# Protein

Protein is one of the most discussed topics in sports nutrition, and for good reason. It is the second-most abundant molecule in fat-free bodily tissues (water being the most abundant). It plays a pivotal role in exercise recovery and it is involved in nearly all bodily functions and processes. Proteins are responsible for many functions throughout the body, including acid-base balance, energy production, cell signalling, and nutrient transport. For these reasons and many more, protein is an essential dietary nutrient for healthy living.

## Protein structure

Similar to other organic molecules, protein is made from the elements carbon, hydrogen and oxygen. However, protein is unique from the nutrients carbohydrate and fat because it is composed of nitrogen, as well. The elements carbon (C), hydrogen (H), oxygen (O) and nitrogen (N) combine to form the building blocks of protein, which are known as amino acids.

### Amino acids

All proteins are composed of amino acids. There are hundreds of amino acids in nature, yet there are just 20 amino acids that the human body requires to perform its various functions. Amino acid structure and arrangement has five components: a central carbon, a carboxyl group (organic acid – COOH), a hydrogen, an amino group (NH2), and a side chain (R group). The side chain is what makes each individual amino acid unique, and, therefore, it is different between every amino acid. For example, glycine only has a single hydrogen in the side-chain position, while leucine’s side chain is a more complex carbon and hydrogen structure. Nutrition Coaches must know whether an amino acid is nonessential, conditionally essential, or essential in the human diet.

Essential amino acids (EAA) must be consumed in the diet because they are necessary for bodily functions and cannot be synthesized within the body. There are nine EAAs, which include three branched chain amino acids. There are also six conditionally essential amino acids. Unlike EAAs, conditionally essential amino acids are considered nonessential under normal circumstances and can be synthesised in the body; however, under certain physiological conditions, requirements can outweigh their availability or rate of synthesis, making them essential for some individuals. When this occurs, the conditionally essential amino acid must be obtained in the diet. Healthy adults typically do not need to be concerned about consuming enough conditionally essential amino acids, as they only become essential during infancy, injury, disease or trauma. Nonessential amino acids can be synthesised in the body from other amino acids, typically the EAAs, so they do not need to be consumed in the diet.

| **Nonessential Amino Acids** | **Conditionally Essential Amino Acids** | **Essential Amino Acids** |
| --- | --- | --- |
| Alanine  Asparagine  Aspartic acid  Glutamic acid  Serine | Arginine  Cysteine  Glutamine  Glycine  Proline  Tyrosine | Histidine  Lysine  Methionine  Phenylalanine  Threonine  Tryptophan    Branched Chain Amino Acids  Isoleucine  Leucine  Valine |

A classic mnemonic to remember the EAAs is PVT TIM HALL (which borrows arginine, a conditionally essential amino acid, for the “A.”)

* Phenylalanine
* Valine
* Threonine
* Tryptophan
* Isoleucine
* Methionine
* Histidine
* Arginine\*
* Lysine
* Leucine

Because the conditionally essential amino acids so rarely become essential for individuals, which amino acids to classify as conditionally essential remains a debated topic. For example, some experts advocate that serine be added to the list of conditionally essential amino acids, while others argue that amino acids only become conditionally essential in the presence of disease. Clients should always be referred to their primary care doctor to have bloodwork analysed if any concerns regarding amino acid deficiency exist.

Another classification system for amino acids is based on their potential to become glucose or ketones for use in energy metabolism. These are known as glucogenic or ketogenic amino acids. While amino acids should not be relied on for optimal energy production, they can be broken down preferentially over fatty acids in times of negative energy balance when more intense activity needs to be sustained and carbohydrate availability is insufficient. Glucogenic amino acids can have their carbon backbone converted to glucose by the process of gluconeogenesis, or they can be converted to an intermediate compound that may enter the Krebs cycle directly. Ketogenic amino acids may become acetoacetate (a ketone body) or acetyl-CoA prior to entering the Krebs cycle for the generation of ATP. Some amino acids will always be specifically glucogenic or ketogenic, while others can be both glucogenic and ketogenic, with the outcome depending on which stage of metabolism they enter.

| **Glucogenic** | **Ketogenic** | **Glucogenic or Ketogenic** |
| --- | --- | --- |
| Alanine  Asparagine  Aspartic acid  Cysteine  Valine  Glutamic acid  Glutamine  Glycine  Proline  Serine  Arginine  Histidine  Methionine | Leucine  Lysine | Tyrosine  Isoleucine  Tryptophan  Phenylalanine  Threonine |

### Protein synthesis

When proteins are consumed, they must first be broken down into amino acids by digestion to be absorbed in the intestines. From there, they can be transported to peripheral tissues and recombined to form new proteins such as collagen, myosin, and hemoglobin. Protein synthesis is the process by which amino acids are joined together to form proteins, such as lean tissues, like muscle.

The amino acids bond together by a chemical reaction called dehydration synthesis. In a dehydration synthesis reaction, a hydrogen from one amino acid and a hydroxyl group (OH) from a second amino acid are removed and joined together by a peptide bond to form the newly synthesised molecule and the byproduct of water (H2O). It is called dehydration synthesis because a water molecule is removed, thus de*hydrating* the molecule. The opposite process is known as hydrolysis, which occurs during digestion when proteins are broken down to amino acids.

When two amino acids are joined, it is known as a dipeptide. When three amino acids are joined, it is known as a tripeptide. When between four and nine amino acids join it is called an oligopeptide, and chains of 10 or more amino acids are called polypeptides. Bodily proteins are most often formed by at least 50 amino acids. The human body is in a constant state of both protein synthesis (anabolic) *and* protein breakdown (catabolic). When an individual is gaining muscle mass, their rate of muscle protein synthesis is greater than their body’s rate of muscle protein breakdown. Conversely, someone who becomes inactive for an extended period of time will have greater rates of muscle protein breakdown as the body returns to equilibrium.

Muscle proteins vary in size, shape, and function. The three major muscle proteins are myosin, actin, and titin, which all contain different amino acid compositions. Titin has about 30,000 amino acids, myosin has about 6,000 amino acids, and actin has about 400 amino acids. Myosin uses energy from ATP to grab actin and flex in unison with many other myosin proteins to produce a muscle contraction. Titin helps provide a muscle’s elasticity so it can return to its resting length following muscle contractions. It is so large because it stretches over the whole muscle cell, whereas myosin and actin go about halfway. Myosin is much larger than actin due to its more complex function.

## Protein digestion and absorption

The first step in protein breakdown is denaturation, changing the shape of a protein but not its primary structure. Denaturation occurs in response to many factors such as temperature, pH, and enzymes, all of which are at work during protein digestion and absorption. For most protein-dense foods, this process begins with cooking the food. The applied heat denatures proteins, which must occur within the body eventually, either by mastication (chewing) or in the acidic environment of the stomach. Even cutting food up into smaller pieces is, in a way, facilitating digestive processes by reducing the amount of necessary mastication. Unlike with carbohydrates and fats, enzymes for protein in the saliva are relatively inactive and do little to aid in digestion.

When you want to see protein denaturation in action, fry an egg! When the clear egg white heats up and turns opaque as it cooks, you are witnessing protein denaturation. Protein denaturation does not make the protein within the food useless, as is often suggested. Many forms of cooking jumpstart the process of breaking down proteins and facilitating more efficient digestion.

However, chewing food causes the stomach wall to release gastrin in anticipation of the digestion process. In turn, gastrin causes the release of hydrochloric acid and the hormone pepsinogen in the stomach. When pepsinogen contacts the hydrochloric acid, it releases the active enzyme pepsin. Together, hydrochloric acid and pepsin begin the enzymatic breakdown of protein in the stomach. Hydrochloric acid denatures the protein and pepsin begins breaking the very long polypeptide chains into smaller peptide chains (hydrolysis reaction). Those smaller peptide chains then move to the small intestine for the next step in digestion.

As the food passes from the stomach into the duodenum of the small intestine, the intestinal cells release the hormones secretin and cholecystokinin. Secretin mostly acts as a regulator of digestion, reducing acid release to help restore pH when eating ceases. Cholecystokinin acts on the pancreas, which releases the protease enzymes trypsin, chymotrypsin, carboxypeptidase, and elastase into the small intestine. The protease enzymes continue to break down peptide chains into even shorter peptides. Finally, peptidases and aminopeptidases reduce the size to single amino acids and dipeptides, which can then be absorbed from the small intestine into the hepatic portal vein, carrying them to the liver.

Within the liver, amino acids may be used for protein synthesis, broken down into urea (urine waste), converted to carbohydrate or fat (gluconeogenesis or ketogenesis), metabolized for energy, or released into the peripheral blood stream for use throughout the body. While the maximum amount of protein that can be absorbed in one meal is yet to be determined, about 85% of plant protein and 95% of animal protein is absorbed and very little protein is found in excrement. Any remaining proteins and peptides that make it past the small intestine and into the large intestine (colon) are fermented by bacteria and secreted as waste.

## Protein function

While fats and carbohydrates may be thought of as energy macronutrients, protein is more of a structural and functional macronutrient, forming bodily structures and serving many necessary bodily functions. Although it is possible for protein to be metabolized for energy, this only occurs when there is an abundance of protein in the diet and/or when there is not enough carbohydrate to support normal energy production (negative energy balance). Protein and amino acids are primarily used to create bodily tissues; to form enzymes and cellular transporters, as cell signals; to maintain fluid balance; to buffer acids and bases (pH balance), in the production of hormones and neurotransmitters; and in the immune system.

**Bodily tissues**

Most bodily protein is located within the musculoskeletal system. However, keep in mind there is no true storage depot for protein like there is for carbohydrates (glycogen stored in muscle tissue and the liver) or fats (adipose tissue, i.e., body fat). Rather, proteins make up the physical structure of the muscles and bones. This is why amino acids are not considered a primary source of energy because the only way to supply them (aside from eating) is by breaking down non-fat bodily tissues.

Along with the mineral calcium, bones are formed from very strong collagen proteins, which are also found in the skin, tendons, ligaments, and joints. Collagen’s molecular structure is a triple helix, which gives it great tensile strength. Collagen protein’s function is to provide structural integrity. The reason collagen is so effective at being strong and flexible is because it is formed from many small amino acids (glycine, proline, and hydroxyproline), which can move around without breaking their bonds. Usually found alongside collagen is elastin protein, which provides elasticity so tissues can bend but not break. Muscle proteins myosin, actin, and titin are another large repository for body proteins that enable movement. Finally, keratin is another tough protein found in human hair and fingernails.

**Enzymes and cellular transporters**

Nearly all enzymes are made from protein. Enzymes are catalysts for chemical reactions and are critical for carrying out many functions within the body, especially in digestion and metabolism. Enzymes are present in saliva, stomach and intestinal fluids, blood, and throughout the cells of the body. For example, pyruvate dehydrogenase is an enzyme involved in the metabolism of glucose. It converts the end product of anaerobic glycolysis, pyruvate, to acetyl-CoA for use in the Krebs cycle within the mitochondria. Without pyruvate dehydrogenase, the energy that humans are able to generate from a glucose molecule would be severely limited.

Cellular transporters are similar to enzymes. However, instead of catalysing a reaction, they are more like doorways in cell membranes. One of the most discussed transporters in biology is the sodium–potassium pump. The sodium–potassium pump actively (using ATP) transports potassium into the cell and sodium out of the cell to create a gradient that the cell can use for other transporters and electrical signaling. This protein-based cellular transporter is, in essence, what allows these electrolytes to do their job within the cells, maintaining the pathway by which the nervous system sends its electrical signals for muscles to contract. Other cellular transporters work passively (without ATP) to allow nutrients to cross cellular membranes.

Proteins are also critical for transporting a wide range of nutrients throughout the body. For example, haemoglobin is a protein in red blood cells that binds to and transports both oxygen and the metabolic waste product of carbon dioxide. Another example is lipoproteins, which are molecules that make the transport of lipids (fats) throughout the body possible. The most well-known example of this is cholesterol. The lipoproteins have historically received negative attention for their role in cardiovascular health (or risk), yet they perform an essential bodily function by moving lipids between the liver, adipose tissue, and other tissues or organs so they may be metabolized or stored.

**Cell signalling**

The concentration of individual amino acids can be interpreted by the nervous system as a signal to perform certain functions. For example, an increase in the amino acid leucine has been shown to signal muscle cells to begin synthesizing new proteins when the other necessary amino acids are present. Leucine in isolation will not build muscle, but supplementing leucine into an otherwise high-protein diet can help enhance muscle hypertrophy. Not only can proteins and amino acids be signals themselves, but they often form the cellular receptors and sensors, as well. These receptors can respond to many different stimuli outside the cell and relay a message inside the cell.

**Fluid balance**

Proteins help maintain fluid balance on the cellular level as part of their role as transporters across cell membranes, allowing water to move between the cells and the blood. Fluid balance is also managed by the protein albumin, the most abundant protein in blood plasma. Albumin is present in the blood but much less abundant within soft tissue. This creates a concentration gradient that helps pull excess fluid from bodily tissues back into the bloodstream by osmosis.

**pH balance**

Proteins and amino acids help regulate the body’s acid–base balance by binding to free hydroxyl groups or hydrogen ions in the blood to help maintain a neutral pH. Hemoglobin is one of the most well-known proteins that assist with this. As a side effect of its role in binding to carbon dioxide to transport it out of the body as waste, it prevents the CO2 from forming carbonic acid and lowering blood pH. The protein’s presence within the blood, cell, and other fluids provide over half of the buffering power in the body.

Can amino acids prevent someone from *staying alkaline*? The short answer is no. Amino acids contain both alkaline (basic) and acidic functional groups. With few exceptions, like the stomach, the body is already slightly alkaline with a blood pH of about 7.4 and amino acids are a major factor in maintaining the slightly alkaline pH.

**Hormones and neurotransmitters**

Many hormones are derived from amino acids, which are known as peptide hormones. For example, human growth hormone (produced in the pituitary gland) contains 191 amino acids. Other examples of peptide hormones can be found throughout the body, such as insulin (produced in the pancreas), gastrin (produced in the stomach), and leptin (produced within adipose tissue).

Peptide hormones often also act as neurotransmitters. While similar to hormones, in that they serve as chemical messengers throughout the body, they are classified differently. Neurotransmitters are part of the nervous system, while hormones are part of the endocrine system. A single peptide hormone can belong to either system depending on how it is behaving. For example, oxytocin is a small peptide hormone that can also function as a neurotransmitter. As a hormone, for example, oxytocin acts within the mammary glands to signal the release of breast milk after giving birth. As a neurotransmitter, oxytocin acts on the prefrontal cortex to stimulate feelings of social connection and sexual attraction, giving rise to its nickname as the love hormone (even though its function in this capacity is within the central nervous system as a neurotransmitter and not the endocrine system as a hormone). Other peptides that function as neurotransmitters include epinephrine, glutamate, dopamine, serotonin, and histamine.

**Immune system**

Like red blood cells with haemoglobin, white blood cells also require protein to become functional. The white blood cells themselves also use proteins to fight infection and disease. In response to an infection, the white blood cell produces antibodies, which are proteins, to protect the body from sickness and disease while leaving friendly microbes and bacteria alone.

Having adequate dietary protein can help prevent sickness and infection. A study conducted on trained cyclists undergoing 2 weeks of high-volume, high-intensity training and divided into either a high-protein treatment (3 grams per kilogram bodyweight) or a normal-protein treatment (1.5 grams per kilogram bodyweight) found that the increased training volume bogged down the immune system. During the normal protein treatment, cyclists reported more symptoms of upper-respiratory tract infection than during the high-protein treatment, and having greater protein intake maintained better white blood cell function.

## Protein dietary needs

Obtaining adequate protein in the diet is essential for athletes and non-athletes alike. For non-athletes, dietary protein is required for the myriad of health functions previously discussed. For active exercisers and athletes, additional protein intake is required for the repair and recovery of muscle tissue, as well. Depending on the goals of the active individual, they may need more protein in their diet than the average sedentary person.

| **Food Group** | **Calorie Level** | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1600** | **1800** | **2000** | **2200** | **2400** | **2600** | **2800** | **3000** | **3200** |
| Dairy (cup-eq/day) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Seafood (oz-eq/week) | 8 | 8 | 8 | 9 | 10 | 10 | 10 | 10 | 10 |
| Meats (oz-eq/week) | 23 | 23 | 26 | 28 | 31 | 31 | 33 | 33 | 33 |
| Nuts, seeds, and soy (oz-eq/week) | 4 | 4 | 5 | 5 | 5 | 5 | 6 | 6 | 6 |

**Total daily protein requirements**

The total daily protein requirement depends largely on the body size, activity level or sport, and body composition goals of the individual. Therefore, it is best to recommend total daily protein intakes on a gram of protein per kilogram of bodyweight basis. In general, individuals need between 0.8 to 2.2 grams of protein per kilogram of bodyweight per day. Inactive persons require less protein than active persons, and those exercising with greater duration or intensity will require more protein than those exercising with less duration or intensity. Additionally, more protein is required to recover from strength training than from cardiovascular training.

The recommendation of 0.8 grams of protein per kilogram (0.013 ounces of protein per pound) body weight is a daily minimum *need* that may be as high as 1.2 grams of protein per kilogram (0.019 ounces of protein per pound) of body weight in non-exercising persons based on new evidence. Exceeding the proposed dietary protein need poses few, if any, negative consequences. Consuming up to 2.2 grams of protein per kilogram of body weight is an acceptable goal, even for sedentary persons, and it is likely that a greater percentage of calories coming from protein will facilitate health goals.

Remember to always teach protein recommendations broadly so that clients can make their own nutritional decisions for themselves.

When working in Australia, always refer to the [ADG Eat for Health Calculators](https://www.eatforhealth.gov.au/eat-health-calculators) to assist with the understanding of macronutrient breakdowns.

Individuals who are seeking weight loss often lose muscle mass and fat mass concurrently and in relatively equal proportions, with typical calorie restricted diets. Maintaining as much muscle mass as possible while dieting can be achieved with greater protein intake (at least 1.8 to 2.2 grams per kilogram) and regular resistance training. Several research studies have verified that simultaneous loss of fat and maintenance of lean body mass is. This requires careful consideration of calorie and protein intake and alignment with a well-designed resistance training program. Those beginning a fat-loss program with a more athletic and muscular physique may be able to lose fat mass with more normal caloric intakes.

Incorporating high-protein snacks, whether they are advertised as such or not, may be an effective strategy as part of a weight-loss plan. Do not be fooled, though; calories are the most important factor in weight loss, gain, and maintenance. Having a snack such as a low-carb, low-fat protein bar can certainly help with weight loss by curbing appetite between meals. However, products that simply add protein into a snack that otherwise has the nutrition profile of a chocolate bar (high sugar/high fat) can be counterproductive to someone who is trying to lose body fat.

Another special consideration for adjusting protein intake is for ageing adults. They are less responsive to dietary protein for the purposes of maintaining or increasing lean muscle (anabolic resistance). This is especially true for the older adult who is also physically inactive. It may be more appropriate to recommend that individuals 65 years of age and older consume at least 0.9 to 1.6 grams of protein per kilogram of bodyweight.

Athletes who are training with unusually high volume or intensity for a brief period of time, such as during a training camp, may have even greater protein needs than under normal training circumstances. During this time, it is appropriate to consider increasing protein intake in proportion to the increase in calorie intake as needed to meet the energy demands of the activity. For example, a 60-kilogram athlete training for a triathlon may regularly train for 12 hours per week, consume upwards of 3,500 calories or more per day, and eat around 120 grams of protein per day.

It is important to understand the difference between minimum needs and optimal amounts of protein, including the differences between government recommendations and suggestions from the scientific literature. Know how recommendations change based on activity type and volume.

### Protein quality

The second-most important factor in meeting protein requirements is the type of protein that is consumed. Protein quality refers to the number of essential amino acids contained within, and the digestibility of, a protein-containing food. Protein quality also refers to the completeness of a protein. A complete protein is a food source that contains all of the essential amino acids in appropriate quantities. In general, animal proteins are complete proteins and plant proteins are incomplete proteins, with the exception of soy, which is also a complete protein.

Vegetarians and vegans often do not consume complete proteins, and, therefore, need to be conscious of consuming a variety of protein sources to meet essential amino acid (EAA) needs. A common example of mixed protein sources are rice and beans. Rice proteins are poor sources of lysine, but they are rich in cysteine and methionine. Beans have enough lysine, but they are poor sources of methionine and cysteine. Thus, they can be combined to form a complete protein in a single meal. Because of this, they are called complementary proteins. In general, people following a vegetarian or vegan diet may pair grains or nuts/seeds with legumes to obtain sufficient EAAs.

Other examples of complementary proteins include wheat/peanut butter, pasta/peas, and lentils/almonds. Complementary protein sources may also simply be consumed in different meals on the same day, as sufficient total daily EAA intake can still be achieved even if the individual amino acids are consumed across meals over a 24-hour period. That being said, it is always important to encourage clients to eat from a variety of protein sources, regardless of the dietary approach they may be following.

**Special Consideration-Leucine**

Protein quality assessment may be taken one step further when working with athletes or recreationally active individuals. The amino acid leucine is a primary factor for increasing muscle protein synthesis to facilitate muscle recovery and growth. Of all the amino acids present in a protein, leucine is the only one that is independently capable of enhancing muscle anabolism. However, it is important to understand that leucine is operating as a signal and *all* of the amino acids are still necessary to form proteins. Therefore, a protein’s quality may be evaluated based on its leucine content when muscle mass maintenance or growth is a primary goal.

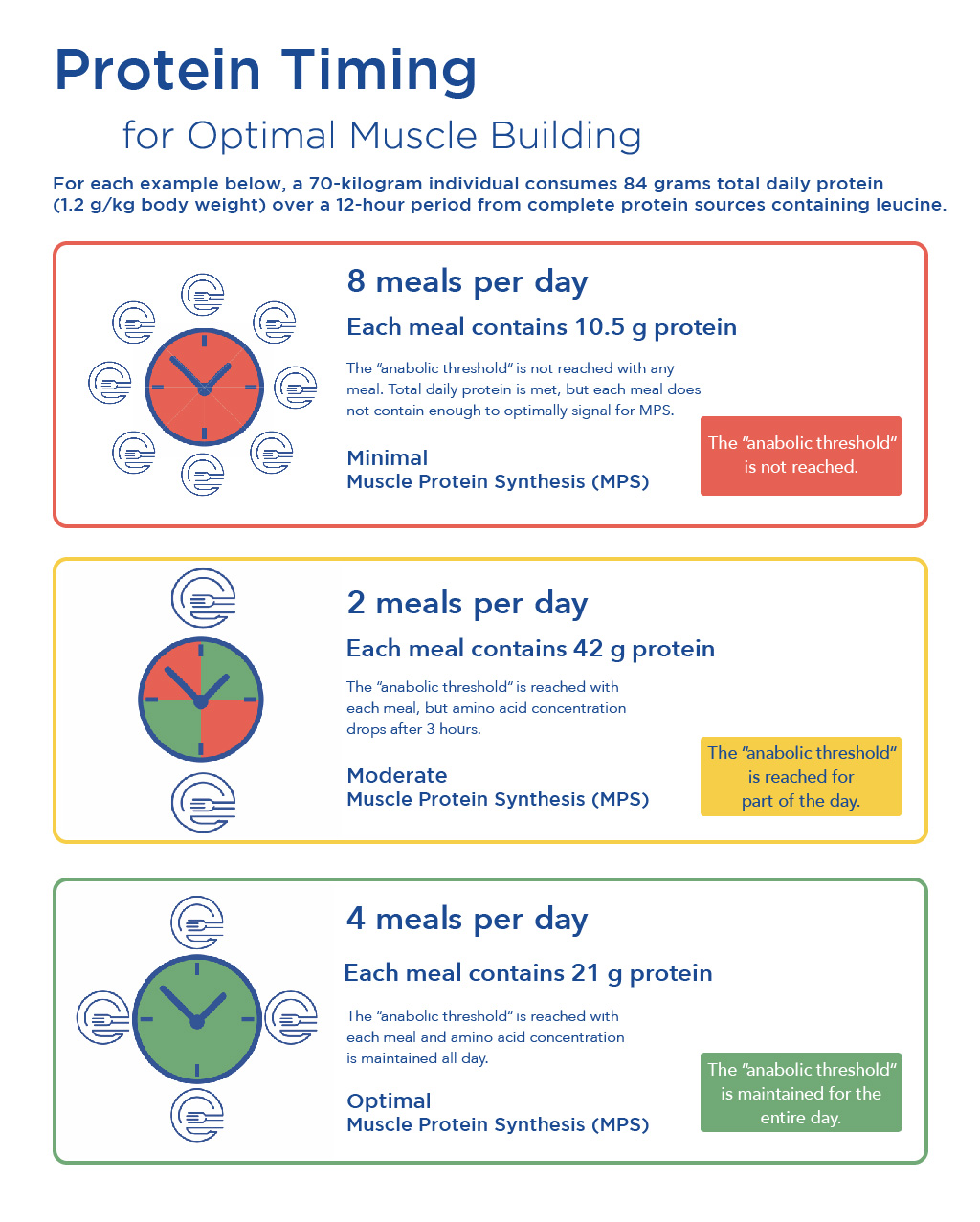
Leucine is capable of enhancing muscle protein synthesis signalling for a period of about 3 hours after ingestion, and the *optimal* dose to maximise protein synthesis is 0.05 grams of leucine per kilogram of body weight.

| **Protein Source** | **Percent of Protein as Leucine** | **Grams of Leucine per Standard Serving** |
| --- | --- | --- |
| Ground Beef (85:15) | 7.8% | 1.2 |
| Chicken Breast | 7.5% | 2.0 |
| Egg (whole – large) | 8.6% | 0.54 |
| Fish (salmon – wild) | 8.1% | 1.8 |
| Milk (2%) | 9.5% | 0.77 |
| Pork Loin | 8.5% | 1.9 |
| Soy Supplement | 8.4% | 2.1 |
| Whey Supplement | 10.5% | 2.6 |
| Casein Supplement | 9.2% | 2.3 |

### Protein timing

Most individuals do not need to concern themselves with the concept of protein timing as they will naturally consume adequate protein by eating balanced meals for breakfast, lunch, and dinner. However, small improvements in long-term physiological adaptations to exercise may be obtained from strategic timing of protein ingestion throughout the day, as well as before, during, and after training. Such strategies should be reserved for thoroughly dedicated individuals (i.e., athletes), as current scientific progress only supports the strategies in theory.

For example, a study comparing the rates of muscle protein synthesis over a 12-hour period found that four servings of 20 grams of whey protein was superior to the timing strategies of two servings of 40 grams of whey protein and eight servings of 10 grams of whey protein equally spaced over the 12-hour period. This is due, in part, to a protein threshold in combination with the kinetics of nutrition and protein synthesis. Ten grams (0.35 ounces) of protein was not enough to stimulate protein synthesis––participants never crossed the threshold. However, they did with 20 grams (0.7 ounces) and 40 grams (1.4 ounces); and with 20 grams (0.7 ounces), they crossed the threshold more frequently, once every 3 hours compared to once every 6 hours. Three hours seems to be about as long as an anabolic signal from a high-protein meal lasts.



In another study design, participants ingested equal amounts of protein during each of three meals (about 30 grams / 1.06 ounces each), or they consumed protein in a skewed distribution, during which about 10 to 15 grams (0.35 to 0.53 ounces) were consumed with breakfast and lunch and about 65 grams (2.3 ounces) were consumed with dinner, but the total amount of protein was still the same. Those with an even protein distribution had 25% greater rates of muscle protein synthesis throughout the day (Mamerow et al., 2014). Such protein timing strategies may also be useful for long-term improvements in overall body composition in overweight or obese individuals. Termed *proteinpacing* by Arciero and colleagues (2016), the strategy consists of six meals per day with 30% of daily calories from protein compared to standard recommendations of three meals per day with 15% of daily calories from protein. Protein pacing enhances total, visceral, and abdominal fat loss and muscle mass maintenance during 3 months of calorie restriction and 9 months of maintenance.

Therefore, 24-hour net muscle protein synthesis may be optimal if stimulated with dietary protein (containing leucine) every 3 hours. This notion was further solidified in a 2018 review on the topic of how protein should be distributed throughout the day for muscle gain, arriving at two key points: every meal should contain *at least* 0.4 grams of protein per kilogram of body weight and *at least* four meals should be consumed throughout the day.

Consuming protein prior to exercise may attenuate rates of muscle catabolism (Bird, Tarpenning & Marino, 2006; Tipton et al., 2007; Tipton et al., 2001). However, pre- and intra-workout protein consumption are typically not emphasised if the individual has eaten a meal 1 to 3 hours prior to training. Protein consumption during exercise may be of some importance for very-long training sessions or athletic competitions (e.g., races lasting longer than 3 to 4 hours). Consuming small quantities of protein or amino acids during endurance events can limit muscle breakdown, serve as an alternative fuel substrate, and reduce muscle soreness (Bird et al., 2006; Greer, Woodard, White, Arguello, & Haymes, 2007). A beverage containing 1 to 2% protein is sufficient for intra-workout endurance purposes (Koopman et al., 2004; Saunders, 2007).

Post-workout protein consumption with carbohydrates in a 3:1 or 4:1 ratio of carbohydrates to protein can accelerate the replenishment of muscle glycogen (Ivy et al., 2002; Morifuji, Kanda, Koga, Kawanaka & Higuchi, 2010; Tarnopolsky et al., 1997; Van Loon, Saris, Kruijshoop & Wagenmakers, 2000). This is of relevance for endurance athletes who train the same muscle groups during each training session (e.g., marathon runners), athletes with multiple training sessions per day, and for multi-day competitions. Although commonplace in popular culture, post-workout protein consumption for the purposes of increasing muscle is actually of less importance.

Several investigations have observed increased rates of muscle protein synthesis when consuming protein 1 to 2 hours after resistance training; however, only a few studies have found that muscle gain is enhanced over time when protein is consumed post-workout and total daily protein intake is controlled. A meta-analysis of 20 studies for muscle growth and 23 studies for muscle strength found no statistically significant effect of post-workout protein consumption when total daily protein intake is equal (Schoenfeld, Aragon, & Krieger, 2013).

However, if the post-workout protein consumption increases the total protein intake for the day, muscle growth may be enhanced. In practical terms, this means that most individuals do not need to be concerned about consuming protein shortly after performing resistance exercise. Instead, they should be focussed primarily on total daily protein intake.

"Although commonplace in popular culture, post-workout protein consumption for the purposes of increasing muscle is actually of less importance."

Getting Technical

Statistical significance does not mean practical relevance. Post-workout protein consumption may not yield such a robust effect that the statistics will support its practice, but consuming protein after resistance exercise may still lead to a net-positive gain in muscle mass over time that may be considered relevant to an individual. Furthermore, while applied observations of muscle size or strength do not firmly support the practice of post-workout protein shakes, mechanistic research (examining rates of muscle protein synthesis) provides further insight. For resistance training novices, post-workout protein may not affect muscle protein synthesis, yet in resistance trained individuals, post-workout protein does further enhance rates of muscle protein synthesis. Thus, the recommendation to consume protein after training can be reserved for more well-trained individuals (Damas et al., 2016; Mori, 2014).

**Protein myths and hot topics**

As with many other topics in nutrition, protein is subjected to a number of myths. In most cases, research is insufficient to provide a clear answer one way or another, or research may have recently become sufficient, but adoption of the new idea is slow. Myths are the result of conjecture. However, there is substantial scientific data available to help us address some of the more common protein myths.