes

| Study | Subjects | Average Daily Protein Intake | Average Daily Energy Intake |
|---|---|---|---|
| Nogueira & Da Costa, 2004 | 29 male, 9 female Brazilian triathletes | Males:<br>Mean = 2.0 g/kg, 142 g<br>Females:<br>Mean = 1.6 g/kg, 88 g | Males:<br>Mean = 3,660 kcal<br>Females:<br>Mean = 2,300 kcal |
| Onywera, Kiplamai, Tuitoek et al., 2004 | 10 male elite Kenyan runners; 8 ran cross country, 2 ran 1,500 m | Mean = 1.3 g/kg, 72 g | Mean = 2,987 kcal |
| Jonnalagadda, Ziegler, & Nelson, 2004 | 23 male, 26 female elite figure skaters | Males:<br>Mean = 1.2 g/kg, 82 g<br>Females:<br>Mean = 1.16 g/kg, 54 g | Males:<br>Mean = 2,112 kcal<br>Females:<br>Mean = 1,490 kcal |
| Paschoal & Amancio, 2004 | 8 male elite Brazilian swimmers | Mean = 2.27 g/kg<br>Range = 1.30 to 2.85 g/kg | Mean = 53.4 kcal/kg |
| Leydon & Wall, 2002 | 20 male and female New Zealander jockeys | Males:<br>Mean = 1.1 g/kg, 58 g<br>Range = 44 to 74 g<br>Females:<br>Mean = 0.95 g/kg, 47 g<br>Range = 18 to 75 g | Males:<br>Mean = 6,359 kJ (1,514 kcal) Lowest mean = 3,371 kJ (803 kcal)<br>Females:<br>Mean = 6,213 kj (1,479 kcal); Lowest mean = 3,454 kJ (822 kcal) |
| Poortmans & Dellalieux, 2000 | 20 Belgian male bodybuilders (BB) and 17 male athletes (OA) in the sports of cycling, judo, and rowing | BB: Mean = 1.94 g/kg, 169 g<br>OA: Mean = 1.35 g/kg, 99 g | BB: Mean = 3,908 kcal<br>OA: Mean = 2,607 kcal |
| Mullins et al., 2001 | 19 female American heptathletes | 1.4 g/kg, 95 g<br>Range = 0.7 to 3.1 g/kg, 53 to 186 g | 36 g/kg, 2,357 kcal<br>Range = 21 to 87 g/kg, 1,553 to 5,276 kcal |

**Legend:** g/kg = grams per kilograms body weight; g = gram; kcal = kilocalorie; kcal/kg = kilocalories per kilogram body weight

Protein supplements are heavily advertised to strength/power athletes.

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bodybuilders and strength athletes. These supplements are marketed as powders, premixed drinks, and bars. They are heavily advertised to athletes who are building and maintaining large amounts of muscle mass.

As illustrated in the Spotlight, Marcus, a running back, and Lucas, a distance runner, both consumed more than enough protein from food alone. Obtaining protein from food is relatively easy and reasonably affordable. Obtaining protein from supplements is usually more expensive but may be more convenient because of portability and preparation (e.g., adding protein powder to water can be done quickly anywhere). For example, Marcus typically goes home after lifting weights and has a quick snack of chocolate milk and a banana. But he also keeps a protein powder handy for a number of reasons—he likes the variety, it is easy to bring to the gym if he is not going back home, it does not need to be refrigerated, and he sometimes comes home to find that his roommate has eaten his bananas and finished the carton of milk. The protein powder he buys has about the same number of calories as his usual postexercise snack but has more protein and less carbohydrate, so he must consider the differences in their nutrient content. Marcus may choose a protein supplement for a number of good reasons, but because he can get enough protein from food, protein supplements are not a required part of his diet. For those who choose to supplement, such supplements seem to be safe for healthy adults.

**Table 5.7** Nutrient Content of Selected Protein Supplements

| Protein Supplement | Amount | Energy (kcal) | Protein (g) | Fat (g) | Carbohydrate (g) |
|---|---|---|---|---|---|
| 100% Whey Protein Fuel (powder)* | 1 scoop (33 g) in 6 oz of water | 130 | 25 | 2 | 1 |
| Myoplex Original** | 1 packet | 270 | 42 | 3 | 23 |
| Heavyweight Gainer 900*** | 4 scoops | 630 | 35 | 9.5 | 101 |
| Protein Plus bars**** | 1 bar (85 g) | 320 | 34 | 8 | 29 |

**Legend:** kcal = kilocalories; g = gram; oz = ounce

*TwinLab, Hauppauge, NY

**EAS, Golden, CO

***Champion Nutrition, Concord, CA

****Met-Rx, Bohemia, NY

Protein supplements often contain whey, casein, and soy proteins, some of the same proteins that are contained in milk, meat, fish, poultry, eggs, and soy. In the presence of resistance training and adequate calories, proteins from either food or supplement sources can contribute to increasing muscle size and strength. Protein supplements are neither more nor less effective than food proteins for muscle growth.

Table 5.7 lists some popular products advertised as protein supplements. Protein powders may contain only protein but many also contain some carbohydrate to make them more palatable. Sometimes athletes will mix protein powders with sugary or artificially sweetened drinks, such as Kool-Aid or Crystal Lite. Protein bars vary in their protein, carbohydrate, and fat content. Reading the label carefully helps consumers determine the nutrient content of a product and how such a product may fit into their overall diet plan.

**Whey versus Casein.** Advertisements for protein supplements often make a special point of the type of protein contained—whey or casein. Whey and casein are both milk proteins but they have different amino acid profiles. Whey protein has long been popular among strength athletes because of its protein quality.

Both whey and casein are processed from milk. When milk is coagulated (thickened) whey is found in the liquid portion while casein is found in the semisolid portion known as curds. The whey can be processed further into whey protein isolate, whey protein concentrate, or whey powder. Whey protein concentrate and whey powder contain lactose. Whey protein isolate, which is typically added to protein supplements and infant formulas, is a concentrated source of protein because both the carbohydrate (e.g., lactose) and the fat are removed. The end product is high in indispensable amino acids, particularly the branched chain amino acids (i.e., leucine, isoleucine, and valine) (Geiser, 2003). Casein has a different amino acid composition and is particularly high in glutamine, an amino acid that is considered conditionally indispensable under physiological stress such as endurance exercise.

When whey is compared to casein, the amino acids in whey are absorbed faster. This difference in absorption rate is not surprising since whey has a high percentage of indispensable amino acids, which are absorbed more rapidly than the dispensable amino acids. Whey is often referred to as a "fast-acting" protein while casein is described as a "slow-acting" protein. The purported benefit of taking whey is that a faster rate of absorption would lead to high levels of indispensable amino acids in the amino acid pool and, ultimately, to an increase in muscle size. This theory has not been proven.

Whey protein supplements have been marketed to athletes for a long time. There are some studies (reviewed below) that have found that whey protein supplements are associated with an increase in muscle size and strength in some subjects However, there is little evidence that the gains in muscle size or strength associated with whey proteins are greater than those of other protein sources (Lemon, 2000).

Preliminary research reported that resistance-trained athletes who used whey supplements had a greater increase in lean tissue than those who received a placebo. However, the increase was small, approximately 2 kg (~4½ lb), and the whey-supplemented group did not always perform better (e.g., squat strength, knee flexion peak torque) than the placebo group (Burke et al., 2001). A 2006 study found that a combination of whey and casein resulted in greater increases in fat-free mass and performance (bench and leg presses) in resistance-trained male athletes than a carbohydrate placebo or a combination of whey, BCAA, and glutamine (Kerksick et al., 2006). Cribb et al. (2007) reported gains in muscle size and strength in some of the recreational bodybuilders who consumed whey protein supplements. Study comparisons are difficult because of small sample sizes, differences in subjects (resistance-trained versus untrained), and protein sources (whey-only versus whey + casein versus whey + individual amino acids). This is an area of active research and supplementation with whey protein shows some promise, but more studies are needed to clarify the effectiveness of whey protein supplements.

Those athletes who choose to supplement with whey proteins often consume them when they want an immediate rise in amino acid concentrations, such as immediately after exercise. Those who supplement with casein do so for its more sustained effect on the amino acid pool. Either whey or casein taken after exercise seems to increase muscle protein synthesis (Tipton et al., 2004). Many protein supplements contain both whey and casein to take advantage of their different absorption rates. In recent years whey's popularity has increased because of preliminary studies that suggest whey may also have antioxidant properties. The likely mechanism is whey's influence on the intracellular conversion of the amino acid cysteine to glutathione, a powerful antioxidant.

## AMINO ACID SUPPLEMENTS

Proteins are made up of amino acids. Amino acids, especially the indispensable amino acids, stimulate muscle protein synthesis in the presence of resistance training. This fact has made supplementation of specific amino acids popular. Essential amino acids (EAA) and $\beta$-hydroxy-$\beta$-methylbutyrate (HMB) are popular supplements marketed to strength athletes. Endurance athletes may consider use of supplemental branched chain amino acids or glutamine because of the impact that the stress of endurance exercise has on these amino acids. In each case the purported benefit of these amino acids in supplement form is that the amounts are more concentrated than the amounts found in food.

**Essential Amino Acids (EAA).** Many supplements marketed to strength athletes advertise the number or amount of indispensable (essential) amino acids contained in the product. While it is true that the body cannot manufacture these amino acids, there is no evidence that indispensable amino acids cannot be provided in ample amounts by consuming protein-containing foods. While there are theories as to the optimal amounts or combinations of indispensable amino acids in improving athletic performance, there is a lack of studies to show a performance benefit for EAA supplements (Wagenmakers, 1999). However, this is an active area of research since indispensable amino acid supplementation has been shown to stimulate protein anabolism in elderly subjects (Volpi et al., 2003).

**$\beta$-hydroxy-$\beta$-methylbutyrate (HMB).** HMB is a metabolite of leucine, one of the indispensable amino acids. Three grams of supplemental HMB is hypothesized to increase muscle size and strength. The proposed mechanism is the effect HMB has on minimizing cellular protein breakdown after exposure to resistance exercise (Slater and Jenkins, 2000).

In 2003, Nissen and Sharp conducted a meta-analysis of studies of dietary supplements used in conjunction with resistance training to increase muscle size and strength. HMB was one of two supplements (the other was creatine) that was found to be beneficial. In the nine HMB studies that the authors reviewed, six included untrained subjects. There have also been reports of gains in muscle size and strength in elderly men and women who are experiencing muscle protein wasting.

However, studies in trained male athletes (e.g., rugby and American football players) have generally shown no effect on muscle size, strength, body composition, and aerobic or anaerobic capacity (Hoffman et al., 2004; O'Connor and Crowe, 2003; Ransone et al., 2003; Slater et al., 2001). HMB supplements of 3 g per day seem to be safe (Crowe, O'Connor and Lukins, 2003) but not effective in trained athletes.

**Glutamine.** Under normal conditions glutamine is considered a dispensable amino acid, but its status changes under physiologic stress, such as prolonged endurance exercise and illness. Glutamine is a fuel source for immune system cells. If glutamine is not available, some immune cells are impaired, which increases the risk for infections. Endurance athletes are at increased risk for upper respiratory infections (Krieger, Crowe, and Blank, 2004). Low blood glutamine levels have been detected in endurance athletes, so the question of whether supplemental glutamine is necessary or beneficial has been raised.

Glutamine supplements of 5 to 10 g seem to be safe. Unfortunately, it is hard to draw conclusions about effectiveness because the number of studies is small and the results inconsistent. Castell (2002) reported a decrease in the incidence of infections in endurance athletes who supplemented with glutamine. However, Gleeson, Nieman and Pederson (2004) and Nieman (2001) reviewed a number of studies and concluded that glutamine supplementation is not an effective countermeasure for immunological stress. Because glutamine supplementation is controversial, a prudent approach for the endurance athlete may be to increase protein-containing foods in the diet. Glutamine is found in protein foods and it is known that some endurance athletes consume diets low or marginal in protein.

**Branched Chain Amino Acids.** Leucine, isoleucine, and valine are the branched chain amino acids, so named because of their chemical structure. During prolonged endurance exercise when glycogen stores are low, skeletal muscle can metabolize these amino acids for energy. In addition to being used as an energy source, BCAA compete with tryptophan, an amino acid associated with mental fatigue. BCAA are also involved in the immune system (Newsholme and Blomstrand, 2006; Gleeson, 2005; Wagenmakers, 1999).

Endurance athletes may seriously consider supplemental BCAA based on functionality. In theory, greater availability of BCAA late in prolonged exercise could provide a much-needed fuel source. Higher blood levels of BCAA in the presence of tryptophan could help to delay fatigue. Immune response, particularly the ability to resist upper respiratory infections, might be improved. Strength athletes are interested in the possibility that BCAA supplements could reduce delayed-onset muscle soreness.

Supplemental BCAA of 10 to 30 g/d seem to be safe. However, supplemental BCAA have not been shown to improve endurance performance in trained endurance athletes. Nor have they been shown to protect the breakdown of muscle during exercise or help repair muscle faster after exercise (Gleeson, 2005), although results of preliminary studies do warrant more research (Shimomura et al., 2006). Mental fatigue is a complex neurophysiologic condition. A few studies have shown that BCAA supplementation has little to no effect on fatigue while other studies have shown that fatigue is reduced (Newsholme and Blomstrand, 2006). Although the trials are small, some positive effects have been reported in studies that examined immune response (Bassit et al., 2000, 2002). BCAA supplementation remains an active area of research, but at the present time the evidence for positive effects from supplementation is lacking or not convincing. Adequate daily protein intake, which provides BCAA, is important.

The decision to take a dietary supplement should be based on legality, ethics, safety, and effectiveness. The supplements listed above do not appear on the National Collegiate Athletic Association (NCAA) banned substance list. However, the institution cannot provide such supplements to student athletes because they are considered muscle-building supplements. NCAA Bylaw 16.5.2 (g) states that only nonmuscle-building nutritional supplements may be given to student athletes for the purpose of providing additional calories and electrolytes (as long as the nonmuscle building supplements do not contain any NCAA banned substances).

**Glucosamine.** Glucosamine, sold separately or in combination with chondroitin, is a dietary supplement marketed to relieve joint pain both in athletes and in those with osteoarthritis. Glucosamine is manufactured by the body from glucose and the amino acid glutamine and is not related to dietary intake. It is part of glycosaminoglycan (an unbranched polysaccharide), which is found in the extracellular matrix of the joints. Because of its ability to attract water, it is referred to as a "joint lubricant." Chondroitin is also synthesized by the body; supplements are typically obtained from shark cartilage or seashells (Delafuente, 2000).

The exact mechanism of glucosamine/chondroitin supplements is not known, but it is theorized to prevent the breakdown of cartilage and/or stimulate the synthesis of cartilage. Evidence suggests that glucosamine/

## KEEPING IT IN PERSPECTIVE

### The Role of Protein for Athletes

Protein is an important nutrient and it receives much attention because of its role in the growth and development of skeletal muscle. It deserves attention, but no nutrient should be the sole or predominant focus of the athlete's diet. Overemphasizing protein can mean losing sight of the broader dietary picture, which includes adequate energy, carbohydrate, and fat intakes.

Protein is no different from other nutrients in that both the "big" picture and the details are important. The "big" picture issues include an adequate amount of protein (based on energy intake) and macronutrient balance (the amount of protein relative to the amount of carbohydrate and fat needed). There is no point to the strength athlete taking in large amounts of protein only to find that carbohydrate intake is too low to support a well-planned resistance training program. Determining the appropriate energy intake and the amount of protein required are important first steps. Athletes need to assess their current dietary intake to determine if, and how much, more protein is needed. Protein is one of several nutrients that should be consumed in the postexercise recovery period, although the amount needed is small compared to the amounts of carbohydrate and fluid needed.

The athlete's fundamental protein needs should be met before the fine-tuning takes place. Protein quality (e.g., animal or plant), absorption (e.g., whey or casein), and source of protein (e.g., foods or supplements) are issues that each individual athlete should consider. Some of the questions that athletes have do not yet have scientific answers. For example, what is the maximum amount of protein that the gastrointestinal tract can absorb at one time? How much protein is needed daily for maximum muscle protein synthesis? The answers are not yet known. Part of keeping protein intake in perspective is to understand what is known, what is theorized, and what is pure conjecture. This is known: Protein is one important aspect of the athlete's diet.

chondroitin supplements can be effective in delaying the progression of osteoarthritis (Wang et al., 2004). However, athletes and those with osteoarthritis often use these supplements as an alternative medication to nonsteroidal anti-inflammatory drugs (NSAID) even though the supplements do not provide the immediate pain relief associated with NSAID use. Part of the popularity is that glucosamine/chondroitin supplements are purported to be less toxic and have fewer side effects than NSAIDs. The expected outcome of supplementation is joint pain relief and improved range of motion over time (McAlindon et al., 2000).

Although no **dose-response studies** have been conducted, typical daily doses are 1,500 mg of glucosamine and 1,200 mg of chondroitin sulfate for the first 60 days and a daily maintenance dose of 750 mg of glucosamine and 600 mg of chondroitin sulfate. These doses seem to be safe. Because these compounds are sold as dietary supplements in the United States, quality control (e.g., purity, potency) could be a problem. In Europe, glucosamine sulfate is sold as a prescription medication. Those allergic to shellfish should be aware that chondroitin supplements may be derived from seashells and some residual fish could be left after the cleaning process.

The effectiveness of glucosamine/chondroitin supplements and, especially their potential benefit over NSAIDs, have been controversial because of concerns over the experimental design of the various studies conducted. Some studies have shown that glucosamine/chondroitin supplements provide relief from knee pain that may be a result of cartilage damage (Braham, Dawson, and Goodman, 2003). There is a critical need for well-designed studies using trained athletes as subjects.

Clegg et al. (2006) conducted a randomized, double-blind, placebo-controlled intervention study that examined the effect of glucosamine and chondroitin, both singly and combined, and an NSAID (celecoxib) as a 24-week treatment of knee pain from osteoarthritis. The average age of the participants was 59 years and knee pain ranged from mild to moderate to severe. The supplements, whether administered separately or together, were not more effective than placebo for reducing knee pain by 20 percent. The response rate was lowest with placebo and highest with celecoxib, although some subjects did not receive pain relief from any compound. Further study is needed because the data suggested that those with moderate or severe knee pain who took glucosamine/chondrotin supplements had a significantly higher rate of response when compared to placebo. This remains an active area of research.

**Dose-response studies:** A research experiment for the purpose of finding out the degree of result that occurs for a given amount of stimulus.

## Summary

**Proteins** are made up of **amino acids,** which contain carbon, hydrogen, oxygen, and nitrogen. Protein is a critical nutrient, in part, because of the roles that it plays in the growth and development of tissues and the immune system. It has many other important roles including the synthesis of enzymes and hormones. Amino acids can also be **catabolized** to provide **energy.** Protein functions optimally when energy intake from carbohydrate and fat is sufficient. When energy intake is insufficient, such as with fasting or starvation, more amino acids are broken down to provide the carbon skeletons needed by the liver to manufacture glucose.

The recommended daily protein intake for endurance athletes is 1.2 to 1.4 g/kg while the recommendation for strength athletes is 1.6 to 1.7 g/kg. Ultraendurance athletes may need as much as 2.0 g/kg/d during some phases of their training. Recently, the timing of protein intake has received more attention as the importance of the consumption of a small amount of protein within one to two hours after exercise has been found to be beneficial to muscle protein synthesis and repair. Most athletes consume an adequate amount of protein but some consume too little protein, usually in conjunction with too little energy. Low protein and energy intakes have the potential to impair performance and health.

Proteins are found in both animal and plant foods. When animal foods are consumed the likelihood is high that the diet will provide **protein** of sufficient **quality.** Vegetarians who do not consume any animal-derived proteins can also obtain sufficient protein quality by correctly combining different plant proteins. Athletes can consume enough food to meet their higher-than-average protein needs. Protein supplements are popular, particularly among bodybuilders and strength athletes, and seem to be safe but no more or less effective than proteins found in food. Individual amino acid supplements do not seem to be effective for increasing muscle size or strength in trained athletes. Supplemental glutamine and **branched chain amino acids** have been studied in endurance athletes and seem to be safe, but their effectiveness is still unknown due to small study size and inconsistent results.

## Post-Test Reassessing Knowledge of Proteins

Now that you have more knowledge about protein, read the following statements and decide if each is true or false. The answers can be found in Appendix O.

1. Skeletal muscle is the primary site for protein metabolism and is the tissue that regulates protein breakdown and synthesis throughout the body.
2. In prolonged endurance exercise, approximately 3 to 5 percent of the total energy used is provided by amino acids.
3. To increase skeletal muscle mass, the body must be in positive nitrogen balance, which requires an adequate amount of protein and energy (calories).
4. The daily recommended protein intake for strength athletes is 2.0 to 3.0 g/kg body weight, twice that recommended for endurance athletes.
5. Strength athletes usually need protein supplements because it is difficult to obtain a sufficient amount of protein from food alone.

## Review Questions

1. Amino acids contain which chemical elements?
2. How do the structures of amino acids differ? How do these structural differences influence function?
3. What is meant by protein quality? How do plant and animal proteins differ in quality?
4. Briefly describe the digestion, absorption, and transport of protein found in food.
5. What is the amino acid pool? Why is such a pool important?
6. Describe anabolic and catabolic processes that involve amino acids.
7. What is nitrogen balance? Under what conditions is nitrogen balance positive or negative?
8. Describe the role the amino acid leucine plays in fueling endurance exercise.
9. Explain how protein metabolism is affected when the body is faced with short- and long-term starvation.
10. What is the recommended daily intake of protein for adult nonathletes? Endurance athletes? Strength athletes? Ultraendurance athletes?
11. Why is the timing of protein intake important?
12. What effect might exceptionally high protein intake have on training, performance, or health?
13. What effect might a low protein intake have on training, performance, or health?
14. Compare and contrast animal and plant proteins.
15. Describe how vegans can met their protein needs.
16. Are protein and individual amino acid supplements safe and effective? What information is needed to draw conclusions about safety and effectiveness?

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