Protein and Resistance Exercise: Separating Truth from Myth.

Adam Thompson

Introduction

Arguably the most revered and discussed nutrient in all of sports nutrition is protein. Books, magazines and internet articles all push the critical importance of this macronutrient for anyone training for increased strength and hypertrophy. With such a strong emphasis placed on protein one can easily be led to believe that success in the gym is dictated by how much protein is consumed. Turn back the clock a couple of decades and carbohydrates were part of any discussion on sports nutrition. Now days carbohydrates are the enemy and protein is king. This paradigm shift has also produced many questions that can leave weight training athletes confused: how much protein do you actually need each day to build muscle? What is a high protein diet? What are the best sources of protein? Do you need supplements? When is the best time to take supplements? Does a high protein diet pose any health risks? This *Muscle Building Science Special Report* will review the scientific evidence behind protein and its relationship to resistance exercise adaptations.

Protein Basics

The role of dietary protein is to supply amino acids for the body. Amino acids are used to construct proteins that may be used to build new cells or tissues or repair damaged ones. Amino acids are also the building blocks of the enzymes that control chemical reactions in the body. Skin, hair, hormones and blood cells are also constructed of proteins.

In human nutrition there are 21 amino acids. Of those, 9 are considered essential or indispensible as they cannot be made by the body and so must be included in the diet. The remaining amino acids are considered non-essential as the body is able to synthesise them using existing amino acids. Provided all 21 amino acids are present in the diet the body is able to manufacture any protein it requires.

While the primary role of protein and amino acids is structural, proteins can be used as an energy source. The energy content of protein is 4 calories, the same as carbohydrates.

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The word protein implies that we are talking about a single nutrient. While this is technically correct, there are countless different proteins found throughout nature. What makes a protein unique is its amino acid composition with different proteins composed of different quantities and sequences of amino acids. It is this property that makes some proteins more suitable for human consumption than others. Those proteins that supply the body with all the amino acids it requires is said to be of the highest quality. Proteins that may be deficient or lack certain amino acids entirely are said to be of a lower quality.

The quality of a particular protein is dependent on two factors: the amino acid composition of the protein (particularly the essential amino acids) and the ability of the body to absorb and utilise those amino acids. This is measured via a Protein Digestibility Corrected Amino Acid Score (PDCAAS). The highest quality proteins are given a score of 1 while lower quality proteins are scored accordingly. Other methods have been used in the past and may still be used in some practices, however the PDCAAS is the preferred method adopted by the World Health Organisation and Food and Agriculture Organisation[1]. Table 1 shows PDCAAS for selected proteins.

Table 1. PDCAAS for selected proteins[2,3,4]

Protein	PDCAAS
Beef	0.92
Milk	1.00
Egg	1.00
Soy	1.00
Casein	1.00
Whey	1.00
Black Beans	0.75
Peanuts	0.52
Wheat Gluten	0.25
Rolled oats	0.57
Lentils	0.52

With the exception of soy, animal proteins have a higher PDCAAS than vegetable proteins. PDCAAS are widely used in nutrition and research circles for measuring the quality of a protein however they do have limitations. One problem is that all PDCAAS are truncated at 1.0 regardless of what the actual score is. This means a protein with measured PDCAAS of 1.2 and another at 1.0 will both be valued at 1.0 even though

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one protein is of a higher quality than the other. This limitation however is of little consequence for athletes as both proteins are of a high quality.

Another limitation of the PDCAAS is that it only refers to individual foods and not the protein content of an entire meal. This is something that only concerns individuals on a vegan diet or vegetarians with limited intake of dairy and eggs. For example, lysine is the limiting amino acid for wheat, corn and rice and for legumes it is methionine. Individually these foods have a PDCAAS less than 1.0. By combining different foods the limiting amino acid in one is complemented by the presence of that amino acid in the other. This means the PDCAAS for the meal is greater than the PDCAAS of the individual foods in that meal.

Due to these and other limitations an Expert Consultation of the Food and Agriculture Organisation of the United Nations has recommended a new digestible indispensable amino acid score (DIAAS) be adopted as the preferred method for measuring protein quality[5]. The DIAAS measures how dietary protein and amino acids are metabolised and used by the body with greater accuracy than the current PDCAAS. This will likely become the preferred method for scoring protein quality in the future.

Protein Requirements

Perhaps the most confusing thing about protein is the question of just how much we need each day. The World Health Organisation and the Food and Agriculture Organisation recommend adults consume 0.83g/kg/day of protein with a PDCAAS of 1.0[6]. This number provides a good starting point however it is based on the requirements of inactive to moderately active adults, not athletes and certainly not athletes engaged in heavy resistance exercise. If weight training athletes do benefit from a protein intake above this recommendation what is the optimum intake?

Nitrogen Balance

Some of the earliest protein recommendations for weight training athletes were based on the quantities needed to maintain a positive nitrogen balance. Protein is a nitrogen containing compound therefore individuals that are in a positive nitrogen balance are retaining nitrogen in the body. It has long been believed that at least some of this retained nitrogen would be used to build new muscle proteins. A positive nitrogen balance was therefore believed to correlate with an anabolic state in the body (i.e. building muscle). The problem is that nitrogen balance has no relationship to muscle mass[7].

The link between protein intake and nitrogen balance is tenuous as nitrogen balance improves as energy intake increases, independent of protein[8]. This means an active individual can improve their nitrogen

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balance by maintaining their level of protein consumption and increasing their daily energy intake through consuming more carbohydrate and fat. Energy intake may therefore be at least equally if not more important than protein intake in determining nitrogen balance[8].

Another problem with nitrogen balance is that impossible rates of muscle mass accrual are predicted at very high levels of nitrogen retention. For example studies have shown that body builders consuming 2.5-2.8g protein/kg/day can retain up to 20g of nitrogen per day[9]. Using this data Phillips[10] demonstrates how it would result in a protein deposition of up to 500g per day. If this were to be extrapolated out over the course of year it would result in a gain of over 180kg of muscle! This is predicated on the assumption that all the retained nitrogen would go towards the deposition of new muscle tissue, a physiological impossibility. Even if only 10% of the retained nitrogen went towards building new muscle tissue that would mean a gain of over 18kg of lean body mass in a year. This demonstrates the flaw in trying to link nitrogen balance to the accretion of muscle mass. For this reason nitrogen balance studies will not be discussed in this report.

Protein Requirements For athletes

The subject of protein intake and resistance exercise is often discussed in such a way as to give the impression that there exists a linear relationship between protein intake and training adaptations. This so called 'more is better' principle implies that the more protein you consume the more strength and muscle mass you will accrue. Lemon et al[11] put twelve men through 4 weeks of bodybuilding training. One group consumed a low protein diet of 1.35g/kg/day and the other a high protein diet of 2.62g/kg/day. At the conclusion of the 4 weeks the increases in strength and muscle mass were no different between the two groups, indicating no advantage to the high protein group. The 4 week duration of this study was perhaps too short for any additional increase in muscle mass or strength to be observed in the high protein group over the low protein group. If this was the case then any additional gains obtained by the higher protein consumption must have been incredibly small. It seems unlikely then that significant differences would be observed with the higher protein intake over the course of a 12 month training period.

Tarnopolsky et al[12] put a group of strength athletes on one of three protein intakes: 0.86g/kg/day (low), 1.40g/kg/day (moderate) or 2.40g/kg/day (high). The low protein diet resulted in a decrease in protein synthesis indicating the intake was insufficient for training adaptations to occur. The moderate intake resulted in an increase in protein synthesis.

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The high protein intake also resulted in an increase in protein synthesis however the increase was no greater than that seen in the moderate intake group. This suggests that increasing protein intake produces increases in muscle protein synthesis up to a certain point. At that point protein synthesis is occurring at its maximum rate and further increases in protein will not accelerate the process. This is supported by the finding that the high protein group had a significant increase in leucine oxidation, indicating that the body responded to the excess protein not by depositing it in muscle tissue but by catabolising it for energy. This observation was not seen in the moderate protein group. This suggests the maximum daily protein intake the body of a weight training athlete is able to handle may lie between 1.40 and 2.40g/kg/day.

Further evidence showing the body responds to high protein intake by increasing the rate of protein metabolism and excretion comes from Morens et al[13]. Subjects consumed either 1g or 2g of protein/kg bodyweight over a 7 day period. The individuals consuming 2g protein per day were shown to have a lower rate of protein retention after a meal compared to the group consuming 1g protein per day.

Many individuals may find it hard to accept that a protein intake only slightly above the recommended daily intake is sufficient to support improvements in hypertrophy and strength. Over 100 years ago it was demonstrated that increases in strength and muscle mass could be attained with a protein intake of 1g/kg/day[14]. More recent studies have shown that protein intakes as low as 1.2[15] to 1.4[16] grams per day are sufficient to support a hypertrophic response to resistance exercise.

Masedu and collueagues[17] studied two groups of bodybuilders during 6 months of training. One group consumed an average 2.03g protein/kg/day and the other an average 1.04g/kg/day. At the conclusion of the study the high protein group increased their muscle mass no more than the low protein group. This finding is similar to that of Lemon et al[11] who reported no advantage in increasing protein intake from 1.35g/kg/day to 2.62g/kg/day.

Not all studies have concluded that weight training athletes benefit from only slightly more dietary protein than the recommended daily intake. Falvo et al[18] found that a group of experienced weight training athletes consuming 2g protein/kg/day increased their 1 repetition maximum squat significantly more than a similar group consuming 1.24g/kg/day over the course of a 12 week resistance training program. Interestingly there was

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no significant difference between the two groups for improvement in 1 repetition maximum bench press.

Vukovich et al[19] conducted a similar study where participants consumed an average of 2.2g protein/kg/day or 1.1g /kg/day during a 6 month resistance training program. After 3 months it was observed the high protein group had greater increases in lean body mass and decreases in body fat compared to the low protein group. These differences were no longer evident however at the conclusion of the study. Despite the similar changes in body composition between the two groups, the subjects with the higher protein intake gained more strength in their 3 and 6 repetition maximum bench press and squat compared to the low protein group.

Hoffman and colleagues[20] put 21 experienced strength and power athletes through 12 weeks of resistance exercise. One group consumed 2g protein/kg/day and the other consumed 1.24g/kg/day. After 12 weeks the high protein group improved their 1 repetition maximum squat more than the low protein group however no differences in 1 repetition maximum bench press, anaerobic power or increases in muscle mass were observed between the two groups.

Tipton[21] examined whether increasing protein intake would influence the rate of recovery following resistance exercise. Increasing protein from 1.5 to 2.0 g/kg body weight made no difference to muscle soreness, function or creatine kinase concentrations during the 72 hour post-exercise period. Increasing protein to 3.0 g/kg resulted in a reported decrease in muscle soreness in the first 24 hours however there was no improvement in muscle function or creatine kinase concentrations during this period, indicating an increase in protein consumption above 1.5g/kg body weight does not enhance recovery from resistance exercise. This is in line with the results of Tarnopolsky et al[12] where increasing protein intake was shown to increase muscle protein synthesis up to a certain point (somewhere between 1.4 and 2.4 g/kg). At that point muscle protein synthesis is occurring at its maximum rate and any further increases in protein intake will not further enhance the process.

Evidence disproving the theory that higher protein intakes correlate higher rates of hypertrophy comes from an interesting study by Thalacker-Mercer et al[22]. 66 men and women completed a 16 week resistance training program during which time they were instructed to follow their normal diet and record their food intake over a set period of time. At the conclusion of the study measurements were taken to determine increases in muscle mass from baseline measurements. Based on those results

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participants were grouped into non-responders (no increase in lean mass), moderate responders (average lean mass increase 916g) and extreme responders (average lean mass increase 1,528g) to resistance exercise. Analysis of dietary records revealed no significant differences between any groups. The non-responders consumed an average 0.97g/kg/day of protein, moderate responders 1.07g/kg/day and extreme responders 1.05g/kg/day. Total energy, carbohydrate, fat, essential and branched chain amino acid intake also showed no significant between group differences. All participants consumed more protein than the recommended daily intake of 0.8g/kg/day yet the identical training protocol plus similar dietary intake resulted in vastly different results. This leads to the conclusion that the hypertrophic response to resistance exercise is highly individual and is not dictated by protein intake.

The wide variation in results demonstrates the futility in trying to identify an optimum protein intake to support increases in hypertrophy and strength in individuals engaged in a weight training program. The studies[11,12,15,16,20] showing that a protein intake around 1.4g/kg/day is sufficient for increases in strength and muscle mass should not be viewed as evidence that this is all the protein weight training athletes require. Would the gains observed in those studies have been enhanced by a slightly higher protein intake? Likewise, those studies[18,19] showing enhanced results from a protein consumption of 2g/kg/day and above should not be viewed as evidence that athletes require this amount of protein in order to see results from their training. Would similar results have been seen with a slightly lower protein intake?

It is not possible to simply recommend one number as the optimum protein intake for weight training athletes and expect that level of protein to support training adaptations under all circumstances and conditions. Based on the available data, it would appear that for individuals engaged in resistance exercise, protein consumption somewhere between 1.4 and 2.0g/kg/day should be sufficient to support optimum increases in hypertrophy and strength. This is also the recommendation of the International Society of Sports Nutrition which states that athletes engaged in strength/power exercise should consume protein at the upper level of this range[23].

Why athletes may need less protein

There is a belief that athletes engaged in resistance exercise require more protein than the average person in order to repair and remodel muscle tissue damaged through training. The argument is that resistance exercise increases the requirement for protein however the evidence shows that the opposite is true.

Exercise, particularly resistance exercise, is a powerful anabolic stimulus for the body. This stimulus triggers a protein-conserving response and not a protein-consuming one[10]. When muscles undergo repetitive contractions such as occurs with exercise, damage inevitably results. The body responds by breaking down the damaged muscle proteins. The amino acids that are released during this process re-enter the circulation where they can be used again to repair the damaged tissues. The anabolic stimulus provided by resistance exercise makes the body more efficient at this process and actually reduces protein turnover in the body[24-26]. Resistance exercise therefore results in the body retaining its circulating pool of amino acids more than would occur in untrained individuals. This greater efficiency in utilising circulating amino acids is why post-exercise muscle protein synthesis is greater than muscle protein breakdown[27].

The greater retainment of dietary protein as a result of resistance exercise is not implying that weight training individuals actually need less protein than the general non-exercising population. It does however provide a rationale as to why increases in hypertrophy and strength can occur at protein intakes lower than one may expect.

Amino Acids

With so much focus on protein intake it is easy to overlook the importance of individual amino acids. Far from being simple constituents of dietary protein, amino acids, in particular the branched-chain amino acids (BCAA) leucine, isoleucine and valine, have a central role in supporting the adaptation response to resistance exercise.

Approximately one third of muscle protein consists of BCAA[23]. As well as being constituents of muscle tissue BCAA activate key anabolic pathways in the body that result in elevated rates of muscle protein synthesis[28-30]. This nutrient driven increase in muscle protein synthesis occurs independently of resistance exercise. Leucine in particular has been shown to have powerful anabolic effects on its own[31,32]. Koopman et al[33] reported that the addition of leucine to a carbohydrate/protein supplement resulted in greater muscle protein synthesis over the 6 hour post-exercise period compared to an identical carbohydrate/protein supplement without additional leucine.

One study[34] found the retarded growth that occurred in newborn rats whose mothers were placed on a low protein diet during pregnancy was completely reversed by supplementing the mothers' diet with branched

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chain amino acids (BCAA). The mothers placed on a low protein diet resulted in pups born underweight and with lower than normal muscle mass. The simple addition of BCAA to the low protein diet of one group resulted in pups being born whose bodyweight and muscle mass was comparable to pups whose mothers were on a normal diet.

The triggering of anabolic pathways appears unique to BCAA as non-essential amino acids do not display the same effects[35-37]. The increased rate of muscle protein synthesis is maximised by consumption of 20-25g of high quality protein[7,38]. This nutrient driven anabolic response occurs for a limited time and switches off after approximately 1.5 to 2 hours, even in the presence of a continued supply of BCAA[29,39]. This means the human body cannot be held in a constant anabolic state through the continued consumption of high quality protein.

Exercise increases the rate of BCAA oxidation in muscle tissue[40,41]. Consuming 10g of essential amino acids enriched with 3.5g of leucine during exercise may help spare muscle protein from catabolic degradation[38]. Shimomura et al[41] reported that consuming 77mg/kg body weight of BCAA prior to exercise was sufficient to suppress muscle protein breakdown.

Table 2 lists the BCAA content of different plant and animal proteins. (source: USDA nutrient database[42]).

Table 2. BCAA content of different proteins

Protein	BCAA (g/100g)		
	Leucine	**Isoleucine**	**Valine**
Roast Beef	2.206	1.167	1.233
Chicken Breast	2.328	1.638	1.539
Egg White	1.016	0.661	0.809
Tuna (canned)	1.920	1.088	1.217
Lentils	1.871	1.116	1.281
Soy beans	3.309	1.971	2.029
Peanuts	1.672	0.907	1.082
Rice	0.620	0.318	0.440
Non-fat milk (per cup 245g)	0.782	0.426	0.541
Whey[43]	12.533	5.333	4.867

Protein Sources

Dietary protein comes from two sources: plants and animals. The scientific literature has very little data comparing the effects of a diet emphasising plant-based proteins versus animal-based proteins on resistance training adaptations. Given the omnivorous nature of the typical western diet this

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is a non-issue for most weight training athletes. The limited research that has been done in this area is contradictory however.

Haub and collegues[44] reported that 12 weeks of resistance training produced similar increases in strength and muscle size regardless of whether the individuals' diet contained meat or was meat-free. Campbell and collegues[45] on the other hand reported that a diet containing meat resulted in greater increases in lean body mass compared to a diet without meat during a 12 week resistance training program.

It is beyond the scope of this report to discuss the possible explanations for the contradictory findings. A meat-free diet can provide all the essential amino acids required by the body however it does require careful planning to ensure deficiencies are avoided. Whether an optimum protein and essential amino acid intake for weight training athletes can be obtained solely through plant based sources has yet to be determined.

Supplements

Perhaps the most controversial area of sports nutrition is supplementation. Some see supplements as an integral part of their nutrition strategy while others view them as producing little more than expensive urine. Magazines and websites would have you believe they are essential for building muscle mass and strength. Are they though?

There is considerable evidence showing that consumption of protein supplements before and/or immediately after resistance exercise results in greater long-term hypertrophy compared to a placebo[46-50]. Supplementation may also enhance post-exercise muscle recovery[51]. Individuals that consume a protein supplement post-workout have higher circulating levels of the anabolic hormone IGF-1[52].

As far as protein supplements go, research has focussed on whey, casein and soy. Popular media portrays whey protein as the gold standard in supplements. This is misleading as some research has shown that soy and whey can produce equivalent increases in hypertrophy when used in conjunction with resistance exercise[47,53]. This observation may be attributed to the fact both proteins have a PDCAAS of 1.0 and both contain high levels of BCAA.

Despite soy and whey both being high quality proteins they are not treated equally in the body. Milk proteins are more likely to be directed towards muscle protein synthesis while soy proteins are more likely to be directed towards other parts of the body[27,54]. This seems at odds with the findings of the previously discussed studies[47,53] showing equivalent increases in

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hypertrophy from soy and whey. These studies were of short duration (6 weeks[47] and 12 weeks[53]). Given the preferential treatment of milk proteins towards hypertrophy it is likely that whey protein would give better long-term (>12 weeks) training adaptations[27].

Whey and soy protein both produce a rapid rise in blood amino acid levels. This is critical during the immediate post-exercise period where the rapid aminoacidemia produces greater increases in muscle protein synthesis and anabolic signalling compared to lower and more sustained rise in blood amino acids[55]. Tang and collegues[56] reported that ingestion of whey protein resulted in a greater increase in branched chain amino acids in the blood compared to either soy or casein. Furthermore, it was demonstrated that following resistance exercise whey consumption produced a 31% greater increase in muscle protein synthesis compared to soy and a 122% increase greater than casein. This further supports the contention that greater long term increases in hypertrophy could be expected from whey protein supplementation before and/or immediately after resistance exercise.

The advantage of whey protein is that it is rapidly digested to produce a sharp rise in blood amino acid levels. This is also its Achilles Heel. Long term increases in hypertrophy require a constant steady supply of amino acids, something whey is unable to provide. Casein on the other hand clots in the acidic environment of the stomach, slowing the rate of digestion and releasing amino acids into the blood much more slowly and over a longer period[57].

Consuming a fast protein (whey or soy) and a slow protein (casein) together has been shown to produce a greater and more prolonged anabolic response than the individual proteins by themselves[49,58]. There is still a question however as to what ratio of fast and slow proteins gives the optimum anabolic response.

Milk protein consists of approximately 80% casein and 20% whey. Post-exercise consumption of fat-free milk has been shown to result in larger increases in muscle mass compared to a nutritionally equivalent soy protein drink[59,60]. Kerksick et al[49] on the other hand found that a supplement containing 40g of whey protein and 8g of casein (83% whey 17% casein) produced greater increases in muscle mass compared to 48g of whey protein alone over the course of a 10 week resistance exercise program. Despite the different compositions of the proteins used in these studies they all demonstrate that a blend of fast and slow proteins produces superior resistance training adaptations compared to an

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individual protein. The ideal composition of fast and slow proteins for optimum anabolic performance is yet to be determined.

Protein Timing

Nutrient timing refers to the periods of time, usually the pre-, intra- and post-workout periods, when the body has a heightened sensitivity for carbohydrates and proteins and is able to use them at an accelerated rate. The idea is that by effectively utilising these 'windows of opportunity' you can enhance recovery and produce greater training adaptations. While nutrient timing is often portrayed as a scientific approach to sports nutrition a recent review of the literature[61] found that in regards to protein supplementation the existing evidence was contradictory and ambiguous. This ambiguity could be attributed to experimental design factors such as the length of each study, training variables such as exercise selection, frequency, intensity and volume, other dietary factors such as daily energy intake, nutritional composition of the supplements used and methods by which hypertrophic gains were measured.

Despite the authors of this review failing to find a clear consensus as to the effectiveness of nutrient timing there is evidence suggesting it may be a useful strategy for athletes. Tipton et al[62] reported that post exercise uptake of amino acids into the muscles was greater when an essential amino acid and carbohydrate supplement was given prior to resistance exercise rather than immediately after. A separate study by Tipton et al[63] found the anabolic response with whey protein was the same regardless of whether it was taken pre- or post-workout. This suggests different anabolic effects when amino acids are given in free form compared to intact proteins.

Levenhagen et al[64] reported that consuming a supplement containing protein/carbohydrate/fat immediately post-exercise resulted in a 300% increase in muscle protein synthesis. When the same supplement was delayed 3 hours the increase in muscle protein synthesis was only 12%.

Cribb and Hayes[65] put a group of experienced weight training athletes through a 10 week resistance exercise program. One group consumed a protein/carbohydrate/creatine supplement pre- and post-workout while a second group consumed the same supplement in the morning and late evening. The pre- and post-workout supplementation group gained more lean body mass and strength compared to the group who consumed their supplement outside of these times.

The pre- and post-workout periods are the most discussed in regards to nutrient timing however intelligent supplementation during the intra-

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workout period may also provide a favourable metabolic response. Bird and colleagues[66] reported that consumption of a carbohydrate/essential amino acid drink during a weight training workout helps suppress cortisol levels and muscle protein breakdown. The supplement group had a 7% increase in cortisol levels compared to the placebo group that experienced a 105% increase. The carbohydrate/EAA group also had a 27% reduction in 3-methylhistidine (a marker of muscle protein breakdown) from baseline levels compared to the placebo group which had a 56% increase.

The type of protein supplement may also be a determining factor on its effectiveness in relation to nutrient timing principles. Burk et al[67] found that a casein supplement consumed in the morning and 5 hours post-workout resulted in a significantly greater increase in muscle mass compared to a consuming the supplement in the morning and immediately prior to a workout. This appears at odds with existing studies[65] showing improved training adaptations when supplementation is consumed immediately before and/or after training. Given the slow digestion rate of casein it is possible that the appearance of amino acids in the blood may have been too slow to offer any anabolic benefit. The post-workout supplementation occurred approximately 1.5 hours before bed in those subjects. Consuming casein before sleep produces a rise in blood amino acid levels which remain elevated throughout the night, resulting in an increase in protein synthesis during the night as much as 22% compared to consuming no protein before sleep[68]. The subjects that produced greater increases in muscle mass by consuming their casein supplement at night were inadvertently feeding their muscles during another important time period: sleep. This may have provided the greater anabolic environment that allowed them to gain more muscle compared to the group that consumed their supplement pre-exercise.

Nutrient timing is not a straight forward concept. Far from being an exact science there is contradiction in the scientific record. This review has intentionally only looked at those studies which demonstrated favourable outcomes. While many people will view this one-sided approach as unbalanced and the conclusions therefore unscientific, it must be remembered that the huge number of variables that exist in these studies can muddy the waters. It is not possible to compare the results of studies of different durations where different training protocols were employed, different supplements used and different timing strategies tested. The purpose of this review is to assist readers with nutrition strategies that can assist their weight training goals. While no one can say employing nutrient timing principles *will* result in greater training adaptations there is enough

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evidence to suggest that carefully timing your supplementation is a relatively simple strategy that *can* offer a performance enhancing benefits.

Potential Dangers

No discussion on dietary protein is complete without addressing the alleged dangers. The concerns regarding a high protein intake usually revolve around bone and kidney health and metabolic disturbances such as metabolic acidosis.

Poortmans and Dellalieux[69] studied 20 bodybuilders and 18 other athletes and found no renal impairment with a protein intake up to 2.8g/kg/day. Similar results were reported by Brändle and colleagues[70] who studied a group of individuals which included 40 bodybuilders with protein intakes of up to 2.6g/kg/day. It was concluded that healthy kidneys could effectively deal with the increase in dietary protein without any negative effects.

No research could be identified examining the relationship between bone health and protein intake in athletes. Given that load bearing exercise has more of an effect on bone mass than does diet[71] it would seem plausible that weight training athletes would have stronger bones than sedentary individuals, regardless of protein intake. A study published in 1998[72] found that a group of powerlifters had significantly greater whole body bone mineral density compared to sedentary individuals. No conclusions can be drawn from this study in relation to protein intake as it was not measured as part of the investigation. This study does show however that regular heavy weight bearing exercise is a major contributor to bone mineral density.

Metabolic acidosis is a condition in which the body produces acid at a rate faster than the kidneys can remove it. As a result the total acid load of the body increases leading to deleterious physiological effects. High protein, low carbohydrate diets can result in chronic metabolic acidosis[73]. Kim and collegues[74] examined the metabolic responses of high protein diets in a group of elite bodybuilders. Despite consuming an average 4.3g protein/kg/day no negative metabolic changes were identified. The authors conclude that resistance exercise combined with an adequate mineral intake may provide adequate protection against metabolic induced changes caused by high a high protein diet.

The studies discussed above are the only ones that could be identified that directly relate to weight training athletes. There are many more studies in the scientific literature based on inactive individuals and even these fail to support many of the fears surrounding diets with protein intakes above

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the recommended daily intake[75]. The International Society of Sports Nutrition Position Stand on Protein and Exercise[23] concludes '*there is no substantiative evidence that protein intakes in the ranges suggested above [1.4-2.0g/kg/day] will have adverse effects in healthy, exercising individuals'*. The evidence used to support this conclusion is based on studies using non-exercising individuals, however the existing evidence suggests the same is likely true for weight training individuals.

The studies discussed above examined the effects of protein intakes in the range of 2.6-4.3g/kg/day. Despite no negative consequences being observed within this range in healthy individuals the possibility still exists that intakes above this amount could pose potential dangers. Individuals with underlying medical conditions may also be more susceptible to deleterious effects from a high protein diet.

Conclusion

The relationship between resistance training adaptations and protein is a complex one. The idea that there exists an ideal daily intake that will provide optimum anabolic support under all training conditions is wrong. Based on the available evidence a daily protein intake between 1.4 and 2.0g/kg/day should be sufficient to support an optimum hypertrophic response in most weight training individuals. Any suggestion that weight training athletes need a daily protein intake above this level is not evidence-based. Protein intakes above 2.0g/kg/day will unlikely lead to additional increases in strength and hypertrophy.

The scientific literature has limited data on the long term effects of animal versus vegetable protein sources however what limited information is available suggests that protein from animal sources will produce superior training adaptations.

Protein supplements taken pre- and/or immediately post-workout may result in greater long-term accretion of muscle mass. The ideal supplement should consist of a fast protein such as whey and a slow protein such as casein for an optimum anabolic response. A casein supplement taken prior to sleep can further support resistance training adaptations by elevating blood amino acid levels and muscle protein synthesis during the night.

A supplement consisting of approximately 10g of EAA and carbohydrates taken during training may impart a preferable anabolic response by inhibiting cortisol release and muscle protein breakdown. Enriching a protein or EAA supplement with leucine may further enhance the anabolic response.

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The concerns about possible negative health consequences due to protein intakes above the recommended daily intake are unfounded in healthy individuals. Intakes approaching 5g/kg/day have not been tested so there does remain the possibility that very high protein consumption may cause problems.

This report is not intended as a critical review of all the scientific literature regarding the relationship between resistance exercise, protein and training adaptations. The studies discussed here are almost exclusively based on human research as these replicate the conditions weight training athletes will face every day more closely than animal studies could. As evidenced by the length of this report the subject is incredibly complex with many conflicting findings in the literature. In some cases the information presented here may conflict with that expressed in popular media. It must be kept in mind however that the conclusions reached in this review are based on the best available scientific evidence.

Conflict of interest: The author declares no conflict of interest.

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