14 Protein as a Functional Food Ingredient for Optimizing Weight Loss and Body Composition

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14.1 INTRODUCTION

Obesity continues to plague our society as a major public health issue. The latest obesity prevalence statistics show over 70% of U.S. adults are overweight and 40% of U.S. adults and 20% of youth are obese. Unfortunately, the prevalence of obesity among non-Hispanic blacks and Hispanic adults is even higher at 47%.\(^1\) Healthcare costs associated with obesity-related disease are in excess of $190 billion per year.\(^2,3\) In addition, the economic impact expands past healthcare costs and includes indirect costs associated with wages lost due to employee absenteeism, decreased work productivity, poor academic performance, impaired cognition, and low morale both in the present and future.

These staggering numbers clearly highlight the necessity for immediate intervention among all groups and ages of our population. While progress has occurred in illuminating certain pathways controlling energy homeostasis,\(^4,5\) scientific advances have thus far failed to prevent the worldwide spread of obesity. The current definition of overweight for an adult is a BMI between 25–29.9 kg/m\(^2\) and for obese \(\geq 30\) kg/m\(^2\).
To date, lifestyle intervention programs including healthy nutritional intake and fitness training remain the foundation of obesity treatment and prevention, as well as for attaining optimal body composition levels. Despite the abundance of both research-based and trending popular dietary and fitness interventions available, controversy remains regarding the most effective nutrition and fitness lifestyle strategies to combat obesity and its related complications, as well as to optimize body composition. This chapter will focus on the plethora of new research supporting the role of increased dietary protein intake as a first line of defense for both obesity prevention and treatment (weight loss) as well as optimizing body composition. In addition, combining the benefits of increased protein intake with an appropriate and effective exercise program further improves health (and performance) outcomes.

There are a myriad of causes of overweight and obesity, including a genetic link. However, the epidemic increase in overweight and obesity during the past 40 years is primarily the result of lack of proper quality, quantity, and timing of nutrients and physical activity. The purpose of this chapter is to provide a basic overview of protein, followed by current research findings pertaining to the impact of protein quality, quantity, and timing on optimizing body weight control (weight loss) and composition, as well as physical performance outcomes.

14.2 OBESITY, MACRONUTRIENTS, AND WEIGHT LOSS

Given the current epidemic of overweight and obesity among all age groups, 20% in children and >40% in adults, and the overwhelming societal and media focus on obesity, it’s no surprise that most people worldwide admit to trying to lose weight or being on a diet at any given time. Thus, the question is: What is the best type of meal plan to optimize weight loss and body composition? Most experts agree that, in general, for weight loss to be successful, energy (calorie) intake needs to be below energy (calorie) expenditure. However, to what extent does the deficit need to occur and for how long? Perhaps more importantly, what role does variation in macronutrient intake play on the degree of weight loss and weight loss maintenance, as well as optimal body composition? Finally, what impact does the interplay of nutrition and exercise have on weight loss and body composition?

There are three primary “macronutrients” required to nourish the body: Protein, carbohydrates, and fats. To date, a growing body of scientific evidence is showing that macronutrient distribution combined with a negative energy balance (caloric deficit) plays a vital role in both the prevention and treatment of overweight/obesity. Dating back to the 1970s, dietary fat came under heightened scrutiny for its purported association with obesity and even heart disease. As such, government agencies, certain health organizations, and the food industry began ostracizing dietary fat, and hence the low-/no-fat craze began. In turn, weight loss recommendations included reducing dietary fat intake to less than 60 g per day. The fallout from this “fat-phobia” reduction of dietary fat intake, by default, left Americans with a disproportionate excess of carbohydrate intake, including too many simple sugars, as well as a surplus of an additional 250 calories per day increase that still exists today, nearly five decades later! Another interesting “side effect” from this low-/no-fat diet craze began. In turn, weight loss recommendations included reducing dietary fat intake to less than 60 g per day. The fallout from this “fat-phobia” reduction of dietary fat intake, by default, left Americans with a disproportionate excess of carbohydrate intake, including too many simple sugars, as well as a surplus of an additional 250 calories per day increase that still exists today, nearly five decades later! Another interesting “side effect” from this low-/no-fat diet craze began. In turn, weight loss recommendations included reducing dietary fat intake to less than 60 g per day. The fallout from this “fat-phobia” reduction of dietary fat intake, by default, left Americans with a disproportionate excess of carbohydrate intake, including too many simple sugars, as well as a surplus of an additional 250 calories per day increase that still exists today, nearly five decades later! Another interesting “side effect” from this low-/no-fat diet craze began.

The metabolic consequences of this major shift in dietary intake of reducing fat and protein intake and increasing carbohydrate and total energy (calorie) intake, was a significant reduction in dietary protein intake that has persisted since the 1970s. It’s interesting to make note of the alarming rise in the overweight and obesity epidemic during this exact same time period. The metabolic consequences of this major shift in dietary intake of reducing fat and protein intake and increasing carbohydrate and total energy (calorie) intake, included a reduction in body fat oxidation, an increase in blood triglycerides, and a reduction in satiety, which continues to have most people either completely unaware or utterly confused as to where to find the most accurate information regarding the best food choices to prevent or treat obesity and optimize body composition.

The above trend has coincided with the increasing prevalence of obesity and its association with excess calories in a high-carbohydrate, particularly high–simple sugar and high–glycemic index, meal
plan. It’s well known that a high carbohydrate intake (simple sugars, glycemic index) increases blood glucose levels and subsequent elevated secretion of insulin into the blood to increase tissue uptake of glucose and/or decrease the amount of glucose in the blood (circulation). Interestingly, the increased insulin output and potential postprandial hypoglycemic response may be contributing factors to excess energy consumption and positive energy balance because of the high simple sugar intake.

A growing body of scientific research suggests that a higher intake of dietary protein may be an effective strategy to promote weight loss and improve body composition by increasing postprandial thermogenesis, increasing satiety, and enhancing protein synthesis. Dietary protein has relatively no effect on blood glucose levels and minimal effect on insulin response. Recent evidence demonstrates that a higher protein intake evenly distributed throughout the day, termed “protein pacing®,” favorably alters blood glucose, insulin and energy homeostasis hormones, body weight, and composition. Furthermore, combining protein pacing with a comprehensive exercise training program extends these benefits by enhancing physical performance outcomes as well. Collectively, this new research has led to rethinking dietary recommendations for weight loss and optimization of body composition.

14.3 PROTEIN OVERVIEW

The term “protein” originates from the Greek word proteios meaning “primary or first,” and it is vital to human life. The three major macronutrients are carbohydrates, proteins, and lipids, all of which contain carbon, oxygen, and hydrogen. However, protein is unique because it also contains nitrogen and sulfur. The energy content from protein is approximately 4 kilocalories per gram, like carbohydrate, and less than half that of fat (9 kilocalories per gram). Unlike carbohydrates and fats, protein is not regarded as a readily available fuel source or energy-contributing macronutrient because it’s not readily stored as a source of energy inside the body, although it can be made available as a limited source of energy during periods of energy deficit, stress, trauma, disease, and so on (Figure 14.1).

Increasingly, protein is regarded and even marketed as the premier macronutrient as a functional food ingredient in the areas of weight loss and diabetes, and for good reason. The weight loss market annual revenue is nearly $70 billion and will likely continue to increase in concert with the growing number of people who are overweight and obese. Despite an abundance of misinformation, fad diets, and marketing hyperbole, higher-protein diets have clearly emerged as a science-based efficacious lifestyle strategy to both prevent and combat overweight and obesity and improve body composition. This makes protein an ideal macronutrient to incorporate as a foundational ingredient for weight loss products.

![FIGURE 14.1 Bars on left represent percentage of total body weight contributed by each nutrient. Bars on right represent percentage of available fuel contributed by each macro-nutrient. Bars based on typical healthy, lean adult. Directional arrows on left indicate variability. (Adapted and used with permission from www.internationalproteinboard.com.)](image-url)
14.4 AMINO ACIDS AND PROTEINS

Within the body, a protein molecule contains varying amounts of amino acids, ranging from 51 amino acids for the hormone insulin to as many as 6100 amino acids for the structural protein myosin found in a single skeletal muscle fiber. Amino acids are referred to as the “building blocks” of proteins. Although the human body contains a wide variety of proteins as structures, hormones, enzymes, cells, and so on, each protein is built from just 20 individual amino acids assembled with different amounts and sequences. This allows each individual protein to have its own unique size, shape, and function inside the body.

Amino acids are categorized in two groups, as shown in Table 14.1. There are nine essential amino acids, as they must be consumed (eaten) on a daily basis, and 11 nonessential amino acids, because the body is capable of making them in sufficient amounts and therefore they are not required to be consumed on a daily basis. Although the majority of amino acids inside the human body are part of protein or used to synthesize protein, a few amino acids, such as citrulline, ornithine, homocysteine, and beta-alanine, play other critical roles.

Amino acids and the resulting proteins have multiple bodily functions, including serving as:

- Structures in cell membranes, muscles, and bones
- Enzymes to help regulate chemical reactions
- Antibodies for the immune system
- Hormones as regulators of metabolic processes
- Clotting factors in the blood
- Blood proteins for transporting nutrients and oxygen
- Receptors on cells
- Enzymes for digestion and absorption of food
- Unique metabolic regulators (such as leucine) in protein synthesis and arginine in nitrous oxide
- An important energy source for muscle, liver, and the intestine

Perhaps the most significant amino acids for optimizing weight loss and body composition are the branched chain amino acids (BCAAs) of leucine, isoleucine, and valine. Of these, leucine plays the vital role. Obtained through the diet with subsequent uptake into skeletal muscle, leucine performs the highly regarded roles of chief regulator of initiating translation of protein synthesis, modulator of the insulin-PI3 signal cascade, and nitrogen donor for muscle production of alanine and glutamine. The quality and quantity of protein differ among food sources due to the amino acid amounts and

---

Table 14.1

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

In general, foods from animal sources contain more protein and leucine and thus provide a more complete amino acid mixture than foods from plant sources (Table 14.2). A complete protein such as whey protein contains adequate amounts of each of the essential amino acids in proper ratios, whereas an incomplete protein such as a rice does not have all the essential amino acids in adequate amounts or correct proportions.

<table>
<thead>
<tr>
<th>Food Item</th>
<th>Protein (g)</th>
<th>Leucine (g)</th>
<th>% Leucine</th>
<th>% BCAA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whey, powder*</td>
<td>24.00</td>
<td>2.53</td>
<td>10.54</td>
<td>26.38</td>
</tr>
<tr>
<td>Pork, lean</td>
<td>8.83</td>
<td>0.71</td>
<td>8.04</td>
<td>21.63</td>
</tr>
<tr>
<td>Chicken, breast</td>
<td>8.79</td>
<td>0.66</td>
<td>7.51</td>
<td>21.27</td>
</tr>
<tr>
<td>Beef, lean</td>
<td>8.66</td>
<td>0.69</td>
<td>7.97</td>
<td>20.90</td>
</tr>
<tr>
<td>Tuna</td>
<td>8.50</td>
<td>0.69</td>
<td>8.12</td>
<td>21.88</td>
</tr>
<tr>
<td>Halibut</td>
<td>7.57</td>
<td>0.61</td>
<td>8.06</td>
<td>21.80</td>
</tr>
<tr>
<td>Peanut butter</td>
<td>7.11</td>
<td>0.46</td>
<td>6.47</td>
<td>13.50</td>
</tr>
<tr>
<td>Cheese, low-fatb</td>
<td>6.75</td>
<td>0.61</td>
<td>9.04</td>
<td>22.81</td>
</tr>
<tr>
<td>Nuts, peanut</td>
<td>6.71</td>
<td>0.43</td>
<td>6.41</td>
<td>13.41</td>
</tr>
<tr>
<td>Turkey, breastb</td>
<td>5.00</td>
<td>0.40</td>
<td>8.00</td>
<td>22.40</td>
</tr>
<tr>
<td>Soybean, cookedb</td>
<td>3.78</td>
<td>0.38</td>
<td>10.10</td>
<td>24.34</td>
</tr>
<tr>
<td>Egg</td>
<td>3.57</td>
<td>0.3</td>
<td>8.40</td>
<td>20.73</td>
</tr>
<tr>
<td>Cottage cheese, 1%</td>
<td>3.51</td>
<td>0.32</td>
<td>9.12</td>
<td>21.65</td>
</tr>
<tr>
<td>Egg whites</td>
<td>3.09</td>
<td>0.27</td>
<td>8.74</td>
<td>21.04</td>
</tr>
<tr>
<td>Hummusb</td>
<td>2.24</td>
<td>0.14</td>
<td>6.25</td>
<td>15.18</td>
</tr>
<tr>
<td>Bread, white</td>
<td>2.17</td>
<td>0.15</td>
<td>6.91</td>
<td>13.36</td>
</tr>
<tr>
<td>Tofu, firm</td>
<td>1.98</td>
<td>0.15</td>
<td>7.58</td>
<td>18.18</td>
</tr>
<tr>
<td>Yogurt, low-fatb</td>
<td>1.75</td>
<td>0.15</td>
<td>8.57</td>
<td>20.57</td>
</tr>
<tr>
<td>Black beansb</td>
<td>1.73</td>
<td>0.14</td>
<td>8.09</td>
<td>19.65</td>
</tr>
<tr>
<td>Milk, skim</td>
<td>0.96</td>
<td>0.09</td>
<td>9.38</td>
<td>20.83</td>
</tr>
<tr>
<td>Rice, white</td>
<td>0.76</td>
<td>0.06</td>
<td>7.89</td>
<td>15.79</td>
</tr>
<tr>
<td>Potato, baked</td>
<td>0.71</td>
<td>0.04</td>
<td>5.63</td>
<td>15.49</td>
</tr>
</tbody>
</table>


* Commercially available whey protein powders.


types present in each protein. In general, foods from animal sources contain more protein and leucine and thus provide a more complete amino acid mixture than foods from plant sources (Table 14.2). A complete protein such as whey protein contains adequate amounts of each of the essential amino acids in proper ratios, whereas an incomplete protein such as a rice does not have all the essential amino acids in adequate amounts or correct proportions.

14.5 PROTEIN REQUIREMENTS

Initially introduced in 1943, the recommended daily allowances have been used as the standard nutrition guidelines. The RDAs were set as minimal levels of intake to prevent deficiency in otherwise healthy people. The reality is, the RDA for protein (0.8 g/kg) is likely too low for most people. The International Protein Board (www.internationalproteinboard.com), composed of the leading protein scientists in the world, is dedicated to providing key insight, research, and opinions on all matters related to dietary protein, health, and performance. They’ve concluded that “a re-evaluation of the current RDA for protein requirements is necessary to identify areas of improvement, application and globalization and be based on the most current information and research available.” The RDA for protein serves as a minimum requirement for certain age groups, and during pregnancy and lactation. However, evidence suggests that this may be too low for older people and vegetarians, as
well as that required for weight loss, exercise/sport, sickness, and disease, which collectively make up a significant portion of the adult population. In response to these limitations of meeting the “requirement” to prevent deficiency versus the optimal “recommendation” for protein, the Food and Nutrition Board (FNB) of the National Academy of Science developed the Dietary Reference Intakes for macronutrients. In the case of protein, it ranges from 10%–35% of energy intake or roughly 0.8 to 2.0 g/kg. The challenge, of course, is understanding how to appropriately apply this range of protein in terms of quality, quantity, and timing/frequency to produce the greatest health benefit in various settings. One example would be if 10% of energy for protein was targeted for diet planning for weight loss or athletic performance, this would mean 90% of the remaining energy would need to be split between carbohydrate and fat, which may not be ideal from an optimal health standpoint. More specifically, in a society struggling with an expanding obesity (and cardiometabolic disease) epidemic mostly driven by a high (refined) carbohydrate intake, menu/meal planning providing the minimum amount of protein to prevent deficiency (RDA and/or lower limit of DRI at 10% energy intake) is not consistent with current scientific research or optimal health across the lifespan.

14.6 DIETARY PROTEIN SOURCES

Dietary protein sources vary within different foods, such as gluten in wheat, albumin in eggs, and casein and whey in milk. Specifically, these proteins are made up of a group of proteins or chemically associated protein molecules. The protein in egg albumin includes ovalbumin, ovotransferrin, ovomucoid, ovomucin, and lysozyme. In the case of milk whey protein, it includes β-lactoglobulin, α-lactalbumin, immunoglobulins, bovine serum albumin, lactoferrin, and lactoperoxidase, as well as glycomacropeptide (GMP), a casein-derived protein in cheese whey, whereas the principal milk casein fractions are α(s1) and α(s2)-caseins, β-casein, and kappa-casein.

Of all the animal proteins, milk has evolved as the most popular form of protein powder due to its protein composition. Casein, the main protein in milk, makes up roughly 80% of total milk protein and is deemed a slow-acting protein. Because of the complex chemical nature of casein protein, digestion and absorption of its amino acids can take up to a few hours, depending on the amount consumed. Therefore, casein would provide a slow, steady rise in blood levels and uptake of amino acids into circulation. Whey, on the other hand, is more readily digested, allowing for a quick increase in blood amino acid levels and an increase in protein synthesis. Therefore, the combination of whey and casein protein (fast- and slow-acting proteins) has been shown to be beneficial during muscle recovery, especially the time that immediately follows a vigorous exercise training session.

Whey protein has proven very effective and versatile. For example, it is ideal for fitness enthusiasts to help with lean muscle mass support, yet it is also ideal to support weight loss by increasing postprandial thermogenesis, satiety, and protein synthesis. Interestingly, whey is also a major part of infant formulas due to its high nutrient value, by providing calcium, phosphorus, lactose, water, magnesium, fat, and, of course, protein. One advantage of whey versus casein is the greater satiety due to higher levels of circulating amino acids after a meal is consumed. Whey is rich in the essential amino acids, particularly the branched-chained amino acids, leucine, isoleucine, and valine. These amino acids are major contributors to skeletal muscle replenishment after exercise or short-term periods of food restriction, such as overnight fasting. If the meal plan is adequate in leucine, then the muscles can build or maintain muscle protein. However, recent evidence has focused on the use of casein protein consumed pre-sleep in an effort to have a slow and steady release of amino acids into the blood stream while sleeping to aid in overnight muscle protein synthesis, metabolism, and general health.

14.7 PROTEIN DIGESTION AND ABSORPTION

The process of converting dietary protein into amino acids for use in the body is a complex process involving the stomach, small intestine, and liver. Although the process is complex, it is highly
efficient, with nearly 100% of dietary protein digested and absorbed into the intestinal cells, known as enterocytes. Protein digestion begins in the stomach as gastric acids denature complex protein structures, and pepsin begins to cleave protein chains. The resulting polypeptides are released into the small intestine, where proteases derived from the pancreas and enterocytes continue protein digestion. Ultimately, protein digestion produces a mixture of free amino acids and di- and tri-peptides in ratios of approximately 1:1:1. These amino acid mixtures and small peptides are absorbed into the enterocytes by amino acid and peptide transporters. Once inside enterocytes, the remaining peptides are hydrolyzed to amino acids before being released into portal circulation and delivered to the liver (Figure 14.2).

Amino acids within the enterocyte can be used for intestinal enzyme synthesis, for example, proteases, used for energy, or transported to portal blood for use by the rest of the body. Use of amino acids by the intestine varies greatly among amino acids. Dietary glutamine and glutamate are completely removed by the enterocyte to provide nourishment and optimal function; neither one of these amino acids, from a meal (or supplements), reaches the blood. In total, the enterocytes remove approximately 25% of dietary amino acids before they reach the blood and become available to other tissues. This is a major reason glutamine, and protein in general, are critically important for the overall health and function of the intestinal tract and immune system.

Amino acids leave the intestine via the portal blood to the liver. The liver is the most active amino acid metabolism tissue in the body. Amino acids that reach the liver can be used for protein synthesis, as an energy source, or released to the blood to serve the needs of other tissues, including the brain, muscles, and vital organs. Similar to the small intestine, the liver removes a significant portion of ingested amino acids and releases approximately 30% of the total amino acids ingested. Interestingly, the primary energy source for both the intestine and the liver is amino acids. As a result, only about a third of dietary amino acids reach the blood for delivery to other tissues.

Although the liver and intestines use amino acids for energy, amino acids are not removed uniformly. The enterocyte is active in removing glutamine, glutamate, asparagine, and aspartate, whereas the liver is capable of metabolizing most of the remaining amino acids, with the exception of the BCAAs. The liver lacks the necessary enzymes to metabolize BCAAs, so the net result is that BCAAs appear in the blood in nearly the exact amounts present in a meal. This serves the body very

![Protein metabolism step by step](https://example.com/protein-metabolism-step-by-step.png)

**FIGURE 14.2** Metabolism of ingested protein. (Used with permission from MySportScience Ltd.)
well because BCAAs are a valuable energy source for the muscles during times of stress, prolonged vigorous exercise, low energy intake, and recovery from exercise to aid in repair and rebuilding of muscle protein synthesis (Figure 14.3).

14.8 PROTEIN TURNOVER

Approximately 16% and 24% of a lean adult woman and man’s body mass, respectively, is composed of protein. Of this amount of body protein, the vast majority (∼99%) makes up body structures such as lean muscle mass, enzymes, hormones, bones, and so on, and the remaining 1% is circulating in the blood and within cells as free amino acids. Amino acids that enter the blood move throughout the body, referred to as the amino acid pool, are transported into cells, and become available for synthesis of new proteins (see Figure 14.4). This is important because proteins are continually being broken down (degraded) and built (synthesized). Some proteins such as enzymes have a lifespan of only a few hours, whereas other structural proteins such as connective tissues are retained for as long as 6 months. The process of synthesis and degradation of proteins is called protein turnover. Each day, the body makes and degrades over 250 g of protein. The magnitude of this turnover is surprising, as few people consume more than 100 g of protein per day. The lack of direct relationship between the amount of dietary protein and the level of daily protein turnover emphasizes the difficulty in defining protein requirements. Body protein quantity is largely determined by the balance of protein synthesis and degradation. Although the daily turnover is greater than 250 g/d, the actual potential to accumulate new proteins is very limited. During maximum growth, protein turnover is positive; that is, synthesis is greater than degradation, but the net balance is less than 10 g/d. Protein turnover balance appears to be largely regulated by protein synthesis change.
14.9 PROTEIN INTAKE, WEIGHT LOSS, AND BODY COMPOSITION

Protein is arguably the most crucial nutrient for weight loss and body composition because of its role in protein synthesis, energy metabolism, immune support, and satiation. There is little doubt there are more “diet” types available today than any other point in time. Further confusing this diet landscape is the ongoing media propaganda of fad diets, resulting in a quagmire of conflicting misinformation disseminated to the general public. Thus, it is paramount to closely and systematically scrutinize the peer-reviewed scientific literature to generate objective and credible nutrition recommendations to help coaches, trainers, dietitians, nutritionists, athletes, healthcare practitioners, and the general public. Dietary guidelines have consistently recommended a higher carbohydrate (CHO) intake (up to 65% of total kcals), moderate fat (20–35% of total kcals), and 10%–35% of intake as protein (PRO) for proper weight control. Applying this approach to a calorie-restricted diet (e.g., 1200 calories) using the commonly prescribed protein percentage of total calories of 15%, the daily protein level would be 45 grams, or approximately the RDA. Clearly, this would not be an ideal protein intake to support healthy weight loss for overweight and obese conditions. Distributing this amount of protein over three to five meals would result in a significantly inadequate amount of protein on a per-meal basis (9–15 grams/meal). Given the valuable contribution protein plays in satiety, thermogenesis, and body protein, this would be counterproductive to an effective weight loss program. In light of this, recent data suggests that protein consumption at the upper range of acceptable intake (∼25%–35% of total kcals or 1.6 vs. 0.8 grams per kilogram of body weight) enhances weight loss, energy expenditure, and body composition to a greater degree than the lower RDA, and may enhance metabolism and body composition independent of inducing weight loss. This is great news for those interested in improving health outcomes without wanting to undergo caloric restriction and weight reduction. Moreover, recent evidence demonstrates the combined effects of increased protein intake, including protein timing/frequency, with low-glycemic index diets to improve weight loss maintenance and body composition. Of all the diet types currently available, including very-low and low-energy diet (VLED, LED), low-fat diet (LFD), low-carbohydrate diet (LCD), ketogenic diet (KD), higher-protein diet (HPD), and intermittent-fasting (IF), the HPD appears most effective. The prevailing thought on weight loss is the “energy in/energy out” (EIEO), also known as “calories in/calories out” (CICO) concept based on the laws of thermodynamics. Unfortunately, the public health message has been an oversimplification of the CICO/EIEO concept via encouraging an “eat less, move more” approach to the obesity pandemic. This posits that weight loss or gain is dictated solely by either a caloric (energy) deficit or surplus. In a closed circuit environment, these laws hold true. However, in free-living humans, these laws break down due to the dynamic influence of changes in body composition, neuro-psycho-hormonal-biological factors that drive eating and physical activity behaviors, and the significant influence of varying postprandial thermogenic cost of macronutrients. A recent meta-analysis supports the benefit of higher protein intakes for reducing body weight, fat mass, triglycerides, and waist circumference, and preserving fat-free mass and resting energy expenditure. Moreover, a recent comprehensive position stand concluded that increasing dietary protein above the recommended dietary allowance may improve body composition. Taken together, the scientific evidence supports higher protein intake as an effective lifestyle strategy to enhance weight loss and body composition.

14.10 PROTEIN PACING, ENERGY METABOLISM, AND BODY COMPOSITION

Following consumption of a meal, a series of metabolic, physiologic, and digestive processes occur that transition the body from a catabolic to an anabolic state, including an increase in protein synthesis and decrease of protein breakdown. It’s well established that energy expenditure and metabolism differ greatly in response to macronutrient intake of isoenergetic meals. Specifically, protein has the highest metabolic cost (thermic response, expressed as a percentage of energy content of the food) of.
all macronutrients at 25%–30%, carbohydrate at 6%–8%, and fat at 2%–3%. In support of this, both higher protein intakes as well as timed-daily protein feedings throughout the day have been shown to enhance energy metabolism (postprandial thermogenesis) and maximize protein synthesis and thus lean muscle mass accretion compared to other dietary approaches. In addition, meals containing whey protein have a higher thermic effect than casein, which has a higher thermic response than soy protein. In addition, compelling evidence favors dietary proteins containing a full complement of essential amino acids, including a high level of the branched-chain amino acid leucine, to maximally stimulate muscle protein synthesis. In this case, whey protein is considered the ideal protein source because it has a high content of leucine per serving to maximize protein synthesis and serve as a fuel source for skeletal muscle and as a nitrogen donor for production of alanine and glutamine in skeletal muscles. Leucine’s ability to fulfill each of these important roles is dependent upon the amount consumed in the diet. This is especially relevant during energy restriction. Intakes of 10 grams of leucine per day, equivalent to approximately 125 grams of protein intake per day, have been shown to stimulate protein synthesis during energy restriction to a greater degree than commonly recommended protein intakes. Thus, the precise mechanism responsible for enhanced energy expenditure following macronutrient intake is partly due to an increase in muscle protein synthesis (MPS) that is triggered by protein (especially leucine) ingestion. In addition, there is evidence that a frequent macronutrient intake of protein-containing meals favors an anabolic state resulting in an increase in protein synthesis and lean body mass accretion. Specifically, distributing protein feedings in 20 grams of whey protein every 3 hours following resistance exercise maximizes MPS, including increased signaling proteins and transcriptional activity of muscle cells compared to either smaller (10 grams every 1.5 hours) or larger (40 grams every 6 hours) feeding. Indeed, not only does this have beneficial implications for enhanced functional capacity of muscles and an increase in lean body mass, but also for increased energy expenditure, all of which lead to improved body weight control and optimal body composition.

The frequency and timing of meals eaten is another important factor for optimization of energy metabolism and body composition. Several studies have suggested meal frequency is inversely related to body weight. Expanding on the body of literature of these major diet types is work by Arciero et al. on Protein pacing. Protein pacing involves the consumption of 4–6 high-quality protein-based mini-meals/day, evenly spaced approximately every 3–4 hours, containing 20–40 grams (or 0.25–0.4 grams of protein/kg BW) at each meal. The protein pacing meal plan has consistently shown superiority over conventional, low-fat, LED, and lower-frequency meal patterns (three meals/day) for enhancing energy metabolism and body composition under both eu-caloric and hypocaloric conditions.

Arciero et al. recently compared a protein pacing (~35% of total kcals as protein) meal pattern (~50% from whey protein and 50% from both plant and animal sources), moderate in CHO (~40% of total kcals), consumed as either three (HP3) or six (HP6) meals/day versus a traditional diet (~15% of total kcals as protein; TD3), higher in CHO (~60% of kcals), consumed at three meals/day, consumed throughout 28 days of energy balance (weight maintenance) and deficit (75% of energy requirements resulting in a negative energy balance of 25%), respectively (56 days total). The results demonstrated that postprandial thermogenesis during both weight maintenance and weight loss was significantly elevated by 67%–128% in HP6 compared to both HP3 and TD3 groups (Figure 14.5). The increased thermic response in HP6 may partly explain the significant total and abdominal fat loss and increased lean body mass that also occurred in the HP6 group. Layman et al. proposed that enhanced quality and quantity of protein during weight loss increases plasma leucine, which in turn stimulates muscle PRO synthesis and may increase fat oxidation, both of which support the findings of increased lean muscle mass in HP6 versus TD3. However, the study design does not rule out the possibility of eating frequency or an interaction of the two as playing a major role in mediating these responses. In a follow-up study, Arciero and colleagues demonstrated that overweight/obese men and women respond equally to a hypocaloric (1500 kcals
Protein as a Functional Food Ingredient

men; 1200 kcals women) protein pacing meal pattern (four to six meals/day) combined with a
1 day/week intermittent fast (450 kcals men; 350 kcals women) over a 12-week weight loss phase.
As a group, they lost 11 kg (24 lbs), of which 9.5 kg (21 lbs.) was fat mass, and 0.8 kg (1.8 lbs.) of
visceral fat and the proportion of lean body mass (LBM/BW) increased by 9%.12 In this study,
following the initial 12-week weight loss phase, subjects were then divided into two groups, a
protein pacing and heart-healthy group, and followed an additional 52 weeks. The heart-healthy
group observed the dietary guidelines that are in compliance with the National Cholesterol
Education Program Therapeutic Lifestyle Changes (TLC) diet (i.e., <35% of kcal as fat, 50–60%
of kcal as carbohydrates, <200 mg/dL of dietary cholesterol, and 20–30 g/day of fiber). At the end
of the 52-week weight maintenance phase, the protein pacing group maintained body weight
and composition, whereas the heart healthy group regained body weight (12.1 lbs./5.5 kg) and fat mass
(3.9 lbs./1.8 kg) and lost a greater proportion of lean body mass (2%). Collectively, these findings
indicate that macronutrient composition (increased dietary protein), nutrient quality (high quality
whey protein, low glycemic index carbohydrates), and frequency of eating (6 × per day) using
the protein pacing meal pattern are more impactful than total energy intake to enhance energy
metabolism (post prandial thermogenesis) and body composition (reduced total and abdominal
obesity and increased lean body mass) during both weight loss and weight loss maintenance.

In support of these intervention studies, a recent position stand on nutrient timing summarizes
consuming a 20–40 g protein dose (0.25–0.40 g/kg body mass/dose) of a high-quality source
every 3 to 4 hours favorably increases MPS rates when compared to other dietary patterns and is
associated with improved body composition (and performance) outcomes.65

From a practical application standpoint, protein pacing from both animal (mostly whey protein
sources) and plant (mostly from legumes) food sources, more often (four to six meals/day)
throughout the day (every 3–4 hours) increases postprandial thermogenesis and lean body mass and reduces
total and abdominal fat mass compared to traditional protein (15% of total kcals as protein) and meal
frequency (three meals/day) intakes. These favorable metabolic and body composition changes may
directly lead to enhanced health improvement. Importantly, these beneficial improvements were
achieved even though total kcals consumed were identical among all groups and in the absence of
any physical activity/exercise training. These data indicate that macronutrient distribution (protein
pacing), nutrient quality (high-quality protein, low GI, essential fats) may be more important
than total energy intake to improve energy metabolism (postprandial thermogenesis) and body
composition, and thus overall health.

FIGURE 14.5 Change in postprandial thermogenesis following meal consumption. Letter a denotes
significantly different from CON (P < 0.05); letter y denotes significantly different from TD3 and PP3
(P < 0.05). TD3, traditional diet, three meals/day; HP3, protein pacing, three meals/day; HP6, protein pacing,
six meals/day. CON, control phase of standardized meal pattern; BAL, energy balance; NEG, negative energy
balance of 75% of calculated energy needs.

![Graph showing change in postprandial thermogenesis](image-url)
14.11 PROTEIN INTAKE, EXERCISE, AND GLYCEMIC CONTROL

The ability to control blood glucose and insulin in both the fasted and fed state is crucial for losing and maintaining weight. This is especially important for individuals suffering from overweight/obesity with insulin resistance or type 2 diabetes mellitus (DM), with impaired glucose tolerance and disposal pathways. Following a mixed meal containing carbohydrate, fat, and protein, blood glucose increases, causing an increase in insulin production and secretion from the pancreas. Elevated insulin levels in the blood activate cell membrane receptors, of which muscle cells are a primary target, and cause GLUT 4 receptors to translocate from the cytoplasm to the surface of the plasma membrane for glucose uptake into the muscle cell. This, in turn, suppresses hepatic glucose production in the liver and increases glycogen synthesis and storage in both muscle and liver. Interestingly, an increase in dietary protein intake concomitant with a reduction in carbohydrate, fat, or total calorie intake has been shown to favorably influence glucose and insulin levels by significantly improving insulin sensitivity.\textsuperscript{12,44,66,67} Arciero and colleagues have demonstrated both short-term hypocaloric (10 days) and longer-term ad libitum (3 months) interventions of higher dietary intake of protein (25%–40% of total kcals) results in a significant improvement of glucose disposal and insulin sensitivity, in some cases similar to that obtained with moderate-higher protein intake combined with exercise training\textsuperscript{14,68} (Figure 14.6). Although the precise mechanism(s) is unclear, the reversal of insulin resistance in response to dietary manipulation appears to be induced by a combination of reduced calories and/or dietary carbohydrate\textsuperscript{69} and increased protein intake leading to reduced blood glucose, a negative fat balance, and/or an increased supply of gluconeogenic substrates for the liver. Increased dietary protein intake provides valuable gluconeogenic substrates, in the form of amino acids, to the liver during calorie restriction.\textsuperscript{70} The amino acids are produced by protein breakdown in the muscle. Therefore, dietary intake of protein is vital to provide a continual supply of these amino acids. Alanine and glutamine, derived from BCAA breakdown, are the most common gluconeogenic substrates. Once the muscle releases these amino acids, they travel to the liver, undergo deamination, and provide carbon skeletons for gluconeogenesis, producing pyruvate and glutamate. The fasted state is accompanied with a decrease in insulin and an increase in glucagon, which causes an increase in hepatic glucose production (including gluconeogenesis) and degradation of glycogen, via a series of dephosphorylations, to produce fuel for the body. The increased glucose production by the liver serves the primary role of maintenance of blood glucose during caloric restriction.\textsuperscript{71} An increased dietary protein intake, particularly during caloric restriction, is an effective and proven strategy to manage glucose/insulin levels for the overweight, obese, and those with type 2 diabetes by providing

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{insulin_sensitivity_index.png}
\caption{The insulin sensitivity index in high protein and exercise (HPEx), moderate protein and exercise (MPEx), and high protein and no-exercise (HPNx) before and after 3-month interventions. Each value is mean ± SE. \textsuperscript{a}P ≤ 0.05.}
\end{figure}
greater substrate availability for gluconeogenesis and subsequent hepatic glucose production. With regard to the addition of exercise training to increased dietary protein, it’s now well established that the increase in skeletal muscle insulin sensitivity and glucose uptake after a bout of exercise is due to both the acute insulin-independent stimulation of glucose transport and an exercise-induced increase in GLUT-4 glucose transporters. An increase in muscle GLUT-4 content is associated with increases in insulin-stimulated glucose transport and physical inactivity with an abrupt reduction in GLUT-4 activity. Thus, the combined effects of higher protein intakes (25%–40% of total kcals) with exercise training may very well be supra-additive to glycemic control.

### 14.12 NIGHTTIME PRE-SLEEP PROTEIN FEEDING, METABOLISM, AND BODY COMPOSITION

Nighttime pre-sleep eating is historically considered controversial in terms of its influence on metabolism and body composition. Much of the original data from investigation of this topic used and contributed to the controversy for this window of feeding used high calorie mixed-macronutrient meals and populations such as night-shift workers or individuals with night eating syndrome. It is also documented that the thermic response to identical large mixed meals is lower in the evening compared to the morning. However, recent evidence has identified small (~150 kcals) pre-sleep protein (30–40 g) consumption to be supportive of overnight muscle protein synthesis and advantageous to limiting morning hunger, improving satiety, and improving resting metabolic rate. Interestingly, when 30 g of whey protein, 30 g of casein protein, and 33 g of carbohydrate were provided 30 minutes pre-sleep, resting metabolic rate was elevated compared to a non-caloric placebo. Similarly, although not statistically significant, morning increases in resting metabolic rate were reported in young overweight and/or obese women. It is important to note that most of the research to date with regard to pre-sleep feeding has used protein shakes as opposed to whole-food options. Recently, Lay et al. examined the influence of a bedtime milk snack on next-morning resting metabolic rate, substrate utilization, and appetite in overweight men, and Leyh et al. examined the influence of cottage cheese compared to an energy- and macronutrient-matched powdered supplement in young healthy women. In both instances, there were no significant changes to any outcome measures, which further supports that pre-sleep protein-centric meals (supplement or whole foods) do not interfere with metabolism or change the ability to use fat as a fuel while sleeping or the next morning.

Despite the data, some concern for fat gain as a result of increased calorie intake and/or decreased lipolysis as a result of pre-sleep protein intake remains. In the previous work, it is important to note that there were no differences in respiratory quotient the morning after pre-sleep feeding of either placebo or casein, while both carbohydrate and whey protein were increased compared to placebo. This suggests that casein protein consumed pre-sleep maintains overnight lipolysis and fat oxidation. In a follow-up study, overnight microdialysis was used to measure interstitial glycerol concentrations as an indicator of lipolysis after pre-sleep feeding of 30 g of casein or a flavor- and sensory-matched noncaloric placebo in obese men. It was reported that no differences in overnight or next-morning lipolysis or fat oxidation existed despite the consumption of calories. In addition, data supports that exercise performed in the evening augments the overnight muscle protein synthesis response in both younger and older men. In active individuals and athletes, pre-sleep feeding may be even more important as a mechanism to ensure optimal calories and protein for recovery and training. The influence of pre-sleep protein on next-day performance is a new area of investigation with only one study to date reporting no change in running performance following pre-sleep milk consumption.

Relatively little data exist for chronic nighttime pre-sleep protein consumption. The first study to investigate this randomly assigned young men (22 ± 1 years) to consume a drink containing 27.5 g of casein protein, 15 g of carbohydrate, and 0.1 g of fat or a noncaloric placebo every night before...
sleep for 12 weeks, while also completing a progressive resistance exercise training program (three times per week). Pre-sleep protein resulted in greater improvements in muscle mass and strength at the end of the study. Of note, this study was not nitrogen balanced and the protein group received approximately 1.9 g/kg/day of protein compared to 1.3 g/kg/day in the placebo group. On the other hand, these robust responses to protein-centric beverages ingested both post-exercise and pre-sleep are blunted in older (70 ± 1 years) men.\(^9\)

More recently, nitrogen-balanced study designs have been implemented to see if the pre-sleep feeding was critical or just consuming more daily protein was the key. Antonio et al. (2017) gave casein supplementation (54 g) for 8 weeks in the morning (any time before 12 pm) compared to evening supplementation (90 minutes or less prior to sleep) to investigate the influence on body composition and strength performance outcomes in free-living men and women.\(^9\) The authors reported no differences in body composition or performance between the morning and evening casein supplementation groups. In addition, Joy et al.,\(^9\) designed a similar study and reported that after 12 weeks of pre-sleep vs. daytime casein, there were no differences in outcome measures between groups. In contrast, data from Burk et al.\(^9\) indicate that casein-based protein consumed in the morning (10 am) and evening (10:30 pm) was more beneficial for fat-free mass than consuming morning (10 am) and afternoon (~3:50 pm) protein when young, high school–aged boys were resistance training. Thus, it appears that daily protein needs are most critical; however, protein consumption in the evening before sleep is also an underutilized time to take advantage of a protein feeding opportunity that (1) will not blunt lipolysis or fat oxidation and (2) may improve muscle protein synthesis and metabolism. Indeed, taking advantage of the pre-sleep window to consuming protein is a nutrition approach that may improve overall protein intake and meet recent recommendations for protein consumption\(^9\) and nutrient timing.\(^6\)

### 14.13 PROTEIN AND SATIETY

Increased dietary protein intakes are associated with increased satiety, particularly during negative energy balance of weight loss and long-term weight maintenance and therefore serve as an effective dietary strategy.\(^4\)\(^5\)\(^9\) Protein is the most satiating macronutrient, followed by carbohydrate, then fat.\(^6\) The difference between appetite and hunger is appetite is associated with our desire to consume food and is often influenced by emotional, behavioral, environmental, and certain biological cues. Hunger is our physiological need to eat, and this drives food consumption. Foods that inhibit further consumption produce satiety and a delay in the onset of the next meal. A food that is considered to have a high level of satiety is one that produces a long period of time between feelings of hunger. Diets containing increased protein are associated with reducing appetite and thus reduced caloric consumption. Two studies conducted in a respiration chamber by the same investigators directly assessed increased protein intake and satiety. The first study showed that consuming a higher protein and carbohydrate and lower fat (29%, 61%, and 10% of energy intake, respectively) compared to a lower protein and carbohydrate and higher fat (9%, 30%, and 61% of energy, respectively) diet, both equal in total kcals, reported higher levels of satiety.\(^9\) In the second study, healthy women consuming higher protein (30% of total intake) versus lower protein (10% of total intake) resulted in significant increases in metabolic rate, postprandial thermogenesis, and satiety, and less food consumption over a 24-hour period.\(^9\) Taken together, increased dietary protein intakes, and not the so-called “low-carb diet,” are responsible for the enhanced satiety and energy metabolism in energy deficit and energy balance leading to greater weight loss and maintenance.\(^6\)

### 14.14 PROTEIN, EXERCISE, WEIGHT LOSS, AND BODY COMPOSITION

A growing body of scientific evidence suggests that RDA for protein may not be ideal for specific populations and conditions, including older people, vegetarians, weight loss, exercise/fitness and sport performance, sickness and disease. The International Protein Board addresses several key
points of debate related to current protein requirements. First is the reliance on data from nitrogen balance assessments, the original methodology used to determine protein requirements over a century ago, which may not be the most accurate and comprehensive method. Indeed, more current and sophisticated methodologies, such as indispensable amino acid oxidation (IAAO), suggest base protein requirements may be higher, especially for older people. Second is whether current protein requirement standards were even designed for dietary planning. In the case of RDAs, they were established to provide a standard for minimum levels of dietary protein intake without susceptibility to nutritional inadequacy and the development of signs of protein deficiency, and not necessarily dietary planning. Minimum protein requirements are typically only meant to cover age groups as well as pregnancy and lactation. But, it is now clear that current protein requirements are likely too low for certain conditions such as older people and those deriving dietary protein from plant and other non-animal sources, as well as those with sickness and disease or involved in weight loss, exercise, and sport performance. Diets deficient in dietary protein, especially leucine, often lead to a decrease in muscle mass and physical performance. During and after exercise, leucine is a favored amino acid oxidized and used to promote protein synthesis by the muscles, respectively. A compilation of recent data strongly supports the benefit of higher protein intakes during resistance exercise training to improve body composition and does so with no harmful effects.

An exciting area of new research has examined the combined effects of higher protein intakes, using protein pacing, with various exercise training interventions on body weight control and composition. In two separate 12-week intervention studies, investigators systematically examined the effects of protein pacing (27%–40% of total kcals as protein) compared to normal protein intake (19% of total kcals) with or without exercise training in 87 overweight/obese men and women on body weight and composition. Meal plans consisted of protein pacing (four to six meals/day of 27%–40% of total kcals; 1.3–2.2 g of protein per kilogram body weight per day) or normal (19% of total kcals; 1.1 g of protein per kg BW/day) protein. The exercise training interventions consisted of either combined resistance (4 days/week) and interval (2 days/week) exercise training with protein pacing or cardiovascular/aerobic exercise (6 days/week) training in accordance with the American Heart Association exercise guidelines with normal protein intake. In both studies, the exercise treatment groups all lost weight and body fat, but the protein pacing groups with and without resistance/interval exercise training resulted in significantly greater weight loss and improved body composition compared to the normal protein intake with cardiovascular exercise training. In fact, the protein pacing and exercise groups lost twice as much weight and total and abdominal body fat compared to the normal protein and exercise group, which corroborates previous research. As an extension to these experiments, the same authors conducted a series of studies incorporating protein pacing with a multi-component fitness program of resistance, high-intensity intervals, stretching, and endurance exercise, termed PRISE® compared to other commonly recommended exercise programs. In the first, overweight/obese men and women were divided into three groups: (a) PRISE, (b) protein pacing and resistance (P-RT), and (c) protein pacing only (P), and followed for 16 weeks. The protein intake for all three groups was approximately 1.6 g/kg BW per day. At the end of the 16-week trial, all groups lost significant weight and total and abdominal body fat, with PRISE losing the most. In addition, PRISE and P-RT groups had significant increases in the proportion of lean body mass, with the PRISE group gaining significantly more (Figure 14.7).

It is important to highlight that protein pacing as part of the PRISE protocol is equally effective when consumed as either whole food sources or supplemented with whey protein in terms of weight loss and improved body composition and physical performance outcomes in both men and women. The final two studies involved highly trained men and women utilizing the PRISE protocol with (PRISE) and without protein pacing (RISE) over a 12-week trial. The PRISE group’s protein intake was 2.1 g of protein per kg/BW per day for both men and women, whereas the RISE group’s protein intake was 1.1 g of protein per kg/BW per day for both men and women. At the end of the intervention, all groups had significant improvements in all body composition measures (loss of
body fat both men and women, increased lean body mass in women). But the greatest effect was observed in physical performance outcomes. The PRISE groups (men and women) significantly outperformed the RISE only group on nearly every performance test of muscular strength (men, upper body), power (women, upper body; men, lower body), and endurance (women), core strength (women), as well as aerobic power (men). Taken together, these findings have valuable implications for enhanced body composition as well as general fitness and sport/athletic performance, suggesting that combined protein pacing (∼1.6–2.1 g of protein per kg/BW per day) and multi-component fitness training (PRISE) provides superior body composition and physical performance in overweight/obese and normal-weight trained men and women. These data corroborate recent work by Ormsbee et al. (2018), who had young sedentary men and women complete 5 days/week of concurrent training (strength and endurance) while consuming either 84 g/d of protein or 84 g/d of a carbohydrate placebo (42 g twice per day). In support of these findings, Ormsbee et al. had young sedentary men and women complete 5 days/week of concurrent training (strength and endurance) while consuming either 84 g/d of protein or 84 g/d of a carbohydrate placebo (42 g twice per day).

14.15 CONCLUSIONS

The current recommended dietary allowance for protein of 0.8 g/kg/d is too low for most individuals, and a target value for protein intake should begin around 1.2–1.6 g/kg/d based on the current evidence. These targeted protein intake values are the top priority for protein needs. However, once the daily protein needs are met, data support protein pacing to (1) practically encourage regular protein intake and (2) provide a stimulus for muscle protein synthesis, enhanced postprandial thermogenesis, and appetite suppression for individuals looking to optimize body composition and, potentially, enhanced physical performance (strength, power, endurance, etc.). In addition, if total daily protein intake is difficult to achieve, recent literature suggests that the addition of a pre-sleep protein-centric beverage or small meal will not only help to increase total daily protein consumption but may also improve overnight muscle protein synthesis and recovery as well as metabolism without causing fat gain. Lastly, combining protein pacing with a multi-component fitness training regimen such as RISE (PRISE) produces additional body composition, cardiometabolic, and physical performance benefit compared to standard protein intakes and traditional resistance and/or cardiovascular (aerobic) exercise training. In sum, the bulk of the existing evidence suggests that protein can and should be used as a functional food ingredient to optimizing weight loss, body composition, and physical performance.

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