CHAPTER 5

PROTEIN

LEARNING OBJECTIVES

1 | Define key terms related to protein and amino acids.

2 | Explain the functions and physiological effects of protein and amino acids in the body.

3 | Distinguish between essential and non-essential amino acids.

4 | Understand the digestion and absorption of protein in the body.

Research confirms protein's role as a vital component of health and fitness. However, studies have also established diets too high in protein may be as detrimental as diets lacking sufficient amounts of protein and active individuals require more protein than people with a sedentary lifestyle.

Protein is an essential part of the diet—one of three nutritional macronutrients, along with fats and carbohydrates—and plays many roles in the body. It's roles include providing structure and growth, catalyzing reactions, signaling, supporting immune activity, and transporting across cell membranes. Proteins are not a primary source of energy, but they can be used for energy during intense exercise or when nutrition is inadequate.

Active clients need to balance their intake of protein so as not to experience muscle loss but also to avoid the formation of harmful metabolic waste products. The body converts excess dietary protein to fat and increases the blood levels of the metabolic waste products **ammonia** and **uric acid**.

AMMONIA:
A toxic metabolic waste product produced from the metabolism of nitrogen-containing compounds like protein and amino acids.

URIC ACID:
A toxic metabolic waste product filtered by the kidneys as a result of the metabolism of nitrogen-containing compounds.

AMINO ACID:
An organic compound used as a precursor for other molecules in the body.

PEPTIDE BOND:
The bond that links amino acids together to form a protein.

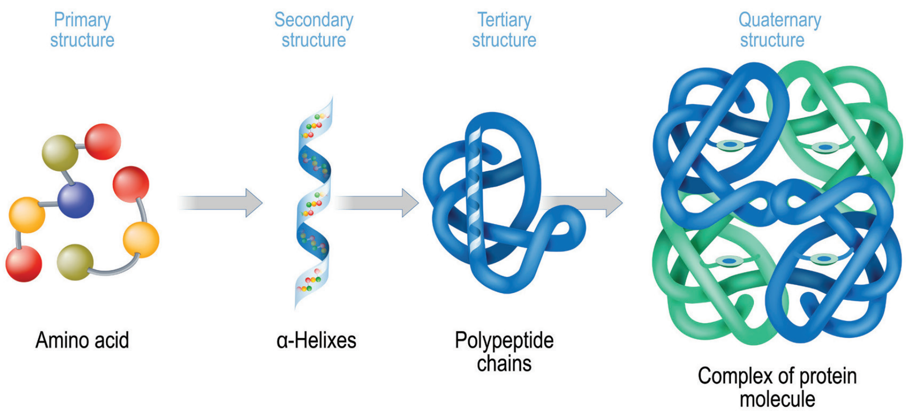
PROTEIN

A protein is a macromolecule and a polypeptide, a compound containing 10 to over 100 molecular subunits. Each subunit is a small molecule known as an **amino acid** which are linked together by a **peptide bond**.

The shape of a protein determines its role and function in the body. There are four levels of structure in each protein:

- The unique sequence of amino acids in a polypeptide chain that is determined by genetics makes the primary structure.
- The local folding of the polypeptide chain makes the secondary structure. The most common structures are the alpha-helix chain and the beta-pleated sheet.
- Combinations of chains and sheets make up the shapes of proteins. The tertiary structure is the three-dimensional shape of the polypeptide. The interactions of R groups between individual amino acids creates this 3-D structure.
- Some proteins are made of several polypeptides—known as subunits. The quaternary structure is formed based on the interactions between subunits.

Figure 5.1 Protein Structure



The amino acid is the primary structure that creates the secondary helix. A series of helices creates a polypeptide chain which, when combined with other polypeptide chains, creates the functional protein structure.

In terms of nutrition it is important to consider the amino acid subunits rather than whole proteins. About 20 amino acids are considered biologically important, but many more exist in nature and in the body. Amino acids are important not only for being the building blocks of protein but also for the individual roles they play in the body. For example, some amino acids are used in metabolic processes such as the **urea cycle** and others act as **neurotransmitters** that transmit nerve impulses.

Each amino acid is made of a central carbon atom known as the alpha carbon. Bonded to the alpha carbon are the following:

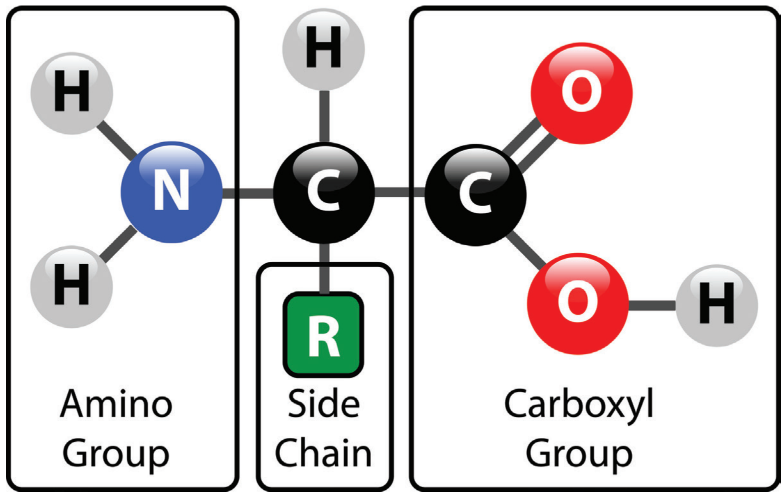
- An amino group: a chemical grouping, also known as a functional group, made up of nitrogen and hydrogen atoms
- A carboxyl group: a functional group containing carbon, oxygen, and hydrogen
- A hydrogen atom
- The R group: a unique functional group that varies depending on the type of amino acid

UREA CYCLE:
The metabolic process in which ammonia is converted to the waste product urea.

NEUROTRANSMITTER:
The molecule that transmits a signal across the synapse between two neurons.

DID YOU KNOW?
While dietary proteins and carbohydrates have uniquely different properties in both appearance and chemistry, when analyzed with bomb calorimetry, they produce the same amount of energy: a 4 kcal/gram value.

Figure 5.2 Amino Acid Structure



All amino acids have an amino group, a carboxyl group, and a unique side chain (R) group attached to a central carbon.

When amino acids attach to each other through covalent bonding, they form **peptides**. These peptide bonds are formed by a **dehydration reaction**. Disaccharides are also created when two smaller molecules link together through a dehydration reaction. To form a peptide through a dehydration reaction, the carboxyl group of one amino acid bonds to the amino group of another amino acid group, and a molecule of water is released.

A polypeptide is created when several amino acids link together via peptide bonds. Polypeptides have a free amino group at one end (called the N-terminal) and a free carboxyl group at the opposite end (the C-terminal). Proteins form when many polypeptides link together as a quaternary structure.

THE ROLE OF PROTEIN IN THE BODY

Protein is needed for the growth, maintenance, and repair of cells, including muscle cells; for the production of enzymes and **hormones**, and for **deoxyribonucleic acid (DNA)**expression. Protein constitutes most of the dry weight of body cells.

Proteins come in a range of sizes and shapes and are divided into two categories: **simple proteins** and **conjugated proteins**. Simple proteins consist only of amino acids, while conjugated proteins also have non-protein molecules or atoms as part of their structures.

PEPTIDES:
Compounds consisting of two or more amino acids linked together by peptide bonds.

DEHYDRATION REACTION:
A chemical reaction that forms a bond and releases a molecule of water in the process.

HORMONES:
Signaling molecules secreted by an endocrine organ or gland.

DEOXYRIBONUCLEIC ACID (DNA):
The large molecule in the cell nucleus that contains the cell's genetic blueprint and determines how the cell will develop.

SIMPLE PROTEIN:
A protein made up of only amino acid subunits.

CONJUGATED PROTEIN:
A protein that includes amino acids as well as one or more non-amino acid units.

Table 5.1 Simple and Conjugated Proteins and Sources

PROTEIN	TYPE	SOURCE
Serum albumin	Simple	Blood
Lactalbumin	Simple	Milk
Ovalbumin	Simple	Eggs
Myosin	Simple	Muscle
Collagen	Simple	Connective tissue
Keratin	Simple	Hair
Nucleic acid	Conjugated	Chromosomes
Lipoprotein	Conjugated	Cell membranes
Glycoprotein	Conjugated	Blood
Hemoglobin	Conjugated	Blood
Phosphoprotein	Conjugated	Milk

Proteins are diverse molecules with several unique properties and roles:

- **Contractile.** Actin and myosin allow muscles to contract and relax, and therefore to move.
- **Hormonal.** Proteins like insulin, **growth hormone (GH)**, and insulin-like growth factors carry signals throughout the body to regulate actions of cells and tissues.
- **Structural.** Structural proteins, like collagen, provide support and structure in the body.
- **Transporter.** Proteins like hemoglobin carry other compounds and nutrients.
- **Enzymes.** Enzymes are proteins that catalyze reactions in the body.
- **Receptors.** Some proteins act as receptors, regulating gene expression and the transportation of molecules into and out of cells.

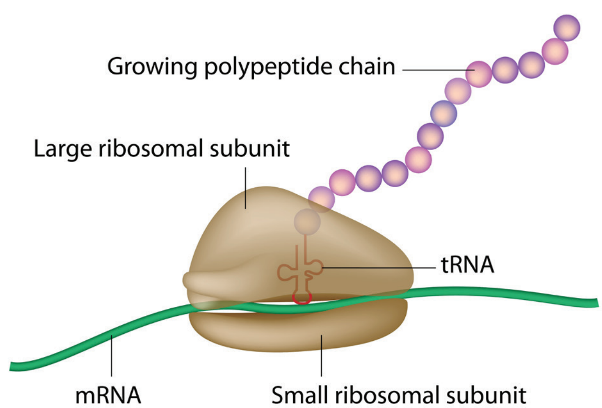
GROWTH HORMONE (GH):
A hormone released from the pituitary gland to stimulate growth, cell regeneration and repair, and cell reproduction. GH also acts homeostatically to increase blood glucose levels.

DID YOU KNOW?

DNA contains thousands of genes or codes for producing proteins. Creating proteins from genes takes two steps: transcription and translation and together, these steps are known as gene expression.

In transcription, information stored in the genes of the DNA molecule is transcribed into **ribonucleic acid (RNA)**. Both RNA and DNA are made up of a chain of nucleotide bases, but with slightly different chemical properties. Messenger RNA (mRNA) carries information, or message, from DNA out of the nucleus and into the cytoplasm for translation.

During translation, the mRNA interacts with a specialized complex called a ribosome, which reads the sequence of mRNA bases and transfer RNA (tRNA) assembles a protein, one amino acid at a time.



RIBONUCLEIC ACID (RNA):
The substance that carries the coded genetic information from the DNA in the cell nucleus to the ribosomes, where the instructions are translated into the form of protein signaling molecules.

ESSENTIAL AMINO ACIDS:
Amino acids the body cannot make and that must be consumed nutritionally.

NON-ESSENTIAL AMINO ACIDS:
Amino acids the body can make on its own and that do not need to be consumed.

CONDITIONAL AMINO ACIDS:
Amino acids that the body can make. Special populations or circumstances may warrant inclusion of these in the diet.

AMINO ACIDS

Nutritionally, amino acids are classified based on the dietary needs of the body. **Essential amino acids** cannot be made in the body and must be included in the diet while **non-essential amino acids** can be produced in the body when needed. **Conditional amino acids** are amino acids necessary in the diet for special circumstances, such as illness or intense athletic training. A diet with a wide variety of foods generally includes all of the nutritionally important amino acids.

Table 5.2 Nutritional Status of Amino Acids

ESSENTIAL	NON-ESSENTIAL	CONDITIONAL
Histidine	Alanine	Alanine
Isoleucine	Arginine	Arginine
Leucine	Cysteine	Cysteine
Lysine	Citrulline	Glutamine
Methionine	Glutamic Acid	Glycine
Phenylalanine	Glutamine	Proline
Threonine	Proline	Serine
Tryptophan	Serine	Tyrosine
Valine	Taurine	
	Tyrosine	

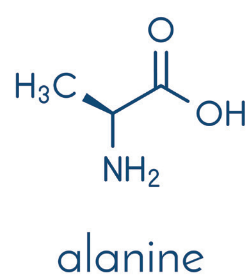
AMINO ACID REVIEW

Some amino acids only act as components of proteins while others have expanded functions as biochemical intermediates or **precursors** of other amino acids or substances. Some amino acids function in all these roles.

PRECURSORS:
Intermediate substances in the body's production of another substance.

ALANINE

Alanine is a non-essential amino acid found in high concentrations in most muscle tissue and is involved in the glucose-alanine cycle. During exercise, glycogen stores in muscle are broken down to glucose and then to a three-carbon-atom molecule pyruvate. Some of the pyruvate is used directly for energy by the muscle, while the rest is converted to alanine. The alanine is transported through the bloodstream to the liver and converted back to glucose.



ARGININE

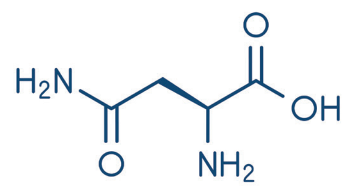
Arginine is a non-essential amino acid that plays a role in stimulating the release of GH and insulin-like growth factor .These increases may help reduce body fat, improve healing and recovery, increase muscle growth rate, increase muscle mass, and boost **nitric oxide (NO)** levels to improve blood flow.

arginine

NITRIC OXIDE (NO):
A free radical that increases blood flow through vasodilation.

ASPARAGINE

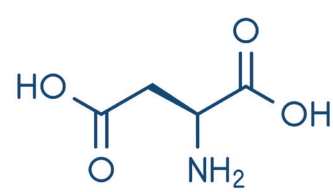
Asparagine is a non-essential amino acid involved in the proper functioning of the central nervous system. It stabilizes the nervous system by preventing both extreme nervousness or calm.



asparagine

ASPARTIC ACID

Aspartic acid, also referred to as L-aspartic acid or L-aspartate, is a non-essential amino acid shown to help reduce ammonia levels in the blood after exercise. The artificial sweetener aspartame contains aspartic acid and it is present in all protein containing foods, both animal and plant based.



aspartic acid

BRANCHED-CHAIN AMINO ACIDS

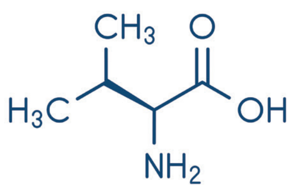
BRANCHED-CHAIN AMINO ACIDS (BCAAS):
Amino acids with chemically branched R groups. They are used for energy during strenuous physical activities.

The **branched-chain amino acids (BCAAs)** include isoleucine, leucine, and valine. Together, these three amino acids make up about 35 percent of the amino acid content of muscle tissue and is used by the body for energy. Under conditions of stress, injury, or exercise, the body uses a disproportionately high amount of the BCAAs to maintain nitrogen balance.

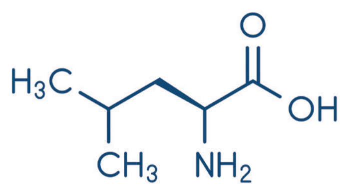
BCAAs have a history of supplemental and medicinal use for patients in stressed states, such as from burns, surgery, trauma, and starvation to help stimulate protein synthesis and maintain nitrogen balance. Additionally, leucine has other growth-related metabolic effects, including releasing GH and insulin and playing a role in controlling protein production.

Some of the related benefits of BCAA supplementation observed include the following:

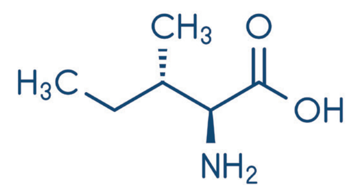
- Increased exercise endurance
- Reduction of exercise-related fatigue
- Improved mental performance
- Increased energy levels
- Stimulated protein synthesis
- Improved immune system function
- Increased lean body mass
- Increased strength



valine



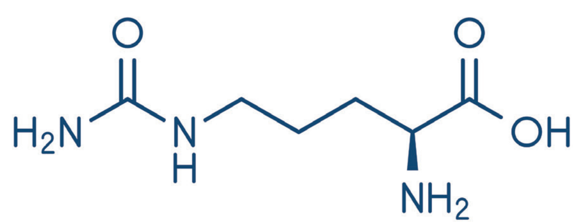
leucine



isoleucine

CITRULLINE

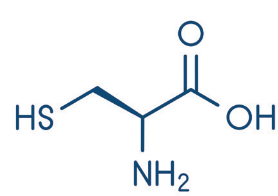
Citrulline is a non-essential amino acid that plays a role in the urea cycle for the removal of ammonia from the blood. It may also increase NO levels, improve exercise performance, and increase muscle protein synthesis, while reducing exercise-related muscle soreness.



citrulline

CYSTEINE

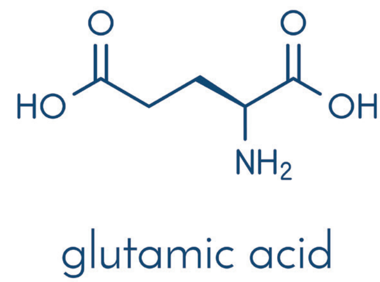
Cysteine is a non-essential sulfur-bearing amino acid that plays a role in energy production that the body manufactures from methionine and serine. Cysteine is important in the production of protein, hair, skin, connective tissues, connective tissue growth factor, taurine, and insulin. It also helps form glutathione, which is an important antioxidant and detoxifying agent.



cysteine

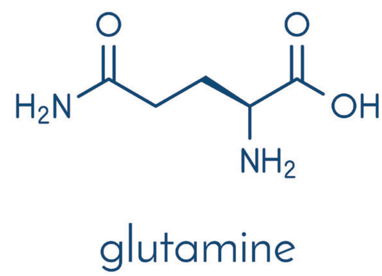
GLUTAMIC ACID

Glutamic acid, also known as glutamate, is a non-essential amino acid that acts as an intermediary in the Krebs cycle and is important for the metabolism of carbohydrates. It is also involved in the removal of ammonia from the muscles.



GLUTAMINE

Glutamine is one of the most plentiful non-essential amino acids present in the body. Researcher suggests that people under stress from injury or disease have decreased glutamine levels that correlates with poor immune system function and reduced protein synthesis. When patients were provided with supplemental amounts of glutamine, their immune system function improved, and nitrogen balance was restored.



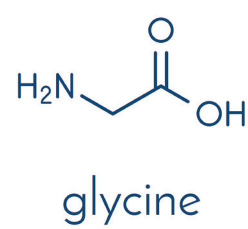
DID YOU KNOW?

At certain times, glutamine can make up more than half of the amino acid pool in skeletal muscle. This large, sustained amount of glutamine allows the body to make use of it as needed like in times of stress.

Glutamine is also reported to have anti-catabolic effects, reduce cortisol levels, improve wound healing, act as an energy source in certain cells, elevate GH levels, stimulate glycogen synthesis, combat overtraining syndrome, promote protein synthesis, support the blood buffering system, and promote gastrointestinal tract health.

GLYCINE

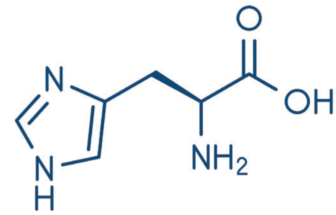
Glycine is a non-essential amino acid that is synthesized from serine, with folate acting as a coenzyme (enzyme cofactor), and is an important precursor of many substances in the body, including protein, DNA, phospholipids, collagen, and creatine. It is also a precursor in the release of energy and has been shown to increase GH levels. Glycine is found in high amounts in connective tissues.



Additionally, glycine is used by the liver in the elimination of toxic substances and in the formation of bile salts. It promotes proper functioning of the central nervous system and is an inhibitory neurotransmitter.

HISTIDINE

Histidine is an essential amino acid, important in the growth and repair of human tissue and the formation and maintenance of hemoglobin, the oxygen transport protein in red blood cells. Histidine is used in the body to make **histamine** and **carnosine**.



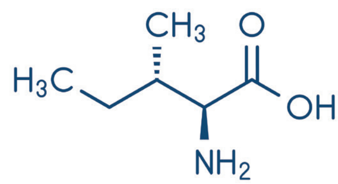
histidine

> **HISTAMINE:**
> A compound and neurotransmitter involved in local immune response and in regulation of functions in the digestive tract.

> **CARNOSINE:**
> A dipeptide made of alanine and histidine, present in large amounts in muscle and brain tissue.

ISOLEUCINE

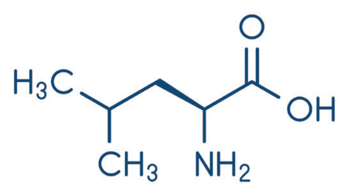
Isoleucine is an essential amino acid and a BCAA needed for the formation of hemoglobin. It is involved in the regulation of blood sugar and is metabolized for energy in muscle tissue during exercise.



isoleucine

LEUCINE

Leucine is an essential amino acid and BCAA important in energy production during exercise. More than half of dietary leucine may be used for energy in contracting muscles and it is a limiting amino acid if supplemental amounts are not taken to compensate for losses during training.

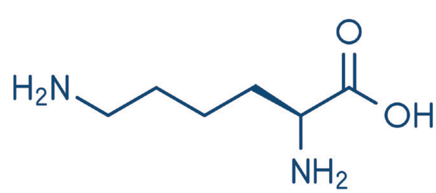


leucine

Leucine may also stimulate the release of insulin, which increases protein synthesis and inhibits protein breakdown.

LYSINE

Lysine is an essential amino acid found in large quantities in muscle tissue. It is needed for proper growth and bone development and it aids in calcium absorption. Lysine enhances immune system function and may be useful for fighting cold sores and herpes viruses.



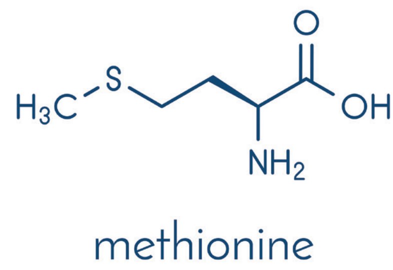
lysine

Together with methionine, iron, and vitamins B1, B6, and C, it helps form **carnitine**, a compound that the body needs for energy production from fatty acids. Lysine deficiency limits protein synthesis and the growth and repair of tissues, particularly connective tissues.

> **CARNITINE:**
> An amino acid derivative found mostly in muscle tissue that helps the body use fat for energy.

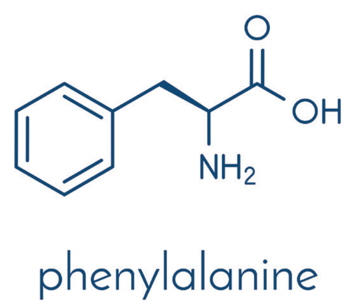
TRANSMETHYLATION: The metabolic process in which an amino acid donates a methyl group to another compound.

METHIONINE



Methionine is an essential sulfur-bearing amino acid involved in **transmethylation**, a metabolic process that is vital to the manufacture of several compounds. It is involved in the synthesis of creatine and important for muscle performance and is a limiting amino acid in many proteins, especially in plant proteins. It functions in the removal of metabolic waste products from the liver and assists in the breakdown of fat and the prevention of fatty buildup in the liver and arteries.

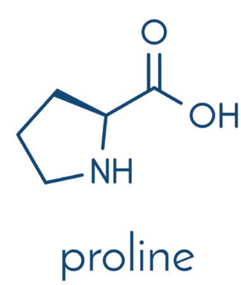
PHENYLALANINE



Phenylalanine is an essential amino acid and a precursor of the nonessential amino acid tyrosine. It is a precursor of several important metabolites, such as the skin pigment melanin and several catecholamine neurotransmitters, including epinephrine, norepinephrine, and dopamine. The catecholamines are important in memory and learning, locomotion, sex drive, tissue growth and repair, immune system functioning, and appetite control. Phenylalanine suppresses appetite by increasing the brain's production of norepinephrine and **cholecystokinin**.

CHOLECYSTOKININ: The hormone that is thought to be responsible for signaling fullness after eating.

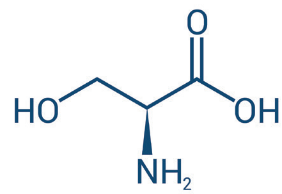
PROLINE



Proline is a non-essential amino acid occurring in high amounts in collagen tissue that can be synthesized from and converted to glutamic acid. It is important in the maintenance and healing of collagen tissues in the skin, tendons, and cartilage. Proline and hydroxyproline are typically provided in supplements from hydrolyzed collagen or gelatin and they may improve joint function and mobility and reduce pain and stiffness, especially in knee joints.

SERINE

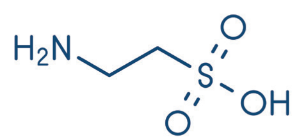
Serine is a non-essential amino acid found in proteins and derived from glycine. Its metabolism leads to the formation of many important substances, such as choline and phospholipids, which are needed to form some neurotransmitters and are used to stabilize cell membranes.



serine

TAURINE

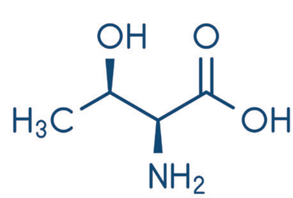
Taurine is a non-essential sulfur-bearing amino acid that plays a major role in brain tissue, nervous system functioning, blood pressure regulation, and in the transportation of electrolytes across cell membranes. It is found in the heart, muscle tissue, central nervous system, and the brain. Other reported functions of taurine include bile acid function, detoxification of xenobiotics (foreign substances in the body), membrane stabilization, antioxidant activity, osmoregulation, cell proliferation, modulation of neuronal excitability, and intracellular and extracellular calcium regulation.



taurine

THREONINE

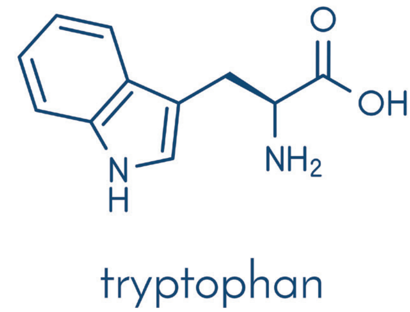
Threonine is an essential amino acid and is an important component of collagen, tooth enamel, protein, and elastic tissue. It can also function as a lipotropic agent, a substance that prevents fatty buildup in the liver. Supplemental threonine has a reported medical use in the treatment of depression in patients with low threonine levels.



threonine

TRYPTOPHAN

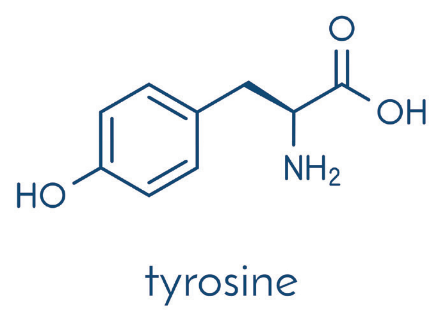
Tryptophan is an essential amino acid necessary to produce vitamin B3 and the neurotransmitters serotonin and melatonin. Taking supplemental vitamin B3 can help conserve tryptophan for its other functions. Supplemental tryptophan has long been used for its pronounced calming effects, for insomnia, and for depression.



Tryptophan is one of the least abundant amino acids in food, which makes it one of the limiting essential amino acids. Some foods that are high in tryptophan are cottage cheese, pork, wild game, duck, and avocado. Eating these foods along with vitamin B3 and the cofactors vitamin B6 and magnesium may be useful for some.

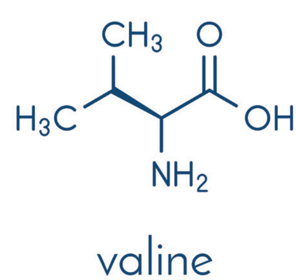
TYROSINE

Tyrosine is a non-essential amino acid that is made from phenylalanine and serves as the foundation for thyroid hormone. Supplementation with L-tyrosine can have a sparing effect on phenylalanine, leaving phenylalanine available for functions not associated with tyrosine formation. It is a precursor of the catecholamines, regulates appetite, and aids in melanin skin pigment production.



VALINE

Valine is an essential amino acid a BCAA. As with isoleucine and leucine, valine is an integral part of muscle tissue and may be used for energy when muscles are being exercised and is involved in tissue repair, nitrogen balance, and muscle metabolism.



PROTEINS, AMINO ACIDS, AND ENERGY

Under conditions of severe calorie restriction, the body releases amino acids from muscle tissue for use as energy. Even in a well-fed state, the body will use amino acids for energy during exercise and sometimes at rest. This catabolism (breakdown) of protein is most likely to occur during intense workouts, like power exercises and prolonged endurance activities. Catabolism may also occur when the body runs out of consumed carbohydrates or stored glycogen from muscle and liver tissue. Muscles use the BCAAs to supply a limited amount of energy during strenuous exercise.

Research has shown that although the body can utilize all three BCAAs for energy during exercise, it uses more leucine than the others. A trained individual uses leucine even when at rest. This makes the BCAAs **limiting nutrients**, nutrients that, through their absence or presence, restrict the use of other nutrients or the body's normal functions.

LIMITING NUTRIENTS:
A nutrient that limits reactions, functions, and use of other nutrients because it is absent or limited.

DID YOU KNOW?

Even with a healthful, balanced diet, a limiting nutrient can restrict muscle growth. For example, a client consumes 100 grams of protein per day, with all the essential amino acids in equal amounts. Their body will use a percentage of leucine for energy during a tough training session which reduces the amount of leucine available for growth and repair of muscles after training. Even if the body has access to adequate amounts of the other amino acids, this diminished leucine supply limits muscle growth. When the leucine supply runs out, protein formation will be negatively affected because leucine is an essential amino acid.

THE QUALITY OF PROTEINS

Not all proteins are nutritionally equal. Some include more essential amino acids and are better suited for growth and muscle development. Scientists have developed several different methods to rate or classify proteins.

COMPLETE VERSUS INCOMPLETE PROTEINS

Because adequate protein intake is essential for optimum growth in children, the World Health Organization has conducted research on protein requirements. It was determined that not all proteins supply the proper amounts and proportions of the amino acids necessary for adequate growth and development.

COMPLETE PROTEINS:
Proteins that contain the essential amino acids in amounts that are sufficient for the maintenance of normal growth rate and body weight.

INCOMPLETE PROTEINS:
Proteins that are deficient in one or more of the essential amino acids.

Complete proteins are proteins that contain the essential amino acids in amounts sufficient for the maintenance of normal growth rate and body weight. Complete proteins have a high biological value. Most animal-based foods have complete proteins.

Incomplete proteins are deficient in one or more of the essential amino acids. This amino acid deficiency creates a limiting amino acid condition, which adversely affects growth and development rates. Most plant proteins are incomplete but can be combined in ways that provide a complete complement of essential amino acids.

Considering the dynamics of amino acids in the body, even high-quality proteins can be considered incomplete when demands are greater than the amino acids availability. Proper proportions of essential and nonessential amino acids are required for optimum growth and recovery meaning clients should consume a diverse source of high-quality protein throughout the day to ensure an adequate intake of amino acids.

DID YOU KNOW?

Proteins are the basis for cellular communication and are critical in sending and receiving messages. Any cell (in plants or animals) that is capable of receiving a signal within the living structure contains protein which means plants contain protein, but sometimes in only trace amounts. Portions of the protein in plants may also be bound in cellulose, a plant starch, which human digestive systems cannot digest which limits how much protein a person can access from plant foods.

FREE-FORM AND PEPTIDE-BONDED AMINO ACIDS

The terms free-form and peptide-bonded are often used to describe the amino acid content of food or supplements. Peptide-bonded amino acids are amino acids that are linked together. Dipeptides are two amino acids linked together, tripeptides are three amino acids linked together, and polypeptides are four or more amino acids linked together. The intestines can absorb free-form, dipeptide, and tripeptide amino acids but not polypeptides.

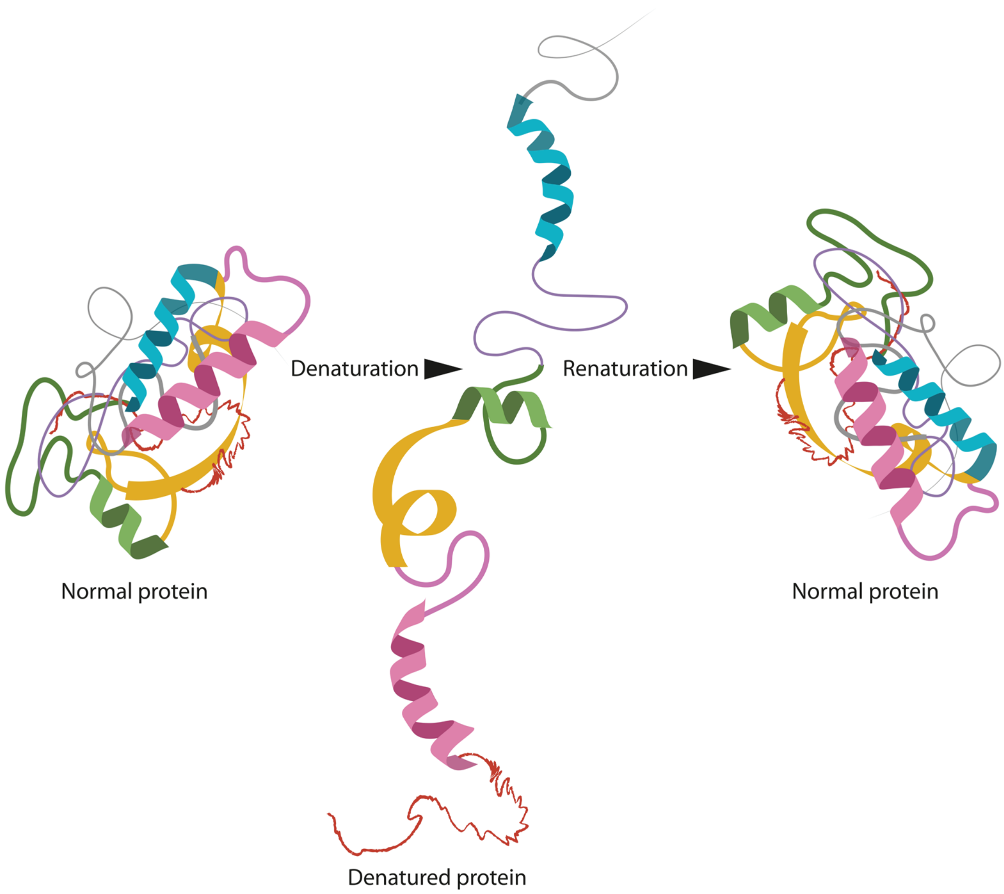
The use of free-form amino acids is still common in clinical applications when intravenous solutions are used to supply amino acids directly into the bloodstream. Free-form amino acids can also be used to fortify food proteins. Taking BCAA supplements with meals, for instance, can compensate for the loss of the amino acids used for energy during a workout. Free-form amino acids are also sometimes added to protein products to selectively increase the amino acid content.

A mixture of free-form and peptide-bonded amino acids could be better than free-form amino acids alone because the intestines can better absorb mixtures for transport into the bloodstream. The upper small intestine is better able to absorb amino acids in di- and tri-form.

PROTEIN DIGESTION

Several factors can change a protein's shape and chemistry. Changes in temperature (cooking), pH (digestion), high salt concentrations, alcohol, mechanical agitation, and exposure to chemicals alter the shape of a protein. When protein loses its shape (bonds are broken), it also loses its function. This is known as denaturation.

Figure 5.3 The Denaturation and Renaturation of Protein



The body digests protein through several steps, beginning with cooking and the mechanics of chewing and followed by chemical and pH changes in the digestive tract.

PEPSIN:
An enzyme released in the stomach that breaks proteins down to smaller peptides and free amino acids.

CHYME:
The mass of partially digested food and gastric juices that moves from the stomach to the small intestine.

PROTEASE:
An enzyme that is produced in the pancreas and plays a large role in the digestion of protein, primarily in the small intestine.

CHYMOTRYPSIN:
A digestive enzyme secreted by the pancreas and converted to an active form by trypsin. It breaks down proteins in the small intestine.

TRYPSIN:
An enzyme that breaks down and digests protein in the small intestine.

MOUTH TO STOMACH

Chewing mechanically breaks down large chunks of protein into smaller pieces that can be swallowed. Saliva is excreted to help the bolus move down the esophagus and there are no enzymes present in saliva that act on protein.

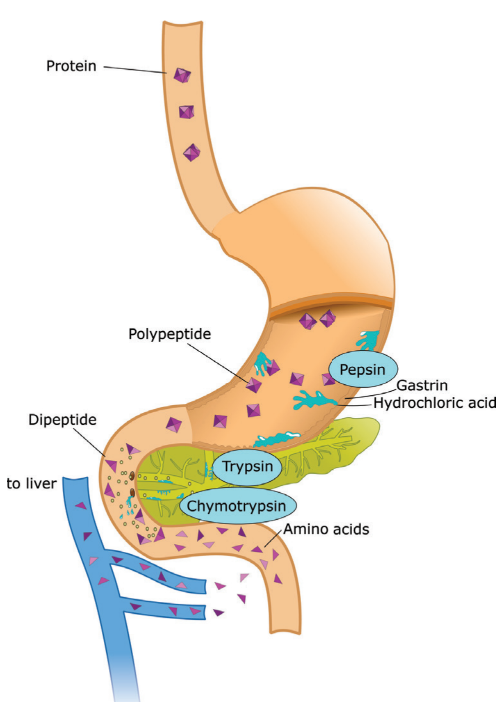
Once food is in the stomach, gastric juices—made of hydrochloric acid and **pepsin** - break down the protein. The acidity inside the stomach environment unfolds any parts of the proteins that still retained some three-dimensional structure after cooking.

Pepsin is secreted by the lining of the stomach to break peptide chains into shorter fragments. The mechanical churning of the stomach turns partially digested protein into **chyme**. Protein takes longer to digest in the stomach than carbohydrates but takes less time than fats.

SMALL INTESTINE TO BLOODSTREAM

Most protein digestion happens in the small intestine with the help of **protease**. When chyme enters the small intestine, the pancreas releases **chymotrypsin** and **trypsin**. The cells of the small intestine release more enzymes to complete the process of breaking down proteins into amino acids and the contractions of the small intestine mix and send the amino acids to absorption sites.

Figure 5.4 The Digestion of Protein



Transport proteins using the energy from ATP move the amino acids through the intestinal cells and into the blood to be sent to the liver before being sent out to other cells or before being broken down further.

About 90 percent of proteins do not get broken down any further than their constituent amino acid subunits. However, if they are broken down beyond the amino acid level—as happens in very high-protein diets—then nitrogen-containing ammonia is released. This substance is toxic in the body and must be excreted.

Ammonia is converted into urea and transported to the kidneys to be removed from the body in urine.

DID YOU KNOW?

When blood glucose levels are low, the hormones cortisol and epinephrine can bind to the liver to signal and activate gluconeogenesis. Gluconeogenesis is a survival mechanism that ensures glucose is spared and readily available for the brain and this process allows serum amino acids to be broken down to help regain homeostasis (increased blood glucose).

Though this does take place in different organs, the liver does the bulk of the work in converting these non-sugar compounds to readily usable energy in the blood. Having excess BCAAs can be beneficial to help spare muscle protein from being broken down when energy availability is low.

FOOD SOURCES OF PROTEIN

Proteins are found in both animals and plants and protein and fat are usually found together in foods, especially animal products. Most animal proteins tend to be of higher quality than plant proteins and contain the proper proportions of essential amino acids.

Most plant protein sources, such as beans and peas, are incomplete in terms of essential amino acid content. Combinations of different plant proteins are required to create a complete protein source. Clients can get complete proteins from plants by combining legumes and whole grains, such as black beans with brown rice.

Some of the best low-fat sources of protein include low-fat/skim milk and other low-fat dairy products, fish, shellfish, lean red meats with the fat trimmed, and poultry with the skin removed.

Table 5.3 Common Foods and Protein Content (per 100 grams)

Protein Source	Grams of protein per 100 grams of source
Almonds	17 g
Apple	0.2 g
Asparagus	2 g
Banana	0 g
Barbeque Sauce	2 g
Beef Sirloin	24 g

Protein Source	Grams of protein per 100 grams of source
Beer	0.3 g
Bread (Brown, 1 slice)	8 g
Broccoli	3 g
Butter	0.4 g
Cashews	18 g
Celery	0.9 g

Table 5.3 Common Foods and Protein Content (per 100 grams) - Continued

Protein Source	Grams of Protein per 100 grams of source
Cheddar Cheese	26 g
Cheese Pizza	9 g
Cheesecake	4 g
Chicken	29 g
Coconut	5 g
Cod	21 g
Coffee	0.2 g
Crab	20 g
Cream Cheese (Plain)	8 g
Doughnut	6 g
Flounder	25 g
Goat Milk	3 g
Grapes	1 g
Hamburger	14 g
Hardboiled Egg	12 g
Honey	0.4 g
Human Milk (Breast Milk)	1 g
Jelly	0.6 g
Lettuce	1 g
Mango	0 g
Margarine	0.4 g
Mayonnaise	2 g
Mustard	29 g
Onion	0.9 g
Orange	0 g

Protein Source	Grams of Protein per 100 grams of source
Oysters (Raw)	11 g
Peanut Butter	23 g
Peanuts	17 g
Pickles	0 g
Pineapple	0.5 g
Pistachios	19 g
Plain Yogurt	4 g
Pork Chop	22 g
Potato	2 g
Prawns/Shrimp	23 g
Raisins	1 g
Red Wine	0.2 g
Rice	2 g
Salami (Sliced)	19 g
Salmon	20 g
Scallops	23 g
Skim Milk	10 g
Spinach	5 g
Sponge Cake	6 g
Swiss Cheese	29 g
Tuna	23 g
Turkey (Roasted)	28 g
Vegetable Oil	Trace
Vinegar	0.4 g
Walnuts	11 g
Whole Milk	3 g

RECOMMENDED DIETARY ALLOWANCES FOR PROTEIN

Table 5.4 RDA for Protein

Category	Age Group	RDA (g/day)
Male	14-18	52
	19-30	56
	31-50	56
	51-70	56

Category	Age Group	RDA (g/day)
Female	14-18	46
	19-30	46
	31-50	46
	51-70	46

PROTEIN AND ATHLETES

Athletes typically require a diet high in protein because of the demands placed on their bodies. Different types and intensities of sports and training require different body compositions and specific amounts of protein. As these factors change throughout an athletic season or as an athlete's body composition changes, their protein needs will also change.

A nutrition coach should consider the following when making protein suggestions to athletes:

- Protein can be broken down and used or stored as fat. To prevent fat storage, the research suggests distributing protein intake throughout the day rather than eating large amounts in one sitting. This strategy allows the amino acid constituents to be used for muscle maintenance, growth, and recovery instead of stored.
- For building lean body mass, daily protein intake must maintain a positive muscle protein balance. Daily intake in the range of 1.4–2.0g protein per kilogram of body weight per day (g/kg/d) is a suggested range and is sufficient for most exercise that is intended to develop mass.
- Carbohydrate intake can also help offset muscle damage and promote recovery through insulin and its downstream effects on the MAPK pathway, which is a chain of proteins in the cell that communicates a signal from a receptor on the surface of the cell to the DNA in the nucleus of the cell. Athletes should consume adequate protein and carbs before and after training.
- Fitness professionals should prioritize whole foods for protein in most nutrition plans but include supplemental protein for athletes if needed. Daily protein needs rise with the intensity and duration of training which creates a problem with packing the gut and speed of assimilation. Supplemental protein can bridge the gap and help athletes get more protein more efficiently.