PROTEIN NUTRITION

for peak performance

A SPECIAL REPORT FROM

PEAK PERFORMANCE

The research newsletter on stamina, strength and fitness

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From the editor

Despite the importance of carbohydrate for high-intensity performance, it’s protein that exercises the minds of many sportsmen and women. How much, how often and what kind of protein is best for performance are questions constantly asked by athletes seeking a competitive edge.

Fifty years ago, the prevailing wisdom was that plenty of steak and eggs was all an athlete needed for peak performance. But in the 21st Century the research is fast-moving; we now know that more is not always better, and that protein quality and timing are just as critical as absolute quantity.

In this special report on protein, we dig deep into the protein conundrum, from the nutritional fundamentals to the latest cutting edge research and come up with the answers you need to optimise your protein intake for maximum sporting prowess and recovery. Some of the answers are surprising; all of them make fascinating reading providing you with the nutritional ammunition to reach new performance heights!

Andrew Hamilton
BSc Hons MRSC ACSM,
Editor

Protein basics; what is it, how much do you need and how safe are high protein diets?

At a Glance

- The basics of protein metabolism are outlined;
- The importance and relevance of protein for sporting performance is explained;
- The pros and cons of high-protein diets are explored

Protein is not just an essential nutrient, but the largest component in the body after water, typically representing about 15% of body weight. Most of this protein mass is found in skeletal muscle, which explains the importance of protein to athletes. However, proteins also play an important role in the following:

- Transport and storage of other nutrients;
- Catalysing biochemical reactions;
- Control of growth and differentiation;
- Immune protection;
- Providing our bodies with structural integrity.

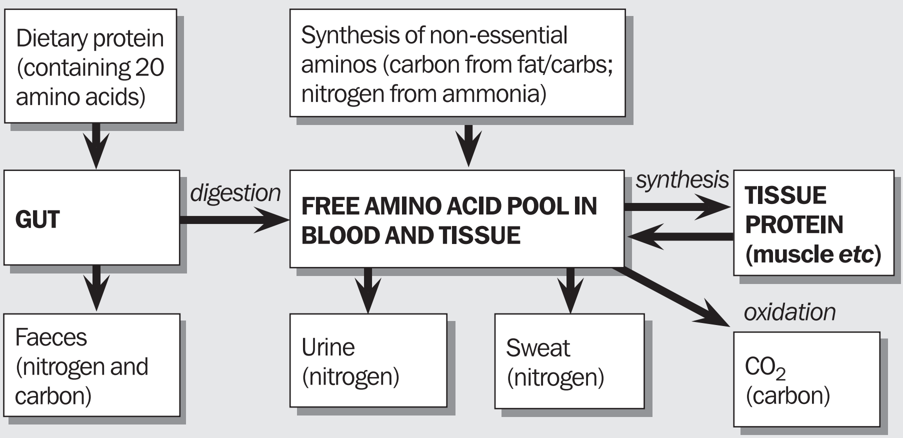
Although the basic biochemistry and functional roles of protein in the body have long been understood, there's still a huge amount of mythology and confusion surrounding protein nutrition, especially where athletes are concerned. This is partly because of general misconceptions about basic protein metabolism and partly because new research continues to throw up surprises about exactly what constitutes optimum protein nutrition!

Figure 1, below, provides a brief overview of protein metabolism. The protein we eat is made up of around 20 amino acid 'building blocks'. The process of digestion breaks down dietary protein into its constituent amino acid building blocks, which can then be absorbed into the body and reassembled to make various kinds of human protein, such as muscle, connective tissue, immune proteins, and so on.

However, it is important to understand that protein metabolism is in a constant state of flux; although muscle and other tissues contain a large amount of stored protein, this protein is not 'locked away'. When dietary amino acids are insufficient, tissue protein can rapidly be broken down back to amino acid building blocks, which are then used to replenish the 'amino acid pool', a reservoir of amino acids that can be drawn upon to support such vital functions as energy production or immune function. This explains why muscle mass is often lost during times of stress, disease and heavy training loads, or poor nutrition.

Conversely, when dietary amino acids are in plentiful supply and other demands for protein are low, tissue protein synthesis can become the dominant process. The overall control of

Figure 1: overview of protein metabolism



protein turnover – *ie* whether the body is in a state of anabolism (building up) or catabolism (breaking down), also known as positive or negative nitrogen balance – is governed by hormonal factors, caloric intake and availability of amino acids, particularly of the nine 'essential' amino acids that cannot be synthesised in the body and therefore have to be obtained from the diet.

Maintaining optimum protein status

An athlete has to move his or her body to perform, and this requires the muscles to generate force to accelerate body mass. As a rule of thumb, the greater an athlete's power-to-weight ratio, the faster he or she can move, and (to a lesser extent) the longer he or she will be able to maintain any given speed of movement. Since all force and movement is generated by muscles, most power athletes benefit from maximising muscle mass and strength, while minimising the amount of superfluous body mass – *ie* fat.

And while out-and-out muscle strength is less important for endurance athletes, maintaining sufficient muscle mass is critically important, not least because high training volumes are known to increase the rate of protein oxidation from the amino acid pool, potentially leading to delayed recovery, a loss of muscle mass and consequent loss of power, and increased injury risk.

Given that athletic training is known to increase the demands on the amino acid pool, many athletes, particularly bodybuilders and strength athletes, adopt high-protein diets to maintain a positive nitrogen balance, or at least prevent catabolism and loss of muscle tissue. However, even today there remains much debate about how much protein athletes really need to optimise and maintain performance.

'While out-and-out muscle strength is less important for endurance athletes, maintaining sufficient muscle mass is critically important'

Protein v carbohydrate

There are other questions too. For example, should any extra protein be ingested at the expense of carbohydrate, the body's preferred fuel for high-intensity training? And what about the possible health implications of high-protein diets, about which health professionals often express concerns?

It used to be thought that the protein requirements of athletes were similar to those of sedentary people, and athletes were advised that they need only consume the recommended daily amount (RDA) of protein (currently set at 0.8-1.0g of protein per kg of body weight per day) to maintain proper nitrogen balance. For a 70kg athlete, this would equate to 56-70g per day.

However, more recent research has indicated that athletes engaged in intense training actually need to ingest about 1.5-2 times the RDA in order to maintain a positive protein balance [1-5]. This equates to 105-140g of protein per day for a 70kg athlete, which is equivalent to three to four medium-sized chicken breasts or 13-20oz of canned tuna per day! There is also evidence that training at altitude imposes an even higher demand for protein – perhaps as much as 2.2g per kg per day [6].

‘A number of nutritional surveys have indicated that protein insufficiency may be a problem for certain groups of athletes, including runners, cyclists, swimmers, triathletes, gymnasts, skaters and wrestlers’

Unfortunately, these more recent findings on protein needs have not yet become widely accepted by some of the powers that be. For example, the UK's Food Standards Agency website (in its section on sports nutrition) simply states that protein is important in the diet.

Meanwhile, the EU's Scientific Committee on Food has acknowledged that the increased training loads and energy expenditure of athletes can increase protein requirements, and now recommends that their protein intake should comprise around 10-11% of total energy intake [7]. For our mythical 70kg athlete, burning 3,000, 4,000 or even 5,000kcal per day (quite easily achieved with two-plus hours of vigorous training at or above 75% VO_2max per day), this equates to just over 75, 100 or 125g of protein per day respectively.

Although foods like breads, cereals and legumes contain significant amounts of protein, which can add to that contributed by high-protein foods, such as meat, fish, milk and eggs, larger athletes, or those engaged in high volumes of training, may struggle to include the increased amounts of protein now recommended in a ‘normal' diet; indeed, a number of nutritional surveys have indicated that protein insufficiency may be a problem for certain groups of athletes, including runners, cyclists, swimmers, triathletes, gymnasts, skaters and wrestlers [8].

Fifty years ago, it was protein that dominated the thoughts of power athletes and bodybuilders. Employing the simple logic that muscles are made of protein, and that to build muscle you need lots of protein, steak-and-egg diets were the order of the day! But as the importance of carbohydrates in supplying energy and driving the insulin system (the most anabolic hormone in the body) became clearer, the emphasis gradually shifted.

This shift in emphasis was encouraged by an appreciation of the health benefits of dietary fibre present in unrefined carbohydrates, and also by research suggesting that very high protein intakes simply resulted in increased protein oxidation, imposing an additional load on the liver and kidneys. A scientific consensus began to form around the notion that diets containing substantially more than 1.0g of protein per kg per day were not only wasteful but potentially harmful, increasing the risk of kidney and liver problems, cardiac disease and even loss of bone density.

‘The meteoric rise in popularity of high-protein diets, such as Zone and Atkins, for slimmers ignited a fierce debate about the safety and efficacy of high-protein diets’

However, the meteoric rise in popularity of high-protein diets, such as Zone and Atkins, for slimmers ignited a fierce debate about the safety and efficacy of high-protein diets, which is also relevant for athletes who routinely consume high-protein diets. In 2001, the American Heart Association’s nutrition committee published a statement on dietary protein intakes, claiming that: ‘Individuals who follow these [high-protein] diets are at risk for… potential cardiac, renal, bone and liver abnormalities overall’ [9].

If you examine the scientific literature, it is hard to see how this consensus, linking high protein intakes to increased health risks, has become so widespread. In a meta-review of the literature carried out in 2004, Finnish scientists searched for any evidence supporting the hypothesis that high protein diets, containing two to three times the current RDA for protein, increase the risk of a number of health conditions – and drew a big fat blank [10]. They concluded that:

- There is no evidence to suggest that (in the absence of overt disease) renal function is impaired by high protein diets;
- Far from reducing bone mineral density, high-protein diets may actually *increase* it;
- Such diets are associated with *lower* not higher blood pressures.

These conclusions have also been confirmed by other researchers; healthy athletes should not, therefore, be dissuaded from increasing their protein intake to up to three times the RDA level if they so wish.

High-protein diets and hydration

There's a fairly linear relationship between protein intake and urea production, which means that high protein diets increase the amount of urea the kidneys have to excrete. With this elevated production of urea comes an increase in the obligatory water requirement of the kidneys to do their job, and that in turn has raised the question of whether athletes (whose fluids needs are already increased) on high-protein diets are at increased risk of dehydration.

To answer this question, scientists at the University of Connecticut compared the hydration levels of athletes consuming low (0.8g per kg per day), medium (1.8g) and high (3.6g) protein diets, each containing the same number of calories [11]. Analysis of the results showed that, while there were significant increases in urine and plasma urea on the high-protein diet, the effects of increasing dietary protein on fluid status was minimal.

Moreover, to date there have been no studies conclusively demonstrating that increased protein intake leads to a loss in total body water. However, the researchers pointed out that the subjects in their study probably consumed enough water to meet any increased requirement, which explains – at least in part – why their hydration status was not compromised. They also concluded that more research is needed. In the meantime, however, it seems prudent to recommend that all athletes on high-protein diets should drink plenty of extra fluid, especially in warm conditions.

For many athletes, power-to-weight ratio is more important than outright power for optimum performance, and this explains why reducing excess body fat is often beneficial. New evidence is now emerging that high-protein diets might actually help in this process. Although research indicates that, providing the same number of calories are eaten, the relative proportions of protein and carbohydrate in the diet do not affect the amount or composition of weight loss in a reduced calorie regime [12-14], these ratios *do* affect appetite, with subjects tending to be more hungry on higher carbohydrate intakes and less hungry on higher protein intakes.

'Recently, the huge popularity of high-protein diets has brought protein to the fore and prompted a re-evaluation of this essential nutrient in the athletic diet'

More generally, scientists now believe that diet composition strongly affects ad lib energy intake, with both laboratory and free-living studies highlighting protein as a more satiating macronutrient than carbohydrate or fat [15]. This theory is supported by studies indicating that subjects consuming high-protein (more than 20% protein by energy) diets consume less energy overall than those on low-protein diets [16,17]. The exact mechanisms are as yet unclear, but probably involve hormonal and chemical changes in regions of the brain known to be associated in hunger and appetite control.

Protein and weight loss

In one of the studies mentioned above [17], 13 obese men were split into two groups and fed low-calorie diets. One group received a high-protein diet (45% protein, 25% carbohydrate and 30% fat) and the other a high-carbohydrate diet (12% protein, 58% carbs and 30% fat). Not only was weight loss greater in the high-protein group but basal metabolism decreased less than in the high-carb group, suggesting that the high-protein diet was able to offset the loss in lean body mass (basal metabolism being a function of lean body mass) that normally occurs while dieting.

No studies of this type have been carried out on athletes, but it seems likely that high-protein diets have something to offer athletes seeking a reduction in body fat while conserving muscle tissue. While high-protein/low-carbohydrate diets of the type described above would not contain sufficient carbohydrate to permit normal training, our mythical 70kg athlete, consuming a 25% protein diet on a mildly calorie-restricted diet of 2,500kcals per day, would be consuming around 600kcal of protein, or 150g, a day. This is well within the 'safety zone' of two to three times the RDA (0.8-1.0g per kg per day) yet with a sufficiently high protein content to exert an increased satiation effect.

'Simply assuming that because you eat more food than the average person you'll be consuming adequate protein is not good enough!'

Moreover, the athlete would still be able to consume up to 50% carbohydrates (1,250kcal per day, sufficient for moderate training volumes), while consuming enough calories (25%) from fat to meet essential fat requirements. However, athletes need to remember, given the importance of carbohydrate for energy requirements, that even this regime would contain insufficient carbohydrate for higher-volume training and competition phases!

In summary, there is good evidence that athletes need a plentiful supply of protein in their diets and that, contrary to previous recommendations, they do need substantially more protein than their sedentary counterparts – at least 50% and possibly up to 120% more. For a 70kg athlete, this can mean up to 150g of pure protein per day.

However, the role of carbohydrates in supplying energy for fuel and recovery remain as important as ever, which means the diet must contain high-quality, low-fat sources of protein in order to enable adequate carbohydrate intake without an overall excess of calories. Simply assuming that because you eat more food than the average person you'll be consuming adequate protein is not good enough!

There is no evidence that routinely exceeding the recommended protein intake has any additional benefits on nitrogen balance, unless this extra protein is consumed as a protein/ carbohydrate drink before, during or after training – something covered in later articles. However, there *is* evidence that even higher protein intakes may help suppress appetite, control hunger and reduce lean tissue loss during restricted calorie routines, which may be useful for athletes needing to reduce or maintain body weight, although such diets are not really compatible with high-volume training routines.

Finally, despite what you may have read elsewhere, healthy athletes can rest assured that high protein diets containing up to three times the current RDA for protein are perfectly safe, although it is important to remain well hydrated on such diets.

Andrew Hamilton

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Optimum protein nutrition: why quality is as important as quantity

At a Glance

- The relationship between protein and carbohydrate and the benefits of protein/carbohydrate mixes are outlined;
- The importance of protein type and digestion rate is explained;
- The role of BCAAs and free-form amino acids are discussed

There's more to protein nutrition than just eating the optimum amount; the timing of consumption and the type of protein selected can both impact on nitrogen balance; and there are a number of nutritional 'co-factors' that are either essential or useful in promoting optimum protein metabolism within the body.

This is especially true where carbohydrate is concerned, because building or even maintaining lean tissue mass is an 'energy-intensive' process. Increasing protein intake at the expense of carbohydrate can be a bad strategy for athletes engaged in heavy training, because without sufficient carbohydrate the body simply switches to other fuels for energy, and amino acids from protein (particularly the branched chain amino acids, leucine, isoleucine and valine) provide a ready source of energy!

Muscle tissue is a relatively rich source of branched chain amino acids (BCAAs), and tends to undergo breakdown during periods of high-energy demand, when carbohydrate and/or the amino acid pool becomes depleted. Furthermore, carbohydrates stimulate the release of insulin, a highly anabolic hormone, which helps to drive both glucose and amino acids into muscle cells. Any athlete seeking to optimise his or her protein metabolism should therefore ensure a carbohydrate intake commensurate with training volume.

Protein-carbohydrate mixes

The role of carbohydrate in enhancing endurance during long events and accelerating post- exercise recovery is undisputed, and research (highlighted in *PP 194*, March 2004) indicates that carbohydrate feeding before and during high intensity exercise can limit the amount of stress hormone release, thereby reducing the risk of post-exercise immune suppression [1,2].

However, research suggests that protein has a role to play, too. A study on resistance training examined hormonal responses to water, carbohydrate, protein or a carbohydrate/ protein mix, given immediately and then two hours after a training session[3]. As expected, those fed the carbohydrate and carbohydrate-plus-protein mix drinks showed an increased insulin response. However, those fed the carbohydrate-protein mix also showed a modest but significant increase in growth hormone levels, suggesting that protein combined with carbohydrate following resistance training may create a more favourable hormonal environment for muscle growth.

'Any athlete seeking to optimise protein metabolism should ensure a carbohydrate intake commensurate with training volume'

Post-exercise protein feeding seems to be beneficial for endurance athletes also. In a study on 40 swimmers given either water or water-plus-glucose during training sessions and then either water, sucrose or a sucrose-plus-milk protein mix after training, the subjects receiving the post-training sucrose-protein mix exhibited lower levels of creatine phosphokinase (a marker of muscle damage) than the others [4]. Moreover, creatine phosphokinase levels returned to baseline levels more rapidly in this group, indicating that the ingestion of protein with carbohydrate accelerates recovery.

A study on ultra-endurance athletes, published in 2004, showed that a carbohydrate-protein mix maintained a positive nitrogen balance during and after a six-hour training session (five hours of cycling and one hour of running), while a straight carbohydrate drink did not [5].

The consensus of scientific opinion now is that, following intense exercise, athletes should ingest a carbohydrate and protein mix (around 1 gram per kg of body mass of carbohydrate and 0.5g per kg of protein) within 30 min of completing exercise, as well as consuming a high-carbohydrate meal within two hours. This nutritional strategy has been found to accelerate glycogen resynthesis as well as promoting a more anabolic hormonal profile that may hasten recovery [6-9].

Research carried out over a decade ago indicated that ingesting a light carbohydrate/protein snack 30-60 minutes before exercise is also beneficial [10,11]. In these studies it was shown that 50g of carbohydrate and 5-10g of protein, taken before a training session, could increase carbohydrate availability towards the end of an intense exercise bout and also enhance the availability of amino acids to muscles, thereby decreasing exercise-induced catabolism (breakdown) of protein.

This research appears to be backed up by a study carried out on 15 trained cyclists, who cycled to exhaustion on two rides 12-15 hours apart, the first at 75% and the second at 85% of VO_2max [12]. During the test, riders were split into two groups and given either a 7.3% carbohydrate drink (1.8ml per kg every 15 minutes), or the same drink with protein added at 1.8%. After 7-14 days, the test was repeated and the drink protocol reversed.

The results showed that riders taking the carbohydrate-plus-protein rode for 29% longer than the carbohydrate-only group during the first (75% VO_2max) ride and 40% longer during the second (85% VO_2max) ride! Furthermore, peak levels of creatine phosphokinase were 83% lower when carbohydrate plus protein was taken. Since the carbohydrate plus protein drink contained 25% more calories overall, further studies are needed to see how much of this effect is due to higher energy intake. However, it seems reasonable to assume that a carbohydrate-protein drink taken during training provides for increased protein concentration outside the cell, which can potentially enhance protein synthesis and repair.

The concept of different glycaemic indexes (the rate at which digested carbohydrate is released into the bloodstream as glucose) for different carbohydrates is now well accepted. However, different proteins display different rates of breakdown into their amino acid building block constituents, and hence uptake into the body.

A study into whey protein and casein (two types of protein supplements that are popular with athletes and bodybuilders) examined the speed at which one of the amino acids (leucine) appeared in the bloodstream after ingestion of a meal of each kind of protein (containing identical amounts of leucine) (13). The researchers found that whey led to a dramatic but short-term increase in plasma amino acids, while casein induced a prolonged plateau of moderately increased levels.

‘An athlete seeking to supply a post-training or mid-training boost to the amino acid blood pool would be best advised to consume a fast-release protein’

They concluded that the differences were probably explained by the slower gastric emptying of casein. Whey protein is a soluble protein whereas casein clots into the stomach, so delaying its gastric emptying. Likewise, soy protein appears to be digested more rapidly than milk protein, resulting in a higher but more transient peak of plasma amino acids (14).

The implications are obvious: an athlete seeking to supply a post-training or mid-training boost to the amino acid blood pool would be best advised to consume a fast-release protein, such as whey or soy. However, when a prolonged period of recovery is in store (*eg* at bedtime) a slower- releasing casein protein drink, such as milk, would be better. Another implication of this study is that, providing a meal or drink supplies the same quantity of the essential amino acids, one type of protein is not necessarily ‘better’ than another. Of more importance is that its release rate is matched to the timing of ingestion.

The situation also appears to be complicated by age. A study that looked at the effects of protein *retention* in young men (mean age 25 years) fed protein meals containing either slow-releasing casein proteins or rapid-releasing whey proteins, found a greater retention (*ie* uptake into muscles) after

Is leucine a 'special-case' BCAA?

Leucine is the most studied of the BCAAs, partly because leucine and its metabolites have been reported to inhibit protein degradation [22]. In the body, leucine accounts for about 4.6% of all amino acids and is involved in many important roles in the body, such as regulating protein metabolism by inhibiting degradation and stimulating synthesis [23].

Of particular interest is the fact that leucine can be oxidised to a compound known as acetylCoA in muscles at a higher rate than the other BCAAs (valine and isoleucine). This is important because acetylCoA is an 'entry point' into the citric acid cycle, one of the main energy-producing pathways in the body, and itself the gateway to aerobic metabolism, which explains why the demands for leucine rise substantially during periods of high energy expenditure. Studies have also shown that leucine oxidation is increased under catabolic conditions, such as depleted muscle glycogen.

Some researchers believe that the current leucine requirement, set at 14mg per kg of body weight per day, should be increased to 30mg in people who regularly participate in endurance activities [24]. This argument is supported by research that suggests endurance athletes can actually burn more leucine than they take in through the RDA of protein [25].

One of the best-known leucine metabolites is a compound called ß-hydroxy ß-methylbutyrate, more commonly known as HMB, which is popular with bodybuilders and athletes as a muscle/strength building supplement. But what is the evidence that it actually works? Some research indicates that 1.5-3g per day of HMB supplementation can increase muscle mass and strength, particularly in untrained subjects beginning training and in the elderly [26-32]. The muscle mass gains in these studies are typically 0.5-1kg greater than for controls during 3-6 weeks of training.

There is also evidence that, in athletes, HMB may reduce the catabolic effects of prolonged exercise. In one study, 13 runners were split into two groups, one taking 3g of HMB per day and the other a placebo [33]. Both groups continued with their normal training for six weeks, after which they completed a 20k run. Before and after the run, creatine phosphokinase and lactate dehydrogenase levels (both measures of muscle damage) were measured, with the HMB group showing much smaller increases in both than the placebo group, indicating significantly reduced muscle damage.

However, the long-term effects of HMB supplementation in athletes are less clear. Most studies conducted on trained subjects have reported non-significant gains in muscle mass [34-36], but further research is needed to clarify whether HMB really does enhance training adaptations in athletes.

casein[15]. However, when the same researchers studied protein retention in elderly subjects (mean age 72 years), their findings were reversed, with whey protein producing a significantly higher uptake of amino acids than casein [16].

The researchers surmised that amino acid availability may limit muscle synthesis in older subjects, and that the higher amino acid peaks produced by whey prevented this from happening. The implication seems to be that ingesting fast-releasing proteins mid- or post- exercise may be more important for older athletes than their more youthful counterparts.

'Free form' amino acids

The process of digestion releases the amino acid building blocks from ingested protein. However, as we've seen, this release rate is variable and the process of digestion itself actually consumes energy. This has prompted some investigators to ask whether the use of 'free form' amino acids before, during or after training could be a rapid method of providing athletes with optimum amounts of amino acids exactly when they're needed.

'One type of protein is not necessarily "better" than another as long as its release rate is matched to the timing of ingestion'

Particular interest has been shown in the branched chain amino acids (BCAAs), which are readily oxidised for energy and therefore in greater demand when energy output is high. In theory, BCAA supplementation might help to minimise protein degradation, thereby leading to greater gains in fat-free mass, or at least minimise lean tissue loss when training volumes are high.

BCAAs and body composition

There is some evidence to support this hypothesis; for example, a study conducted on trekkers at altitude found that taking 10g of BCAAs per day during a 21-day trek increased fat-free mass by approximately 1.5%, while controls on placebo experienced no such change[17]. Meanwhile, another study found that 30 days of BCAA supplementation (14g per day) promoted a significant increase in muscle mass (+1.3%) and grip strength (+8.1%) in untrained subjects [18].

A comprehensive protein strategy

Given the above findings, what reasonable steps can an athlete take to optimise his or her protein nutrition? Below is a 'protein checklist', which crystallises these findings into dietary recommendations:

- Ensure an adequate intake of dietary protein – ie a minimum of 1.5g of high-quality protein per kg of body weight per day. Power/strength athletes, or those engaged in intense training, should consider increasing this to 2g per kg per day;
- Ingest protein-carbohydrate drinks after exercise rather than protein alone. Ideally, consume a drink made up of about 1g per kg of carbohydrate and 0.5g per kg of protein within 30 minutes of training, and eat a high-carbohydrate meal within two hours;
- Consume a light pre-exercise snack: 50g of carbohydrate and 5-10g of protein taken before a training session can increase carbohydrate availability towards the end of an intense exercise bout and also increase the availability of amino acids to muscles. However, make sure your snacks are low in fat to allow for rapid gastric emptying!
- Use protein/carbohydrate drinks during very long events: a solution containing 73g carbohydrate and 18g protein per litre, consumed at a rate of 1ml per kg of body weight per minute, may delay the onset of fatigue and reduce muscle damage;
- Consume quick-digesting proteins such as soy and whey immediately after training: this may be especially important for older athletes;
- At other meals, consume a mix of proteins in order to promote a more sustained release of amino acids into the body;
- Adding BCAAs to your normal protein intake may be useful for athletes undergoing prolonged or heavy training, and this may be particularly true for events/sports requiring large amounts of mental agility and motor coordination;
- HMB supplementation, at 3g per day, may be a useful additional strategy for novice athletes, or those returning to training after a layoff;
- Essential amino acid blends taken 1-3 hours after training may promote additional muscle protein synthesis, although this hypothesis is not proven in athletes;
- Don't forget to ensure that your overall diet is of high quality and as whole and unprocessed as possible: this will ensure adequate intakes of other nutrients essential for protein metabolism, such as zinc and the B vitamins.

These findings suggest that BCAA supplementation may have some impact on body composition. Moreover, some evidence suggests that BCAA supplementation can decrease exercise-induced protein degradation and/or muscle enzyme release (an indicator of muscle damage), possibly by promoting an anti-catabolic hormonal profile [6,10,19]. However, despite the persuasive rationale, the effects of BCAA supplementation on short- and long-term exercise performance are somewhat mixed, with some studies suggesting an improvement and others showing no effect[6]. You can find a more detailed discussion of BCAAs and performance later in this special report.

Having said that, there is good evidence that BCAAs administered during training can reduce the perception of fatigue, while improving mood and cognitive performance. A study on seven male endurance-trained cyclists with depleted glycogen stores examined the effects of BCAA supplementation (versus placebo) on mental fatigue and perceived exertion [20]. The subjects exercised at a work rate corresponding to approximately 70% VO_2max for 60 minutes, followed by another 20 minutes of maximal exercise.

During the 60-minute section, the subjects' ratings of perceived exertion were 7% lower and mental fatigue 15% lower when they were given BCAAs. In addition, cognitive performance in the 'Stroops Colour Word Test' performed after exercise was improved when BCAAs had been ingested during exercise. Interestingly, however, there was no difference in physical performance in the final 20-minute segment of the

Essential amino acids and BCAAs

Essential Amino Acids	BCAAS	Leucine
		Isoleucine
		Valine
	Non-BCCAs (straight chain)	Histidine
		Lysine
		Methionine
		Phenylalanine
		Threonine
		Tryptophan

ride between the placebo and BCAA groups; the amount of work performed during this section was the same regardless of which supplement was taken.

These findings on BCAA supplementation, mental fatigue and perceived exertion were replicated in a study on runners given carbohydrate-plus-BCAA drinks or carbohydrate-only drinks (placebo) during a 30k cross-country run [21]. Subjects on BCAAs improved their post-exercise performance in the above-mentioned Stroops test by an average of 3-7% compared with those on placebo. The BCAA group also maintained their performance in two more complex mental tasks (shape rotation and figure identification) after exercise, while the placebo group showed a 25% and 15% reduction respectively in these tasks.

'Studies on resistance training in healthy adults seem to confirm the potential benefits of essential amino acids'

Researchers believe that this cognitive effect may be due to the ability of BCAAs to compete with and therefore reduce the uptake of another amino acid, tryptophan, across the blood-brain barrier and into the brain. Tryptophan is the precursor to a brain neurotransmitter called 5-hydroxytryptamine (5-HT – more commonly known as serotonin), which is involved in fatigue and sleep and is believed to contribute to the development of central/mental fatigue during and after sustained exercise. During exercise, the concentration of tryptophan in the blood relative to other neutral amino acids seems to rise. But supplementing with BCAAs seems to help block this effect, which would, in turn, reduce levels of 5-HT in the brain.

Essential amino acids

The BCAAs comprise just three of the nine essential amino acids (EAAs), the other six being histidine, lysine, methionine, phenylalanine, threonine and tryptophan (see box). As mentioned, essential amino acids have to be obtained from the diet because they can't be synthesised in the body from other amino acids. Although the six 'straight chain' EAAs are not so readily utilised as fuel, some researchers believe that giving all nine EAAs in a free form (*ie* as a mix of separate amino acids, not as protein), and in ratios that reflect the amino acid composition of muscle protein, is more beneficial for muscle protein synthesis than giving BCAAs alone.

In studies, scientists in Texas have found that ingesting 3-6g of EAAs before and/or after exercise stimulates protein synthesis[37,38]. Moreover, this stimulation appeared to increase in a dose-dependent manner until plasma EAA concentrations are doubled, and was maximised when EAAs were administered to maintain this doubled concentration over a three-hour period. Adding carbohydrate seemed to enhance this protein synthesis, probably through the anabolic effect of insulin.

Although there has been very little research on EAA ingestion by athletes, studies on resistance training in healthy adults seem to confirm the potential benefits of EAAs; for example, muscle protein synthesis was increased 3.5-fold when 6g of a mixture of EAAs was given along with 35g of carbohydrate after resistance exercise [39].

In another study, three men and three women resistance trained on three separate occasions and then consumed, in random order, one of the following:

- a 1 litre solution of mixed amino acids containing both essential and nonessential amino acids (40g);
- a solution containing only essential amino acids (40g);
- placebo [40].

Net muscle protein balance was negative after ingesting placebo but positive to a similar magnitude for both the mixed and essential amino acid drinks. The researchers concluded that: ‘it does not appear necessary to include nonessential amino acids in a formulation designed to elicit an anabolic response from muscle after exercise’.

Andrew Hamilton

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Protein intake for maximum muscle mass – can you have too much of a good thing?

At a Glance

- The issue of optimum protein intake levels for athletes seeking muscle mass gains is addressed and some of the myths are dispelled;
- Protein quality and the role of the essential amino acids (particularly leucine) is discussed;
- The importance of timing of protein ingestion is emphasised.

All athletes know that adequate protein is vital to build lean muscle mass. However, according to Dr Kevin Tipton, the latest research indicates that more is not necessarily better when it comes to optimum protein intake for maximising muscle mass

The metabolic basis for changes in muscle mass is net muscle protein balance (NBAL). Muscle proteins, in fact all body proteins, are constantly being synthesised and degraded; these processes are concurrent. The balance between these two processes determines the amount of proteins in muscle.

More specifically, changes in muscle mass are due to changes in the balance of the synthesis and breakdown of muscle contractile, *ie* **myofibrillar proteins**. Over any given time, the quantity of muscle protein is due to a change in NBAL. Accretion of muscle proteins occurs during periods of positive balance and muscle proteins are lost during periods of negative balance (see figure 1). Nutritional intake and exercise both

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Myofibrillar proteins
Proteins found in muscle and other tissues that provide structure and size and which are necessary for muscle

have profound influences on the duration and magnitude of these periods of positive and negative net muscle protein balance.

The amount of muscle mass gains possible by any individual is ultimately determined by genetics. So, those who gain mass easily may want to thank their parents first. However, environmental influences, such as exercise and nutrition, have a profound impact on muscle mass and will determine what mass within this range will be expressed at any given time. The type, volume, intensity and duration of the exercise training will have by far the largest influence on muscle mass. No matter what or how much is eaten, gains in muscle mass will be minimal without the proper training load.

Exercise and nutrition influence muscle mass through

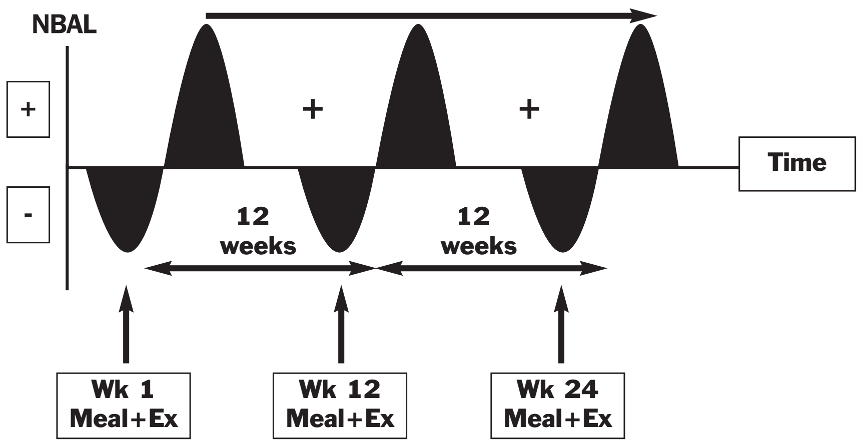

Figure 1: Muscle protein gains are due to the accumulation of muscle protein in response to each individual bout of resistance exercise plus nutrient (amino acid) intake. For illustration purposes, the theoretical daily response to resistance exercise plus ingestion of a meal at weeks 1, 12 and 24 of training is depicted. There is no change in basal NBAL or in the response to a meal plus exercise over time, but instead muscle hypertrophy results from an accumulation of proteins due to the response to each individual exercise bout. The positive area in response to exercise plus nutrient intake is greater than the negative areas during fasting.

changes in muscle protein synthesis and breakdown that will increase (or decrease) NBAL. On a daily, or even hourly, basis NBAL can be either positive or negative, depending on feeding and exercise situations. The length and duration of these periods of positive and negative balance determine the net loss or gain of muscle mass[1]. Consequently, in healthy, mass-stable adults, periods of positive and negative NBAL will be equal, and no growth occurs. Muscle growth only results when a cumulative positive protein NBAL prevails (*see figure 1*).

Nutritional influences on muscle mass have received a great deal of attention lately. Protein and amino acids in various forms are generally thought to be the most important nutrient for muscle building. As such, many athletes consume very large amounts of protein. In a recent article, scientists at McMaster University in Canada gathered data from many published papers. They determined that strength athletes consume well above 2.0g protein per kg body mass per day (g/kgBW/d) on average and many consume up to 3.5-4.0g/kgBW/d[2]. That equates to as much as 400g protein consumed per day!

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Essential amino acids
Amino acids found in body proteins that are not synthesised in the body and must be ingested in foods

How much protein?

The question is whether that much protein is necessary or even desirable for increasing muscle mass and strength? It is clear that protein ingestion is critical for increased muscle mass. Resistance exercise increases muscle protein synthesis resulting in improved muscle protein balance[3]. However, without a source of amino acids, muscle protein balance will not reach positive levels – *ie* muscle anabolism[4].

Protein ingestion before or after exercise clearly results in positive muscle anabolism. Proteins, particularly myofibrillar proteins, accumulate over time in response to each exercise bout and associated protein intake, resulting in increased muscle mass. However, the amount of protein necessary to stimulate muscle anabolism in association with exercise is relatively small – as little as 6g of **essential amino acids** consumed either before or after exercise result in positive net balance[5].

'The main problem with high protein intakes is that other nutrients must be supplanted if energy intake is not to be increased'

Furthermore, recent data presented at the latest American College of Sports Medicine Conference in New Orleans earlier this year demonstrate that the anabolic response to protein ingestion following exercise demonstrates a ceiling effect. Consumption of more than 10g protein results in diminishing increases in muscle anabolism following exercise. Thus, it appears that large amounts of protein are unnecessary. The excess protein is simply oxidised for energy and not used for muscle building.

Protein requirements for athletes are a somewhat controversial topic in the scientific community[6]. Protein requirements are typically determined by measuring nitrogen balance. This technique is based on the fact that protein is unique among nutrients in that it contains nitrogen. Thus, if one measures the amount of nitrogen consumed and how much is excreted, the gain or loss of body (not necessarily muscle) protein may be determined. This method is commonly used to determine protein requirements for various populations. Several well-controlled studies show that nitrogen balance is attained in highly trained athletes at the levels of protein intake mentioned above – *ie* approx 1.2-1.6g/kgBW/d[1,6,7].

Nitrogen balance conundrum

So, why do many athletes and coaches maintain that much higher protein intakes are desirable for increased muscle mass? The answer probably lies in the nitrogen balance method. Athletes desiring increased muscle mass should be in positive nitrogen balance, thus the conclusion is that protein intakes above 1.6g/kgBW/d are considered necessary. Furthermore, when nitrogen balance is measured in athletes, the greater the protein intake, the greater the nitrogen balance[2], thus athletes conclude that the more protein they eat, the bigger they'll get.

Unfortunately, the increase in muscle mass that would be associated with these very high nitrogen balances is simply not possible (*see box 1*), even if anabolic drugs were administered. If this level of nitrogen were actually incorporated into muscle,

Box 1: Why positive nitrogen balance is not the same as muscle gain

- Suppose an athlete eats 2.5g protein/kg/d; this would result in a positive nitrogen balance of around 15g of nitrogen per day;
- But nitrogen constitutes only around 16% of protein by weight, therefore actual protein gain = 15g N x 1g protein/0.16g N = around 94g of protein per day;
- Since muscle is 75% water, amount of muscle accretion per day = 94g protein x 25% protein in muscle (75% water) = 282g muscle per day;
- Per year = 282g protein per day x 365 days = 102930g/yr or 103kg of muscle gained in one year!

these athletes would gain around 100kg of muscle mass in a year[1,7]! Clearly, there are problems with this method for determining nitrogen balance, especially at high levels of protein intake.

More direct evidence that high positive nitrogen balance is disassociated from gains in lean mass has accumulated. Several studies demonstrate that athletes may have a very high nitrogen balance, but lean body mass does not increase[1,7]. Thus, the basis for very high levels of protein intake is unsound.

Recently, two studies from McMaster University in Ontario nicely show why it is not necessary to ingest large amounts of protein during training designed to increase muscle mass[8,9]. Athletes in these studies consumed between 1.2 and 1.6g/kgBW/d of protein for 12 weeks. Muscle mass and strength increased during training on what may be considered – at least by many athletes and coaches – a relatively modest level of protein intake.

These studies clearly demonstrate that the anabolic nature of training actually decreases the requirement for protein and that muscle mass and strength increase on 'normal' levels of protein intake; extremely large amounts of protein (above 2.0g/kgBW/d) are unnecessary and do not increase strength and mass gains. The excess protein is simply oxidised and the nitrogen likely ends up in the urea pool to ultimately be excreted.

Protein dangers?

On the other hand, is there any harm in consuming excess protein? Many scientists and physicians have warned against high protein intakes due to potential health consequences. In particular kidney problems and loss of bone are given as adverse effects of high protein intakes. However, there has never been a documented case of kidney problems in otherwise healthy individuals.

Similarly, bone loss with high protein intake seems to be overstated. The main problem with high protein intakes is that other nutrients must be supplanted if energy intake is not to be increased. Thus, it is likely that carbohydrate intake will go down. Carbohydrates are critical to performance, especially in endurance exercise, but also for maintenance of high-intensity resistance training. Thus, care should be exercised to avoid increasing protein intake at the expense of other nutrients, particularly carbohydrates.

In fact, energy intake is the most important nutritional factor for increasing muscle mass. It is very difficult, if not impossible, to gain muscle mass if energy balance is negative, ie energy intake is less than expenditure. Indeed, it is impossible to maintain positive nitrogen balance in the face of energy deficits; even given high protein intakes[10].

On the other hand, if energy balance is positive, then athletes may gain muscle mass on a wide range of protein intakes. About 100 years ago, it was demonstrated that soldiers in training will gain muscle at relatively low levels of protein intake – around 1.0g/kgBW/d[11].

A more recent study demonstrated that increased muscle mass during resistance training was equivalent when athletes were fed 2,000 extra calories on top of their normal dietary intake in the form of either carbohydrate alone or carbohydrate plus protein[12]. Taken together, these studies suggest that when adequate protein (as little as 1.0g/kgBW/d) is consumed, muscle hypertrophy is dependent on provision of sufficient energy.

Furthermore, by consuming the calories needed to provide the energy necessary to support training, most athletes will automatically consume ample protein without having to resort to supplementary sources. Resistance training at high volumes and intensities is common and necessary to support increased mass and strength. This level of training requires high energy intakes to support it[13]. Therefore, even if protein is a relatively low proportion of the diet (eg around 12%), there will be ample protein ingested to meet the higher estimates of protein requirements for muscle growth based on nitrogen balance.

Since it is clear that muscle mass accumulates in response to each individual exercise session (*see figure 1*), investigations of the acute response of muscle protein synthesis to exercise and nutrient intake provide valuable information for delineation of important strategies for increasing mass and strength.

One important consideration that this research illustrates is that it is rather nonsensical to recommend a general amount of protein to all athletes as the optimal amount to increase muscle mass. Since various factors, such as timing of intake, type of protein and other nutrients ingested with protein influence the overall response, two athletes consuming the same amount of protein will not necessarily experience the same muscle growth.

Studies have demonstrated that the type of protein will influence the anabolic response. Recent research shows that milk ingestion stimulates muscle anabolism following exercise and that response is greater than that generated by soy ingestion[14]. These results may be used to make two important points: 1) protein in foods works just as well as that in supplements and, 2) animal proteins seem to engender a superior anabolic response following resistance exercise.

A subsequent training study from the same research group supported the results of the acute metabolic study – confirming that acute metabolic studies do represent the potential for longer-term muscle gains[15].

Essential amino acids

The important component of the protein seems to be the essential amino acid content. It is now clear that muscle

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Catabolic exercise model
An experimental model that results in a reduction in muscle protein synthesis

Pre-hormones
Compounds that may be used by the body to manufacture hormones

Metabolite
A substance produced during metabolism of another compound

'Additional leucine ingested with the protein and carbohydrate did not result in further stimulation of muscle protein synthesis'

anabolism occurs with ingestion of only the essential amino acids – *ie* the non-essential amino acids are unnecessary to stimulate muscle growth following exercise(4). However, this doesn't mean that essential amino acid supplements are superior to non-essential or to whole proteins. It simply means that essential amino acids can stimulate muscle protein synthesis and there are ample non-essentials to support the elevated levels of synthesis.

Leucine may be the most important amino acid for stimulation of muscle protein synthesis. Leucine, along with isoleucine and valine, is a branched-chain amino acid (BCAA). BCAAs are often touted as the most anabolic amino acids and many BCAA supplements are sold and consumed.

In animal studies leucine stimulates pathways inside the muscle cells that result in increased muscle protein synthesis in rats following intense exercise that would otherwise decrease synthesis(16,17). Thus, in a **catabolic exercise model**, leucine ingestion may be very effective as an anabolic agent. However, the evidence in humans is less clear, particularly following resistance exercise.

Researchers in the Netherlands found that protein ingestion, in addition to carbohydrates, stimulated muscle protein synthesis more than carbohydrate alone(18). However, additional leucine ingested with the protein and carbohydrate did not result in further stimulation of muscle protein synthesis.

Similar results were found in a recent study from a research group in Galveston, Texas. There is evidence that leucine may decrease the amount of muscle protein breakdown in humans, but these studies did not involve exercise(19). The Galveston results demonstrated that the NBAL was not improved with additional leucine, thus casting doubt on the efficacy of leucine supplementation following anabolic exercise in humans. However, it should be noted that few studies have actually examined this issue and a systematic evaluation may be required before leucine can be dismissed as an anabolic agent.

Protein timing

The timing of protein and amino acid ingestion has been given a great deal of attention lately. When an essential amino acid plus carbohydrate solution was ingested before resistance exercise, the response of muscle anabolism was greater than when this solution was ingested following exercise(20). Many people interpreted these results to mean that athletes should ingest protein before exercise.

However, a follow-up study by the same research group showed that the difference in the response of muscle anabolism was very little when whey protein was ingested before and after exercise – a completely different result from the free amino acids and carbohydrate mixture(20,21). Thus, there is an interaction of the type of amino acid source and the timing of ingestion, ie not all proteins are created equally.

The difference is probably explained by the time it takes to digest protein. Since free amino acids do not need to be digested in the gut, the appearance of amino acids into the blood is very rapid. So, when free amino acids are ingested immediately before exercise, delivery of amino acids to the muscle is very high during exercise. However, since protein must be digested, amino acid levels in the arterial blood are not increased rapidly enough to increase delivery so that the

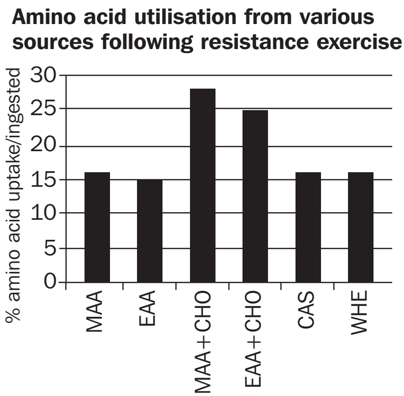

Figure 2: Utilisation of ingested amino acids for muscle protein accretion following resistance exercise. Addition of carbohydrate to an amino acid source increases the utilisation of the ingested amino acids. MAA = mixed amino acids; EAA = essential amino acids only; MAA+CHO = mixed amino acids plus carbohydrates; EAA+CHO = essential amino acids plus carbohydrates; CAS = casein; WHE = whey proteins.

anabolic response is similar to that when proteins are ingested following exercise. It is possible that ingestion of protein 15, 20 or even 30 minutes prior to exercise may be advantageous, but no study has looked into this possibility.

Ingestion of other nutrients alongside protein and amino acids seems to be advantageous for creation of an anabolic response. Ingestion of carbohydrates and fat along with protein appears to increase the uptake of amino acids into the muscle from the protein (see figure 2)[22,23]. These results also support an earlier contention – *ie* that protein in foods is equally effective as that in supplements for stimulating muscle hypertrophy.

Whereas there is clearly a place for protein supplements (supplements may be much more convenient to use in certain situations) there is no reason that muscle growth can't be optimised simply by eating food sources of high-quality proteins such as eggs, milk and dairy products and lean meat. This fact should not be particularly surprising. After all, we did not evolve to forage for individual proteins at supplement stores, but we did evolve to utilise the protein from foods to our best advantage!

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Why high-protein, low-fat diets might not be best after all

At a Glance

- The relationship between dietary protein, fat and hormones in the body is outlined;
- Research on the role of fat and human growth hormone is presented;
- The dietary implications for strength athletes are explained

Years of careful research and scientific studies seem to point to the unavoidable conclusion that a low-fat diet containing ample protein provides the best nutritional environment for strength athletes. But now surprising research suggests that this view may be oversimplified, writes Andrew Hamilton

Scan the ingredients list of any tub of weight gain powder and it's easy to see the current thinking on nutrition and strength building. While the brands may differ, the contents are strikingly similar; all are invariably high in protein, low in fat, with varying amounts of carbohydrate. The reasoning is simple: dietary protein provides the source of amino acid building blocks needed by your body to synthesise new muscle tissue, as well as to replace and repair tissue broken down during exercise itself.

Although the exact protein requirement for an individual athlete remains the subject of debate, the consensus among sports nutritionists is that athletes do need more protein for optimum performance and recovery than their sedentary counterparts (*see previous article for a more detailed discussion on this subject*). In fact, the research suggests that athletes engaged in intense training may need to ingest about 1.5-2

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RDA
Recommended Daily Allowance; the daily amount of a nutrient required to produce health and prevent deficiency diseases

Hormones
Compounds made in the body that act as chemical messengers, telling cells what to do

Essential fatty acids
Certain types of fats that cannot be synthesised in the body, but which are essential for health (ie they have to be obtained from the diet)

times the normal **RDA** for protein in order to maintain a positive protein balance [1-5]. This equates to 105-140g of protein per day for a 70kg athlete.

Fifty years ago, high protein steak and egg diets were the order of the day. The thinking was simple: muscles are made of protein, therefore to develop muscular strength requires a large intake of protein. However, as the understanding of carbohydrate metabolism and sports performance grew, scientists began to realise that this approach was grossly oversimplified. That's because we now know that the uptake of amino acids into muscle cells is strongly regulated by **hormones**.

One of the most anabolic (*ie* muscle-building) hormones in the body is insulin, which is released whenever carbohydrates are eaten. The primary job of insulin is to regulate the amount of glucose in the blood that results from eating carbohydrate, by stimulating cells to take up glucose.

However, this release of insulin also has a potent anabolic effect, helping to drive amino acids into muscle cells, thereby stimulating muscle protein synthesis. In fact, research has demonstrated that feeding protein plus carbohydrate to promote an insulin release results in 50% greater muscle protein synthesis than feeding protein alone [6].

But carbohydrates also play another valuable role in muscle metabolism – that of helping to conserve hard earned muscle tissue. While a high-protein diet provides plenty of amino acid building blocks to build muscle protein, unless there's sufficient carbohydrate present to support training (remember, carbohydrate is the body's 'premium grade' fuel for exercise), these amino acids are simply used to supplement the fuel supply.

A low-carbohydrate diet combined with vigorous exercise therefore results in protein oxidation for energy, and since muscles are the major store of amino acids, this can result in muscle tissue loss, especially when training volumes are high.

Moreover, research has clearly demonstrated the importance of ample dietary carbohydrate in reducing the amount of catabolic stress hormones, such as cortisol and adrenaline, which are released during and after exercise and which stimulate the breakdown of muscle tissue(7,8,9). In short, carbohydrate is as much a part of the anabolic equation as protein.

The protein/fat equation

Given that both protein and carbohydrate are needed for muscle growth and maintenance, it's easy to understand how the consensus that high-protein/ample-carbohydrate/low-fat diets are best for strength athletes has arisen. A diet containing moderate or high levels of fat and plenty of protein/carbohydrate would necessarily contain a lot of extra calories, especially as each gram of fat provides 9kcals of energy – double that of carbohydrate or protein. And as we know, an excessive calorie intake leads to gains in body fat – exactly what most athletes don't want.

Meanwhile, a calorie-controlled moderate/high-fat diet would necessarily have to contain relatively little protein and carbohydrate – again not desirable for an athlete seeking to maintain or build strength. Together, these facts explain why protein is king, and why (notwithstanding the growing realisation of the importance of **essential fatty acids**) fat is almost seen as a dirty word among strength athletes.

Gaining and retaining muscle tissue certainly requires ample protein and carbohydrate, but that's not the whole story. After all, if it were, consuming larger and larger quantities of protein would lead to ever increasing strength and muscle size – something that obviously doesn't happen. This is because hormones also control the metabolism of muscle tissue and protein turnover. Naturally occurring anabolic hormones such as testosterone and human growth hormone (HGH) act as chemical messengers, directing muscle cells to take up amino acids and synthesise muscle protein. They also stimulate the oxidation of fat for energy, thereby increasing lean muscle mass while decreasing fat mass.

The action of anabolic hormones is balanced by 'catabolic' hormones, such as adrenocortico-trophic

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Anabolic steroids
A family of synthetic drugs derived from the male sex hormone testosterone and which are used to promote muscle growth

Pro-hormones
Substances (sometimes used by athletes) that don't have a significant hormonal effect in themselves but which can be metabolised into active hormones once ingested

hormone and cortisol. These hormones are released during 'fight or flight' situations, where energy production becomes paramount, and tend to produce a breakdown of body tissue. Building or maintaining strength requires a hormonal balance that is more anabolic than catabolic. This explains the illegal use of **anabolic steroids**, substances that artificially boost anabolic hormone levels (*see box below*).

But can hormonal balance be influenced by nutrition? Leaving aside the issue of exotic sports supplements such as **pro-hormones**, evidence has emerged that suggests that protein and fat ratios can impact on hormonal balance, but in a rather surprising way.

A joint Finnish and American study examined the relationship between dietary intake patterns and the resulting blood concentrations of the anabolic hormones testosterone (T), free testosterone (FT) and growth hormone [10].

In this study, eight strength athletes and ten physically active non-athletes were examined at rest as well as after heavy-resistance exercise. During the first part of the study, all the subjects were allowed to eat freely, but kept detailed food diaries. The scientists then examined how these differing dietary patterns affected the levels of hormones in each of the subjects . In the second part of the study, a sub-group of five strength athletes and five non-athletes kept diaries for a further four days before undertaking a high-volume, high-intensity resistance workout.

What the scientists found surprised them. During the non-active period, a higher fat intake and lower protein intake was associated with *increased* levels of anabolic hormones across both groups of subjects.

However, during the phase of the study containing the high-intensity resistance exercise, this correlation disappeared for the non-athletes, but remained for the trained strength athletes – *ie* higher fat intakes and lower protein intakes were associated with increased blood levels of anabolic hormones in the strength athletes only. The clear implication is that the role of diet in producing a favourable anabolic environment may be

Anabolic steroids as drugs

Anabolic (or more correctly, androgenic-anabolic) steroids (AAS) form a family of synthetic drugs derived from the male sex hormone, testosterone, and are used to promote muscle growth and increased lean body mass. Although they have many approved medical uses, steroids are sometimes abused by athletes seeking to improve performance.

However, the non-medical use of these drugs carries severe physical and psychological health risks. In males, they can trigger a mechanism in the body that leads to the shut-down of the healthy functioning of the male reproductive system, resulting in a number of effects, including shrinking of the testicles, reduced sperm count, impotence, premature baldness, enlarged prostate gland and enlarged breasts (gynecomastia).

In females, effects include deepening of the voice, the growth of facial hair and reduction in breast size. More generally, other symptoms are commonly observed, including severe acne, weakened tendons (leading to increased injury risk), severe mood swings, uncontrolled bursts of anger, delusions and paranoia and depression (especially when steroid use is discontinued). The longer-term health effects include increased blood pressure and cholesterol, leading to an increased risk of heart disease, as well as kidney and liver disease.

more important for trained athletes.

The researchers went on to conclude that 'the results suggest a possible link between diet and changes in blood hormones during prolonged strength training, and that diets with insufficient fat and/or excessive protein may compromise the anabolic hormonal environment over a training programme'.

Fat and growth hormone

The fact that a higher dietary fat and lower protein intake appears to increase anabolic hormone levels, especially in trained athletes, seems counterintuitive and flies in the face of conventional wisdom. But while more research is obviously needed in this area, some other studies also hint that the low-fat, high-protein route may not be quite the holy grail we all thought it was.

In one of these studies, the interaction between fat metabolism and muscle-building growth hormone was examined [11]. To do this, the subjects fasted for 37 hours in order to suppress their natural production of growth hormone (GH – suppression of growth hormone normally occurs during fasting). They were then infused with one of the following:

- GH alone;
- GH together with a drug called Acipimox, which blocks the release of fat from fat stores and fat metabolism;
- No GH with Acipimox;
- GH with Acipimox plus extra lipid (*ie* to provide the body with an extraneous source of fat).

As expected, urinary urea excretion, blood urea and muscle protein breakdown (all are measures of protein catabolism in the body) were increased by almost 50% during the fast when fat metabolism was being suppressed.

Giving extra GH alone reduced the rate of muscle loss during the fast, but when the subjects were also being infused with Acipimox, extra GH *didn't* reduce the rate of muscle tissue loss. However, when fatty acids were then added to the infusion (to provide a source of fat), the rate of whole body protein degradation dropped to just 15% above baseline values (*ie* the GH was able to exert an effect again), providing strong evidence that fatty acids in the bloodstream are important protein-sparing agents during fasting. The implication is clear; fat seems to play a decisive role in the process of protein conservation during fasting in humans, possibly by helping growth hormone to work more efficiently.

Another fascinating study examined the effect of meat-containing diets and vegetarian diets on strength and body composition when combined with resistance training [12]. In this 12-week study, 19 men were split into two groups:

- Ten subjects were instructed to continue consuming their normal omnivorous diet (containing a mixture of protein sources including meat) while the resistance training was continued;
- The remaining nine men were counselled to select a lacto-ovo vegetarian diet (*ie* exclude all meat) for the duration of the study.

A balancing act in the body; anabolism vs catabolism

The body is in a constant state of flux, building up and breaking down tissue as required. This requires a careful balance of anabolism (tissue synthesis) and catabolism (tissue breakdown).

Naturally occurring anabolic hormones include:
human growth hormone
IGF1 and other insulin-like growth factors
insulin
testosterone
oestrogen (although associated with feminising characteristics, it's an anabolic hormone).

Naturally occurring catabolic hormones include:
cortisol
glucagon
adrenalin and other catecholamines
cytokines.

Other hormones are intimately associated with maintaining the correct balance of the catabolic and anabolic states, such as orexin and hypocretin (which function as a hormone pair) and melatonin (derived from serotonin), which plays a role in sleep, ageing and reproduction in mammals.

All of the subjects kept food diaries, and while carbohydrate, protein, nutrient and alcohol intakes were not significantly different between the two groups, those on the meat diet tended to consume more fat.

Once again, the results confounded the researchers. Although the 12-week resistance training programme produced the same gains in maximal strength (10-38%) in both groups of men, the changes in body composition and skeletal muscle size were significantly different. The meat eaters gained an average of 1.7kg of lean muscle, while the vegetarian group lost an average of 0.8kg. Moreover, the meat group lost an average of 1.3kg of fat, while the vegetarian group actually *gained* 0.1kg.

Although the researchers cautioned that the food diary methods they employed could not be considered 100%

accurate, they did conclude that there was a *real* difference between the two dietary patterns. The exact cause(s) for this difference remains unclear and, once again, more research would be needed – for example to investigate whether it was the higher fat content of the meat diet *per se* that produced these results, or some other factor.

One possible reason advanced by the scientists was that the meat diet may have produced higher levels of the muscle-building hormone testosterone, a phenomenon that has been observed in endurance athletes [13]. Eight male endurance athletes were split into two groups and put on either a lacto-ovo vegetarian diet or a mixed, meat-rich diet. However, the diets were formulated so that the protein/fat/carbohydrate ratio was kept pretty much the same (58%/27%/15% on the vegetarian diet and 58%/28%/14% on the meat diet). After six weeks, the groups were reversed, *ie* those on the meat diet switched to the vegetarian diet and *vice versa*.

The researchers discovered that, compared to the vegetarian diet, consuming the meat diet produced significantly higher levels of the anabolic hormone testosterone. They also noticed that the endurance performance time was better for more of the athletes after the meat diet than after the vegetarian diet, although these differences were not large enough to be considered statistically significant.

Conclusion

Do these findings mean that sportsmen and women should abandon the currently accepted nutritional wisdom and switch to higher-fat, low-protein diets? Of course not! However, these studies perfectly illustrate the complexities of formulating optimum eating regimes for athletes. In particular, they suggest that the practice among some athletes of following extremely low-fat diets, or eschewing all red meat from the diet on the grounds that it contains more fat than other protein sources, may actually be counterproductive. Much research remains to be done, but in the meantime it seems that a little of what you fancy really may do you some good.

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Recovery: why protein replenishment can't start soon enough!

At a Glance

- The role of both protein and carbohydrate in recovery is outlined;
- Therelationship between quick digesting protein and increased muscle mass is expolred;
- Research detailing the benefits of pre-exercise free-form amino acid supplementation is presented.

When it comes to recovery from athletic endeavours, the notion that 'it's not just what you eat but when you eat it' seems intuitively correct. For example, numerous studies have demonstrated that muscles are hungrier for refuelling after exercise than they are before, giving rise to the concept of the 'post-exercise window of opportunity'. However, research now suggests that this window of opportunity may be wider than anyone had imagined, writes Andrew Hamilton

One of the problems with making definitive recommendations about the timing of meals and drinks to enhance post-exercise recovery is the multifaceted nature of the components required for recovery. In broad-brush terms, there are four major nutritional requirements during post-exercise recovery:

- *Water* – to replace fluid lost as sweat and to aid the process of **'glycogen fixation'**;
- *Electrolytes* – to replenish minerals lost in sweat (*eg* sodium, chloride, calcium, magnesium);
- *Carbohydrate* – to replenish muscle glycogen, the body's premium grade fuel for strenuous exercise, and also to top up

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Glycogen fixation
The process whereby glycogen is manufactured from carbohydrate and locked into muscle cells

Amino acid pool
A collective term for the 'free' amino acids (ie not forming proteins) circulating around the body and available for use by the body

Muscle transporter protein
A protein molecule that sits in the cell wall and facilitates the passage of substances in or out of the cell

liver glycogen stores, which serve as a reserve to maintain correct blood sugar levels;

- *Protein* – to repair and regenerate muscle fibres damaged during exercise, to promote muscle growth and adaptation, and to replenish the **amino acid pool** within the body.

Although even a small degree of water loss can impair performance, the process of rehydration to replace lost water and electrolytes is relatively straightforward. Our bodies always strive to maintain optimum water and electrolyte balance, so as long as we consume plenty of fluids after training and eat a reasonably balanced diet (which will contain electrolyte minerals), full rehydration will occur as a matter of course. Moreover, it's quite easy to tell when we're fully hydrated – a pale straw-coloured urine and frequent urination being the most obvious signs.

Refuelling muscles with carbohydrate is less straightforward. Regular *PP* readers will be aware of the importance of carbohydrate feeding after exercise and also during prolonged endurance events. One of the earliest landmark studies demonstrated that a typical diet (with about 45% of calories derived from carbohydrate) produced a steady depletion in muscle glycogen during three successive days of running training (10 miles per day) (1). However, when runners were given additional dietary carbohydrate, they achieved near maximal repletion of muscle glycogen within 24 hours.

Subsequent studies showed that, to maximise the rate of glycogen repletion, carbohydrate consumption should be a priority after exercise. In fact, a recent literature review concluded that the highest muscle glycogen synthesis rates occur when large amounts of carbohydrate (1-1.85g per kg of body weight per hour) are consumed immediately after exercise and at 15- to 60-minute intervals thereafter, for up to five hours (2). Conversely, delaying carbohydrate ingestion by several hours may slow down muscle glycogen synthesis.

We now know that there is actually a two-phase process of glycogen replenishment. In the first hour after exercise, a

muscle transporter protein known as GLUT4 quite literally opens the gates to your muscle cells, allowing glucose to flood in thereby facilitating the rapid synthesis of muscle glycogen. This is supplemented by a slower but longer lasting process, whereby carbohydrate-hungry muscles become much more sensitive to insulin, the **anabolic hormone** that helps drive glucose into muscle cells.

Although animal studies have shown that this second phase of enhanced glycogen replenishment can last for up to 72 hours post-exercise [3,4], the general consensus is that athletes engaged in frequent training should aim to start glycogen replenishment immediately after each training session. This is because the training schedules of most athletes simply don't allow for up to 72 hours of recovery time between sessions, so athletes seeking rapid recovery must take advantage of the rapid phase 1

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Anabolic hormone
Any chemical messenger molecule in the body that promotes tissue (and particularly muscle) synthesis

Essential and non-essential amino acids

Just as words are constructed from letters of the alphabet, so all proteins are constructed from amino acid building blocks chemically linked together. Our diets typically contain around 20 of these amino acid building blocks in the foods we eat. Once the plant or animal proteins we eat have been digested to release the amino acids, our cells reassemble them to produce human proteins such as hair, skin, muscle *etc*.

Of the 20 amino acid building blocks, some are considered absolutely essential because they can't be manufactured in the body from other molecules. These include:

Arginine	*Histidine*	*Isoleucine*	*Leucine*	*Lysine*
Methionine	*Phenylalanine*	*Tyrosine*	*Tryptophan*	*Valine*

The other amino acids are classed as non-essential because they can be synthesised in the body from fragments of the essential amino acids and carbon residues from glucose metabolism. More recently, scientists have identified a third category of amino acids, known as 'conditionally essential'. Conditionally essential amino acids can be synthesised in the body when demand is low, but when demand rises (eg at times of metabolic stress) synthesis can't keep up with demand and dietary sources then become vital. The amino acid glutamine is thought to fall into this category, being non-essential at rest but becoming essential at times of severe metabolic stress.

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Muscle biopsy
A method of mechanically removing a small slither of tissue from a muscle for analysis

Radiolabelling
A chemical technique of replacing an atom in a molecule with a radioactive atom (usually of the same type) so that the movement of the molecule can be tracked in the body

GLUT4 process and consume carbohydrates immediately after training!

Carbohydrate metabolism is a very well researched area of sports nutrition. This is because dietary carbohydrate and the glucose/glycogen our bodies produce from it are premium grade fuels and absolutely pivotal to sports performance. But another, less obvious, reason is that muscle glycogen stores are relatively easy to test by means of **muscle biopsy**. Moreover, muscle glycogen levels change rapidly in response to exercise (depletion) or carbohydrate feeding (replenishment). These factors make it much easier to investigate the relationship between the timing of carbohydrate feeding and its effects.

Contrast this with protein metabolism: unlike with carbs, there's no 'protein store' in the body, other than muscle tissue, and observing changes in muscle fibres in response to protein ingestion is difficult for two main reasons:

- It can take many days to detect an increase in muscle fibre mass as the result of protein incorporation into muscle tissue, which makes it very difficult to deduce a link between timing of protein intake and the body's response;
- Proteins in the body are in a constant state of flux; if protein demand suddenly rises, muscle fibres can be broken down to provide the body with extra amino acids for the amino acid pool and then regenerated from recycled amino acids once this demand has subsided. This explains why many studies on protein intake and muscle growth/recovery are conducted over weeks, not days.

Sampling muscle tissue for protein

Fortunately, however, a chemical imaging technique called **radiolabelling** has enabled scientists to probe the uptake of ingested protein amino acids into muscle cells. In simple terms, one of the amino acid building blocks of protein is 'labelled' by removing a normal hydrogen atom from the molecule and replacing it with radioactive hydrogen. This means you can see what happens to this molecule using scanners when a subject consumes a protein drink or food containing it. If you take a

Fast and slow proteins

Research suggests that the key to stimulating maximal protein synthesis in exercised muscles is to raise the level of circulating blood amino acids as rapidly as possible after exercise – or, even better, beforehand. Whichever strategy is employed, it is clear that proteins that digest and release their amino acid building blocks rapidly are best suited to raising blood amino acid levels quickly.

There are four commonly used proteins in sports drinks; whey, casein, egg and soy. Of these, whey is digested most rapidly, taking only about two hours to release its amino acids. Soy and egg release their amino acids at a gentler rate – around five hours – while casein is a slow-releasing protein, taking up to seven hours to release its amino acids. All these figures are approximate, as there is a large degree of individual variability in digestion rates.

In many of the studies referred to in this article, pure free-form (unbonded) amino acids were used. No digestion is required to release these amino acids, which means they can cross from the gut into the bloodstream within minutes rather than hours. Free-form amino acids can be purchased and mixed with fruit juice to produce an extremely fast-releasing drink. There are two major drawbacks, however: firstly, gram for gram, pure amino acids are very expensive by comparison with ordinary protein; secondly, they tend to taste like old socks, making any drink potentially unpalatable!

sample of muscle tissue and detect the presence of radioactive hydrogen, you know that the body has incorporated the amino acid into muscle tissues – *ie* that protein synthesis has taken place.

One of the first findings to arise from using this technique was that the presence of amino acids in the bloodstream and their availability to muscle cells is vital for protein synthesis after exercise. In a study on six untrained men, American scientists infused them intravenously with a mixture of pure amino acids and studied the protein dynamics both at rest then for three hours after a leg resistance exercise routine [(5)]. They used an infusion rather than oral supplementation because they wanted to be certain that the muscles had an immediately increased supply of amino acids (*ie* without the time delay that digestion would introduce).

The amino acid infusion produced an increase in protein

'It may be that, for optimum recovery and growth, protein replenishment should begin even before exercise!'

synthesis even at rest. However, after the resistance training there was a further substantial increase in muscle protein synthesis of 30-100%! In other words, amino acid supplementation not only enhanced protein balance and synthesis at rest but also led to an interactive post-exercise effect, which resulted in around a two-fold increase in protein synthesis after exercise.

Although an infusion of amino acids before training is extremely effective at enhancing the body's ability to increase protein synthesis, it is not exactly practicable, so the obvious question to ask is whether amino acids taken orally after exercise can produce a similar effect?

A subsequent study was designed to answer this question [6]. A group of healthy subjects performed a leg resistance routine and were then randomly fed one of three drinks:

- Placebo (no amino acids);
- An essential amino acid drink;
- A mixed amino acid drink containing essential and non-essential amino acids (*see box 'fast and slow proteins'*).

After training, the subjects rested for 45 minutes then began ingesting 4-5oz of drink every 15 minutes. Analysis of the results clearly showed that, while protein balance was negative when the placebo drink was consumed (*ie* muscle protein was being broken down overall), it became strongly positive when the amino acid drinks were consumed, and the increase in protein synthesis was almost as great as after infusion. The researchers also found that protein synthesis was not enhanced by the addition of non-essential amino acids.

'So what?', I hear you ask. 'Surely everybody knows that protein is required after training?' Well they probably do, but there's a big difference between amino acids and protein; although amino acid solutions don't reach the muscles instantly, they are absorbed very rapidly by comparison with protein. That's because the process of digesting proteins (consisting of long chains of chemically linked amino acids) to release the constituent amino acid building blocks is quite time consuming

– even for rapidly digested proteins like whey. A post-workout high-protein drink or meal could take several hours to produce maximum amino acid concentrations around muscle cells, yet we know it is the presence and availability of high levels of amino acids that seems to stimulate growth, especially after exercise.

Other studies support the notion that exercised muscles need protein very rapidly. A 12-week study on elderly males on a progressive resistance exercise programme found that a post-training meal immediately after training produced bigger gains in muscle fibre thickness than when given two hours later (7). Some researchers have cautioned that this might be because the muscles of elderly people are 'less sensitive' to amino acids after exercise and that immediate post-exercise feeding of protein is of no benefit to younger people. However, another study throws doubt on this argument (8).

Scientists studied the effects of a fast-digesting protein (whey) and a slow-digesting protein (casein) in two groups of volunteers:

- Nine elderly subjects (average age 72);
- Six young subjects (average age 24).

Protein after exercise

They found that, irrespective of age, whey protein led to a faster rise in blood amino acids than casein, thereby producing a higher rate of muscle protein synthesis. While there was no exercise component in this study, these results mirror those of the infused amino acid study mentioned above (5), suggesting that consuming protein or amino acids as soon as possible after exercise is beneficial for muscle protein synthesis.

The conventional wisdom on recovery nutrition has tended to emphasise the importance of rapid carbohydrate replenishment, with little urgency about protein replenishment. However, the studies to date suggest that we neglect rapid protein replacement at our peril! In fact, it may be that, for optimum recovery and growth, protein replenishment should begin even *before* exercise!

This idea arose from a study on six healthy and active subjects

Using essential amino acids before training

If you've never used free-form amino acids before training but would like to try, there are basically two options:

- **Capsules.** These can be purchased over the counter at health stores. The problem is that often only single types of amino acids are available in capsule form, which means purchasing several different bottles then taking a capsule out of each to ensure you've consumed all the essential amino acids (*see box on page 5*). This will be expensive as well as inconvenient!
- **Powder.** A slightly cheaper and much more convenient option is to purchase a proprietary amino acid blend. These products generally come in a tub containing the premixed powder.

As far as dosage is concerned, there are no precise recommendations. However, for a full body workout, something in excess of the 6g used in the limited leg exercise studies described in this article would seem sensible – perhaps 10-15g. Free-form amino acids are best taken with fruit juice: this not only provides carbohydrate but also helps hide the unpleasant taste!

(three men and three women), who participated in two exercise trials in random order. In one trial, they performed an intense 45-minute resistance training routine for the legs, then immediately consumed an amino acid drink containing 6g of essential amino acids (including radiolabelled phenylalanine) and 35g of carbohydrate [9]. (The carbohydrate was added to generate an insulin response – something that is known to help drive amino acids into muscle cells[10].) Blood samples and muscle biopsies were then taken for two hours after training, and muscle protein synthesis measured. The other trial followed exactly the same protocol, but this time the amino acid/carbohydrate drink was consumed immediately *before* training.

The results were surprising to say the least. In the two hours post-training, almost twice as much phenylalanine was taken up by the leg muscles and incorporated into muscle protein when the protein/carbohydrate drink was consumed before rather than after training. Even more surprisingly, while muscle protein synthesis increased dramatically and then declined after an hour when the drink was consumed after training, the boost in muscle protein synthesis was sustained for longer when the drink was consumed before training.

The researchers went on to conclude that consumption of a relatively small amount of amino acids (combined with carbohydrate) immediately before exercise is a very potent stimulator of muscle protein synthesis.

In summary, there is good evidence for carbohydrate feeding as soon as possible after training; not only does it facilitate the short-term (GLUT4) mechanism of glycogen synthesis, but it also allows for additional glycogen replenishment before the next training session (more often than not the following day). If you're taking a break from training for a few days, however, immediate carbohydrate feeding may not be necessary.

More surprisingly, perhaps, the evidence also suggests that boosting blood levels of amino acids by consuming quick-releasing proteins (or free amino acids) as soon as possible after training is a good idea; indeed, if maximising muscle growth is your goal, it could be an even better idea to raise blood amino acid levels *before* training.

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Milk and muscle mass – what's the story?

At a Glance

- The main nutritional requirements of post-exercise recovery are identified;
- Recent research on the benefits of consuming milk as part of a post-exercise recovery strategy is presented;
- Practical advice is given on using milk-based drinks as an inexpensive alternative to proprietary recovery formulations is given.

The sports nutrition world is filled with high-tech protein formulations designed to make recovery as quick and as efficient as possible, but, according to Amanda Carlson, new research on milk suggests that it could be a cheaper and equally effective alternative.

The words milk and muscle seem to naturally go together. But does the consumption of milk after a training session really promote muscle growth? Can milk give us what we need to attain maximum performance day in and day out?

Recovery revisited

First, let's investigate the efficacy and importance of a recovery drink when paired with training. When we think about what an ideal recovery drink would look like or be made up of, we have to take a step back and think about what the body goes through during a workout.

After a workout your body is in a state of stress and it needs nourishment. More often than not, your body will be dehydrated, your blood **insulin** levels will be low, **cortisol** and other 'breakdown' hormones will be high, your **glycogen** (fuel stores) will be low or depleted, and your muscles will be in a

Recovery nutrition:
Putting the body back into balance (John Ivy PhD)

Post-exercise environment	Converting post-exercise environment from a catabolic state to an anabolic state
● Dehydrated ● Blood insulin is low ● Cortisol and other catabolic hormones are elevated ● Immune system suppressed ● Muscle and liver glycogen reduced or depleted ● Muscle is in a catabolic state with increased proteolysis	● Rehydrate ● Increase blood insulin levels ● Lower blood cortisol levels and other catabolic hormones ● Strengthen the immune system ● Restore muscle and liver glycogen ● Stimulate muscle protein synthesis and tissue repair

state of breakdown. Your recovery nutrition strategy, in simple terms, should reverse all those things and restore your body to a hydrated, fuelled, recovered, and muscle building state (see box above)(1).

The main components of recovery:

Refuelling muscles

When the science of sports started to come into its own, fuel (glycogen) restoration using carbohydrate was the name of the game. Studies have proven that taking in carbohydrate will indeed replenish fuel stores, and that the glycaemic index (GI) of these carbohydrates is important for enhancing glycogen recovery, with higher GI carbohydrates (carbohydrates that are broken down rapidly) producing more glycogen restoration in the post-workout period when compared with their low GI counter parts. In terms of how much carbohydrate is needed in the post-workout period, it is generally accepted that anywhere from 1.0-1.2g/kg body weight is ideal in the post workout period(2). This research leads to our first rule of recovery nutrition:

For optimal glycogen restoration recovery, use a high glycaemic index carbohydrate source (Ivy et al).

Rebuilding muscles

There's more to recovery than just refuelling muscles and scientists soon began to wonder how best to rebuild muscles and promote quick and efficient adaptations to training. The quest to find the perfect post-workout cocktail was now the hot research topic – which protein was best, how much was needed and could you just use amino acids? As an example, US scientists found that as little as 6g of essential amino acids combined with 35g of carbohydrate resulted in muscle building(3).

A study in 2004 at University of Texas looked at the effect of two other types of protein on muscle building(4). The point of this study was to compare the response of muscle protein synthesis after exercise to casein and whey proteins. Casein protein is digested and emptied from the stomach at a slower rate than whey protein; whey protein is therefore deemed the 'fast protein' and casein protein is considered to be its 'slow brother'.

The amino acids from slow protein such as casein appear in the blood more slowly, but the response lasts longer than with fast proteins. In this study the researchers consumed either 20g of casein, 20g of whey, or a placebo one hour after a resistance-training bout. They found that despite the different blood amino acid response, both proteins resulted in net protein balance – *ie* muscle gain.

In 2006, a study by US scientists from Baylor University examined the effects of whey protein supplementation on body composition, muscular strength, muscular endurance, and anaerobic capacity during 10 weeks of resistance training(5). Thirty-six resistance-trained males followed a four-days-per-week split body part resistance training programme for 10 weeks. Three groups of supplements were randomly assigned, prior to the beginning of the exercise programme, to all subjects:

1. 48g carbohydrate placebo;
2. 40g whey protein + 8g casein;
3. 40g of whey protein + 3g branched-chain amino acids + 5g of the amino acid L-glutamine.

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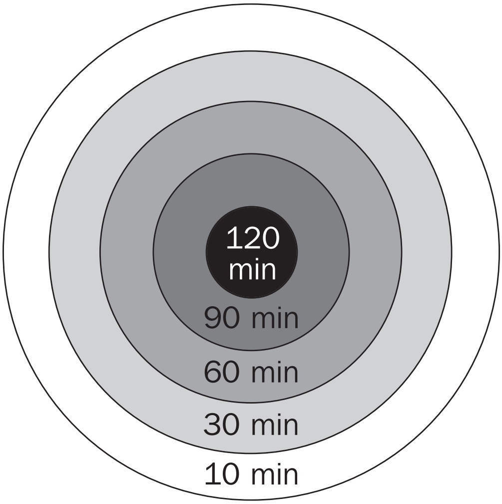
Insulin
A hormone whose presence informs cells that we are well fed, causing liver and muscle cells to take in glucose and store it in the form of glycogen

Cortisol
A catabolic hormone with physiological opposite effects to insulin. When cortisol is high, the body decreases the formation of glycogen and promotes the breakdown of glycogen, fats, and proteins

Glycogen
An insoluble, highly branched form of carbohydrate stored in muscles and liver

Figure 1: Bullseye countdown to optimal recovery

This bullseye picture represents how with every passing minute, your refuelling 'window of opportunity' becomes smaller and smaller. The largest window is in the first 30 minutes or so; after that the window gets smaller and smaller making recovery less efficient.



The whey/casein group experienced the greatest increases in lean mass. Significant increases in one rep-max (1RM) bench press and leg press were observed in all groups after 10 weeks. In this study, the combination of whey and casein protein promoted the greatest increases in fat-free mass after 10 weeks of heavy resistance training. Athletes, coaches, and nutritionists can use these findings to increase fat-free mass and to improve body composition during resistance training. From this, we can formulate our second rule of recovery nutrition:

For the most complete muscular adaptation, make sure to have a combination of whey and casein protein in your post-workout cocktail.

Timing and ratio

In 1988 John Ivy stirred up the world of sports nutrition with his ideas on muscle glycogen recovery and the importance of the timing of carbohydrate. The highest rates of muscle glycogen storage occur during the first hour after exercise due to activation of glycogen synthase (a glycogen building enzyme[6]. The activation of glycogen synthase is actually stimulated by the degree of glycogen depletion[7]. Exercise-induced increases in insulin sensitivity and the permeability of the muscle cell membrane to **glucose** also account for the physiological mechanisms behind post-workout carbohydrate timing[8].

Carbohydrate feeding immediately after exercise appears to take advantage of these effects, as shown by higher rates of glycogen storage during the first two hours of recovery, slowing thereafter to the more typical rates of storage. The most important finding of this study, however, is that failure to consume carbohydrate in the immediate phase of post-exercise recovery leads to very low rates of glycogen restoration until feeding occurs[6]. Therefore the intake of carbohydrate in the first two hours after exercise allows a somewhat faster rate of glycogen synthesis than normal. This is the period where you need to take in the recommended amount of carbohydrate, which ranges from approx. 1.0-1.5g per kilo of body weight. Athletes should ingest sufficient carbohydrate as soon after exercise as is practical to start recovery as soon as possible and maximise the time for glycogen synthesis[9] (*see figures 1 and 2*).

If less carbohydrate is consumed, the addition of protein to equal the caloric content of a supplement between 1.2 and 1.5g carbohydrate per kg of body weight can be ingested. It has been found that the isocaloric content of the combined protein and carbohydrate supplement promotes glycogen storage. The addition of protein to a carbohydrate supplement and its benefits to glycogen synthesis are not conclusive; you should therefore, make sure that carbohydrate is ingested at the level recommended above. However, a combination of carbohydrate and protein still promotes glycogen storage. The addition of protein additionally benefits muscle repair[10].

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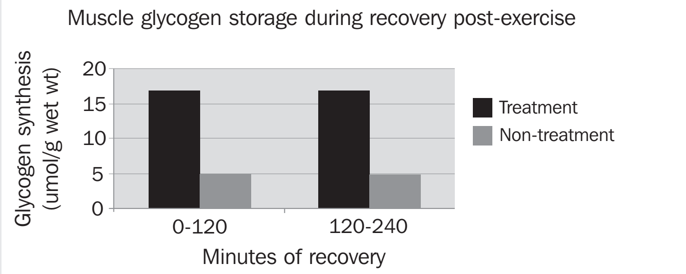
Glucose
A simple sugar that is an important carbohydrate because the cells uses it for their primary source of energy

Figure 2: Timing and glycogen synthesis

The treatment group received a carbohydrate drink and the non-treatment group received a placebo drink. The first group received their drink within two hours of training, while the second group received their treatment after two hours. The first group who received the carbohydrate recovered significantly more glycogen then the group who waited two hours for their post-workout recovery, indicating the importance of nutrient timing on recovery.



The best sources of carbohydrate and protein, as well as the ideal carbohydrate to protein ratio will always be hotly debated. However, the consensus of research suggests that the ideal recovery drink should be liquid and comprised of an easily digested carbohydrate and a whey/casein mixture of protein, with the carbohydrate to protein ratio reflecting your individual weight goals as well as training demands. This ratio should increase with the intensity of your training, leaving it to fall anywhere between 2-4g of carbohydrate for every 1g of protein. As it happens, these guidelines remarkably resemble the components of low-fat milk(1)!

Recovery drinks have long been associated with supplements and therefore much of the research has been focused on the optimal supplements to use after training. However, over the past few years, researchers have investigated the potential of good old-fashioned low-fat milk as a recovery drink. The results may seem surprising, but when looked at objectively they make sense.

Milk research

Several studies have compared the post-training (weight training) effects of milk, soy protein and carbohydrate alone. In each of these studies, the subjects given milk as a post-training recovery drink gained more lean muscle mass than their soy and/or carbohydrate counterparts[11-14].

In 2004, US scientists from Virginia Tech published one of the first studies comparing the effects of a milk and a carbohydrate electrolyte beverage consumed in the immediate post workout period[11]. In this study, 19 men consumed either a milk or carbohydrate electrolyte drink immediately following each workout, during a 10-week resistance training programme. The authors concluded that the milk group tended to increase muscle mass, but the magnitude of the gains weren't large enough to be considered statistically significant. They suggested that more prolonged training and supplementation period would expand the trend for greater muscle mass gains in a milk group.

In 2007, Canadian scientists evaluated the long-term consequences of milk or soy protein, or carbohydrate (as maltodextrin) on muscle mass gains after resistance training[12]. Subjects trained five days a week for 12 weeks and were given isocaloric beverages consisting of either fat-free milk, fat-free soy protein, or maltodextrin within an hour after their training sessions.

In the study, they found no differences in strength development between the groups. However, the researchers did determine that type II muscle fibre increased in all groups; moreover, it increased the most in the milk group. Muscle mass gains were also significantly greater in the milk group when compared with both the soy and control groups. They concluded that the consistent consumption of milk after resistance training can promote greater hypertrophy when combined with resistance training.

Endurance and hydration

The effects of milk have also been shown to aid recovery from endurance exercise. Scientists from Indiana University suggest

Table 1: Examples of milk-based recovery drinks

When choosing a recovery beverage, consider the intensity of workouts. The more intense, the greater the carbohydrate demands to replenish fuel. Low- to moderate-intensity training recovery can be achieved with a 2:1 carbohydrate to protein ratio. Higher-intensity sessions will need a carbohydrate to protein ratio of nearer 3 or 4:1.

For low-moderate-intensity training:	For moderate-high-intensity training:
16oz skim milk w/ 1tbs chocolate syrup: 223 calories 17g protein 36g carbohydrate 1g fat ~2:1 carb:Pro	**12oz Starbucks' chocolate milk:** 190 calories 13g protein 35g carbohydrate 1.5g fat ~3:1 carb:Pro
24oz skim milk w/ 1tbs chocolate syrup: 309 calories 25g protein 48g carbohydrate 1.3g fat ~2:1 carb: Pro	**16oz ready-to-drink non-fat Nestle's Nesquik:** 320 calories 16g protein 64g carbohydrate 0g fat 4:1 carb:Pro
24oz Skim milk w/ 2tbs golden syrup*: 360 calories 26g protein 60g carbohydrate 1g fat ~2.3:1 carb:Pro ** eg – Hershey's or Tate and Lyle*	**16oz skim milk w/ 3tbs golden syrup:** 323 calories 17g protein 60g carbohydrate 1g fat ~3.5:1 carb:Pro
	24oz skim milk w/ 3tbs golden syrup: 409 calories 25g protein 72g carbohydrate 1g fat ~3:1 carb:Pro

that chocolate milk is an effective recovery aid between two exhausting bouts of exercise[15].

In their study nine endurance-trained cyclists performed an interval workout followed by four hours of recovery and then another endurance trial to exhaustion. After the first exercise bout, subjects consumed a post-ride recovery beverage consisting of either chocolate milk or carbohydrate and electrolytes. Time to exhaustion and total work were significantly greater for the chocolate milk compared to the carbohydrate electrolyte group. This suggests that in addition to promoting a greater hypertrophy adaptation in a strength training group, a milk recovery drink can also improve performance on a subsequent endurance bout. For athletes performing multiple training sessions a day, the potential of milk enhancing not only recovery and performance is very real.

Another study worth mentioning looked at the effects of chocolate milk, a fluid replacement drink and a carbohydrate replacement drink on recovery between two exhaustive bouts of cycling. Chocolate milk proved to be an effective recovery option between rides. It allowed riders to cycle for a longer period of time on their second ride than with the use of the carbohydrate or fluid replacement options alone(15).

Research has also shown milk to be an effective rehydration drink. Subjects consuming milk (with added sodium) post-training actually remained hydrated longer than when they consumed sports drinks or water(16). These hydration findings are consistent with the improved fluid retention shown with protein enhanced sports drinks(17).

Conclusion

Based on this compelling research, low-fat milk is an effective post-training recovery drink. When used in conjunction with resistance training, it produces gains in muscle mass, aids in hydration and speeds recovery. To some, this is surprising news! How can something as simple as low-fat milk produce such results? The answer lies in the components of milk. They closely resemble the previously mentioned guidelines for an effective recovery drink. In fact the similarities are startling; milk is first and foremost a liquid, contains easily digested carbohydrate and a mixture of whey/casein protein. In addition, the carbohydrate to protein ratio of milk can easily be manipulated to meet your needs by adding something like syrup, a chocolate stir-in or a wholesome piece of fruit (*see table 1*).

Does this mean that specially engineered recovery supplements are useless? No! But it will allow younger athletes and those who are on a tight budget to effectively recover and make lean body mass gains without breaking the bank.

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Enduring strength – optimising protein intake and muscle mass for endurance

At a Glance

- The main nutritional requirements of post-exercise recovery are identified;
- Recent research on the benefits of consuming milk as part of a post-exercise recovery strategy is presented;
- Practical advice is given on using milk-based drinks as an inexpensive alternative to proprietary recovery formulations is given.

Endurance athletes face an interesting paradox when it comes to muscle mass. Bigger, stronger muscles generate more forceful contractions, resulting in higher power and greater speed. However, the weight of bulky muscles imposes greater demands on our limited energy stores, especially in weight-bearing sports. But as Professor Mike Saunders explains, maintaining adequate sport-specific muscle mass is critical for optimal performance in endurance athletes

Let's begin by clarifying why protein intake and optimum muscle mass is important for endurance athletes:

- *Higher peak power output* – Some endurance sports, such as marathon running, are performed at relatively constant, moderate intensities. As a result, peak power is of secondary importance in these events. However, shorter high-intensity bursts are often needed to power over hills, successfully execute breakaways and win sprints. If you have higher peak power, you will be more successful in these endeavours;

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Mesomorph
An individual with high muscularity; the opposite of an ectomorph

Ectomorph
A person with low levels of muscle mass. Endurance athletes, especially in weight-bearing sports, tend to be among the most ectomorphic competitive athletes.

Protein balance
The balance between protein synthesis (building new protein structures, such as muscle) and protein degradation (breakdown of protein structures in the body)

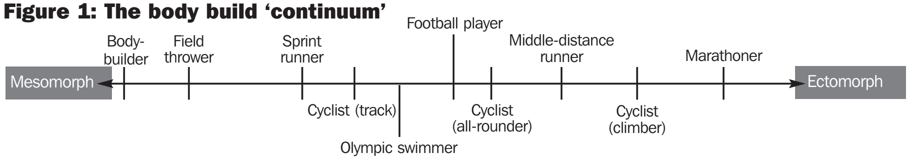
● *Lower relative muscular effort* – Every sport movement (*ie* a running stride at a certain speed) produces a given amount of force on your muscles. By increasing muscular strength, this same force becomes a lower percentage of your maximum effort, prolonging your muscular endurance. This effect is largest in individuals who are the weakest. For example, strength training alone, without any cardiovascular training, can increase the treadmill endurance of the elderly;
● *Reduced injury risk* – Stronger muscles are more capable of withstanding the potentially injury-producing forces that inevitably occur in sport. It is widely believed that increasing muscular strength can reduce the risk for sport-related injuries.

How much muscle does an endurance athlete need?

Scientists use the terms **mesomorph** and **ectomorph** to describe the extremes of muscularity in athletes. Pure mesomorphs, such as body builders, are heavy athletes with lots of muscle mass, while pure ectomorphs are light athletes with low levels of fat and muscle. Endurance athletes tend to be quite ectomorphic compared to other athletes. However, this should not be misinterpreted to assume that skinnier is always better!

The optimal amount of muscularity for an endurance athlete will depend on a variety of factors, including the length and intensity of the event, the mode of locomotion in the sport, and numerous other factors. In general, higher muscularity is more beneficial in events that are shorter in duration, events requiring high-intensity bursts of power, and in sports where body weight is supported, minimising the effects of gravity. Thus, we usually observe greater muscularity in swimmers,

Figure 1: The body build 'continuum'



sprint/track cyclists, and team-sport endurance athletes such as football players. By comparison, distance runners and 'climbing-specialist' cyclists tend to be among the most ectomorphic athletes (*see figure 1*).

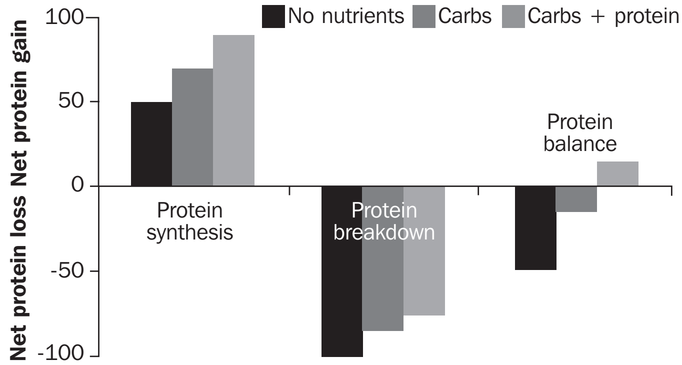
A good comparative example is provided in professional cycling, where time-trial specialists tend to have weight/height ratios of approximately 2.5lbs per inch of height (*ie* former Tour de France prologue winners Fabian Cancellara and Thor Hushovd have reported ratios of 2.4-2.5) while climbing specialists tend to be closer to about 2.0lbs per inch (the three top climbers in the 2007 Tour; Michael Rasmussen, Mauricio Soler, and Alberto Contador had ratios of approximately 1.9-2.0). The greater muscle mass of the time trialists allowed them to generate more power (and thus speed) than the lighter climbers during flat time trials, but their added muscle mass became a disadvantage in the mountains, where the forces of gravity encountered during long climbs slows the heavier riders.

In summary, muscle mass is critical for the performance of all endurance athletes, but its importance, and thus the amount of time you should devote to training to develop muscle mass is related to the specific demands of your event. However, even for the featherweight athlete, maintenance of adequate sport-specific muscle mass is crucial for performance. Adequate muscle mass allows you to generate higher power outputs, produce lower muscular efforts during sub-maximal workloads, and may enhance injury resistance.

Dietary strategies for building/maintaining muscle mass

● *Don't neglect the carbohydrates* – When you think about building muscle, protein is the ingredient that immediately comes to mind, and this nutrient will be the focus of much further discussion here. However, be careful not to neglect carbohydrate intake in your quest for adequate protein. Endurance sports create a very high demand for energy, and the process of muscle building also requires considerable energy. Our bodies use carbohydrate as their primary fuel

Figure 2: Protein turnover during/ following exercise



during most endurance activities, and it is known that inadequate consumption of dietary carbohydrate can lead to depletion of your valuable muscle glycogen stores.

The 'low-carb' diet craze of recent years may have some of you second-guessing your needs for dietary carbohydrates. In case you need another reason to consume your carbs, a study from researchers at the University of Birmingham (England) examined distance runners who were performing 11 days of intensified training on low (40%) and high (70%) carbohydrate diets[1]. When consuming the higher carbohydrate diet, the runners maintained much better endurance performance and fewer symptoms of overtraining, even though the calories were matched between the two diets. The bottom line: if you are performing intensive endurance training, don't skimp on the carbohydrates!

● *Importance of consuming protein* – Protein is in a constant state of turnover in the body, with protein synthesis (building of new protein structures, including muscle) occurring in tandem with protein degradation (the breakdown of body proteins). If your goal is to maintain your existing muscle mass, you must strive for a state of **protein balance**, where the daily losses of protein through degradation are offset by equal gains in protein synthesis. If muscle building is desired, you must sustain a period where protein synthesis outweighs protein breakdown. Scientists are beginning to study how protein intake can influence protein balance in endurance athletes. In addition, the roles of dietary protein on muscle damage, muscle glycogen replenishment and subsequent exercise performance have been recently studied.

Improved protein balance

Exercise stimulates protein synthesis but it also increases the rate of protein breakdown. Researchers at Maastricht University (The Netherlands) examined protein balance in endurance athletes during six hours of cycling/running[2]. When carbohydrate was consumed at 30-minute intervals throughout exercise, protein balance remained in a negative state throughout exercise and during four hours of post-exercise recovery. However, when a mix of carbohydrate and protein was consumed during the exercise, protein synthesis was increased and protein breakdown was decreased, resulting in a positive protein balance during and following exercise (*see figure 2*). This study suggests that even with adequate carbohydrate consumption, endurance training can create a **catabolic** state for the muscles if protein intake is not adequate. So, consuming some protein along with your carbohydrates during/following long endurance events can improve your protein balance.

Muscle damage

A number of recent studies from our laboratory at James Madison University (USA) have shown that consuming mixes of carbohydrate and protein during or following exercise can reduce markers of muscle damage and muscle soreness following heavy endurance exercise. These findings have been observed when carbohydrate-protein drinks were consumed following exhaustive bouts of cycling[3,4], as well as following the daily training sessions of cross-country runners[5].

Interestingly, we also observed an association between the

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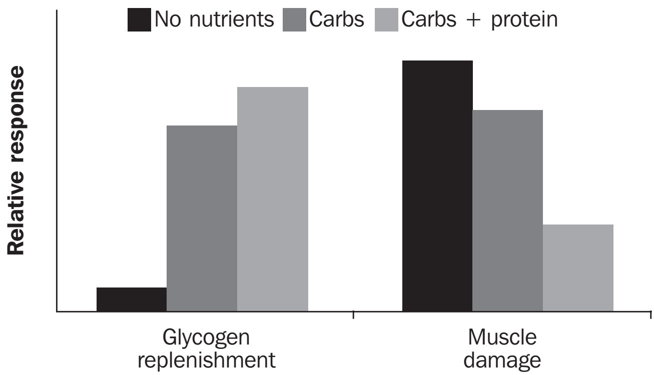
Protein balance
The balance between protein synthesis (building new protein structures, such as muscle) and protein degradation (breakdown of protein structures in the body)

Catabolic
Negative protein balance, where protein degradation is greater than protein synthesis

Figure 3: Post-exercise responses in muscle



mileage the runners were performing, and the amount of benefit they received from the protein. In other words, the harder you train, the more potential you create for muscle damage and the more important it is that you consume a mix of carbohydrate-protein immediately following training sessions.

Muscle glycogen replenishment

Investigators from the University of Texas have reported that consumption of carbohydrate-protein following exercise speeds the rate of muscle glycogen replenishment after exercise compared to carbs alone[6]. However, other researchers have suggested that these effects could also be obtained with frequently repeated doses of carbohydrate throughout recovery. While this may be possible, high-frequency carbohydrate dosing may be impractical, and could lead to high levels of calorie consumption, which may have implications for weight management and other dietary issues.

While scientists will continue to investigate this issue, it appears that when moderate doses of calories are consumed following exercise, a combination of carbohydrate and protein ingestion provides equal or superior rates of glycogen replenishment versus carbohydrates alone. When you consider the added benefits of improved protein balance and reductions in muscle damage, a post-exercise mix of carbohydrate and protein seems a desirable choice for athletes performing endurance training *(see figure 3)*.

Carbohydrate-protein and subsequent performance

A few studies have reported that carbohydrate-protein consumption during recovery from exercise can improve your performance in subsequent exercise[4,7,8]. Although other researchers have not reported benefits in subsequent performance with carbohydrate-protein ingestion[9,10], the variation in these findings may be related to differing effects of the initial exercise bout. For example, if the initial exercise session does not produce a significant amount of muscle damage or glycogen depletion, then it is unlikely that any supplement will improve subsequent performance because you can recover adequately without it.

This concept is supported by a previously mentioned study, in which we observed that high-mileage runners had greater potential for reduced muscle damage and improved performance in subsequent exercise than low-mileage runners[5]. In short, if you are training hard, consuming some carbohydrate-protein immediately following your exercise session could help your muscles recover faster, and allow you to perform better the next day. If you never train hard enough to really tax your muscles, then the potential recovery benefits are less significant, and will not likely influence performance in the short term.

Different protein types

Proteins are groupings of amino acids, and come in many forms. The roles and processes of these amino acids in the body are incredibly numerous and varied. Many nutritional products tout the benefits of **essential amino acids** (EAA). In particular, branched-chain amino acids (BCAA), a subgroup of EAAs, are commonly added to nutritional products and claim to build

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Essential amino acids
Amino acids that cannot be produced by the body, and thus must be obtained from the diet. Eight of the 20 amino acids are considered 'essential' amino acids for adults

Branched chain amino acids
A group of specific essential amino acids, including leucine, isoleucine, and valine

muscle and promote recovery.

Although some studies have shown that BCAA supplementation promotes various aspects of muscle recovery, there does not appear to be strong evidence that their recovery properties are superior to whole proteins, as long as your protein contains similar levels of BCAA. For example, it is likely that the benefits of BCAA supplementation could be attained via whole protein supplements (whey, casein, etc) and other foods (chicken breasts, peanuts, milk products, etc) containing adequate levels of BCAA. Thus, while BCAAs may have some positive muscle building and recovery effects, there does not currently appear to be a clear justification for the higher costs of these supplements for endurance athletes.

Creatine and HMB

Creatine is very widely used by athletes in strength and power sports, and is discussed in more detail elsewhere in this issue. Endurance athletes who need to build more muscle for optimal performance may consider the supplementation of creatine. However, you should be cautioned that at least one study has reported a decline in endurance performance with creatine supplementation, perhaps due to weight gains from water retention.

Thus, the decision to use creatine may depend on various characteristics of the athlete. For example, do you participate in a non-weight bearing sport like swimming or track cycling? Does your sport emphasise high-intensity bursts? Are you a vegetarian (making you more likely to have low creatine levels)? If these answers are yes, then creatine supplementation is more likely to be effective for you.

Another caution: although no research studies have reported detrimental health effects, the American College of Sports Medicine warns that there is no assurance that creatine supplementation is free from health risks, as anecdotal reports have suggested an association between creatine supplementation and various ailments ranging from muscle cramps to alterations in liver and kidney function[11].

HMB (beta-hydroxy-beta-methylbutyrate) is another supplement widely used by body builders due to claims of increased lean body mass and improved recovery. However, most evidence suggests that the potential improvements in lean body mass and strength with HMB are quite small, even in strength athletes receiving relatively high doses. Thus, it seems unlikely that most endurance athletes would receive noticeable benefits from the comparably small amounts of HMB that are in most commercially available recovery products.

It should be clear that carbohydrates and protein are important nutrients for endurance athletes, but how much should you eat, and when? While it is impossible to provide complete nutritional advice so briefly, perhaps the most important advice is to take advantage of your 'post-exercise recovery window'.

'increased lean body mass and improved recovery. However, Most evidence suggests that the potential improvements in lean body mass and strength with HMB are quite small, even in strength athletes receiving relatively high doses'

Window of opportunity

As discussed elsewhere in this report, your muscles act like a sponge for nutrients during exercise and immediately afterwards, bypassing insulin-dependent mechanisms for nutrient uptake and speeding the rate of glycogen replenishment and muscle recovery after exercise. This window of opportunity slowly closes over a period of a few hours after exercise. As a result, consuming a carbohydrate feeding a few hours after exercise is less effective for muscle recovery than consuming the same amount within 30 minutes.

Therefore, athletes who require rapid recovery from exercise should consume their carbohydrates immediately after their training sessions. As previously discussed, the addition of protein to this post-exercise feeding may produce further benefits, such as increased rates of glycogen replenishment, improved protein balance, and reduced muscle damage.

Specific guidelines regarding amounts of carbohydrate and protein are more difficult to provide, as the ideal dose is influenced by many factors. In laboratory studies[12], relatively large amounts of post-exercise carbohydrate and protein (1.2-1.4g carbohydrate and 0.3-0.5g protein per kg body weight) fed every two hours after heavy exercise have been shown to maximise muscle glycogen replenishment and augment muscle recovery.

However, before you begin consuming such large amounts of nutrients after each training session, remember that these values are typically obtained from studies examining recovery following exhaustive exercise. In general, the longer and harder you've exercised, and the shorter time period you have to recover, the more important it is to consume large doses of carbohydrate and protein. Conversely, these large doses are not necessary if you're performing shorter, easier workouts, or if a primary goal of the exercise session is weight management.

A simple approach to your nutrient timing is to move some of your daily caloric intake to the post-exercise timeframe. For example, if you are currently in energy balance (not gaining or losing weight), you could consume a 200-500kcal 'recovery' feeding immediately after your training sessions, and then reduce your dinner amount by the same number of calories. This should allow you the benefits of the post-exercise recovery window, without altering other important aspects of your diet and training.

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BCAAs: nutritional help or marketing hype?

At a Glance

- The rationale for taking BCAAs to enhance various aspects of sport performance is explained;
- The latest evidence for and against the use of BCAAs is examined, conclusions drawn and recommendations made.

The use of branched chain amino acid (BCAA) supplements from protein to enhance sport performance has grown into a multi-million dollar industry. But although there's a scientific rationale for some of the performance claims, the reality is far less clear-cut, as Kevin Tipton and Sarah Jackman explain here

Amino acids are nitrogen-containing compounds that comprise the building blocks of proteins. Our bodies synthesise chains of amino acids in various combinations to provide the unique structure and function of different proteins.

Amino acids can be classed as either 'essential' or 'non-essential'. Essential amino acids are those that must be consumed in the diet because the body can't synthesise them. Of the eight generally termed essential amino acids, the three 'branched chain amino acids' – isoleucine, leucine and valine – are often considered to be the most important, especially in relation to exercise.

Supplementation of BCAAs has been advocated for many purposes, including enhancing exercise performance and recovery. In this article, we'll look at evidence for and against these claims, based on objective research from peer-reviewed scientific publications. Our major focus will be on research conducted in humans.

Claim #1: *BCAA supplementation with resistance exercise increases muscle mass*

Increased muscle mass can benefit performance and comes from increasing the amount of the structural proteins in muscle, such as actin, myosin, troponin, *etc*, which are collectively known as the myofibrillar proteins.

The balance between synthesis and breakdown of these proteins over a given time period will determine changes in muscle size. Stimulating muscle protein synthesis, and thus resulting in a positive net muscle protein balance, is the metabolic mechanism for increased muscle size.

Resistance exercise increases muscle protein synthesis via stimulation of signalling pathways inside the muscle cells that have been contracted. However, without increased availability of amino acids – from ingestion of protein or amino acids in food or in supplements – positive protein balance will not occur. Increased amino acid intake is necessary for two reasons – to stimulate the signalling pathways and to provide building blocks for the new proteins being synthesised. Thus, for increased muscle mass, a source of amino acids should be consumed in conjunction with regular resistance exercise to stimulate muscle protein synthesis and net muscle protein balance.

‘Surprisingly, no study has ever measured muscle protein synthesis in humans in response to leucine (or BCAA) ingestion following resistance exercise!’

BCAAs, particularly leucine, stimulate the muscles’ signalling pathways. In rats that ran on a treadmill for two hours, muscle protein synthesis was decreased following the exercise[1]. Leucine ingestion stimulated the signalling pathways and increased protein synthesis such that it returned to pre-exercise levels. This study is often used as the argument for BCAA supplementation in terms of increasing muscle protein synthesis and thus muscle mass.

However, it is important to note that, unlike the situation in humans, muscle protein synthesis was decreased by the exercise in these rats. The leucine merely returned muscle protein synthesis in the rats to levels observed before the exercise. So while in this ‘**catabolic state** exercise model’ leucine seems to be very effective, it is not certain that the stimulation of the pathways by leucine would be additive to the stimulation of resistance exercise in humans.

Researchers in Sweden investigated the impact of BCAA ingestion following resistance exercise on the signalling pathways in muscle. They found that BCAA supplementation stimulated the signalling over that of exercise alone(2).Unfortunately, the response of subsequent muscle protein synthesis was not measured. In fact, rather surprisingly, no study has ever measured muscle protein synthesis in humans in response to leucine (or BCAA) ingestion following resistance exercise!

There is a good metabolic reason to believe that while the BCAAs could stimulate the signals in the muscle, this increased signalling would not result in increased synthesis because of decreased availability of other amino acids in the blood. Thus, protein synthesis would be limited(3).

Other researchers in Holland have demonstrated that the addition of protein to carbohydrate following resistance exercise increases muscle protein synthesis(4). However, addition of extra leucine to the carbohydrate-protein mixture did not result in a further increase. It is likely that muscle protein synthesis is already stimulated as much as possible by an exercise/protein combination and that leucine cannot stimulate it further. In other words, there is a 'ceiling' effect.

This ceiling notion is supported by unpublished data from a recent study conducted in Galveston, Texas. The addition of leucine to whey protein ingested prior to resistance exercise did not further increase muscle protein synthesis nor did it result in any difference in net muscle protein balance.

Ageing and inactivity are known to decrease signalling pathways in muscle and subsequent muscle protein synthesis when amino acids are given(5). Whereas muscle of young adults does not respond to excess leucine given in addition to other amino acids or protein, the muscle tissue in elderly persons does respond (6,7).

As with the rats we mentioned earlier, it seems that leucine supplementation may be effective when muscle is in a catabolic state (*for summary, see figure 1*). At this time more research needs to be conducted before we can definitively say that BCAA supplementation does not enhance muscle gains during resistance

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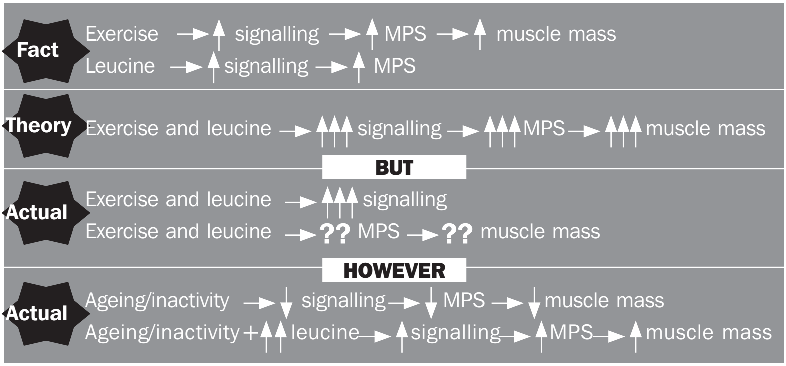
Catabolic state
Muscle protein synthesis is less than muscle protein breakdown resulting in loss of muscle proteins and muscle mass

In vitro
Literally 'in glass'. Refers to studies done outside the body, for example, in a test tube

Lymphocytes
White blood cells which are involved in fighting infections

Figure 1: Summary of what is known and what is speculated about the mechanism by which BCAA/leucine results in increased muscle protein synthesis and muscle mass in healthy, young adults and in the elderly and inactive; ↑ = increase; ↓ = decrease; MPS = muscle protein synthesis



training. On the other hand, there seems to be potential for BCAA supplements to be effective for injured athletes and others. Studies on this aspect of leucine supplementation need more attention from the scientific community.

Claim #2: *BCAAs enhance recovery from muscle damage as a result of intense exercise*

Intense exercise, particularly with an **eccentric** component, may result in damage to muscles, increased muscle soreness and loss of muscle function. It is commonly claimed that BCAAs may alleviate this response to intense exercise.

Two studies found reductions in soreness and blood markers of muscle damage with chronic[8] and acute[9] BCAA supplementation in conjunction with endurance cycling exercise. There is also a report of reduced soreness following squat exercise with ingestion of only 5g of BCAAs[10].

We recently completed a study in our laboratory at the University of Birmingham UK, and found reduced soreness with BCAA supplementation following an eccentric bout of exercise. However, it should be noted that the subjects in these studies are generally untrained. No study to date, including ours, has found BCAA supplementation to have any impact on loss of muscle function. Therefore, the importance of BCAA supplementation may be limited to decreasing muscle soreness in untrained individuals.

Most athletes experience only minimal soreness in their regular training. Furthermore, it is unknown if athletes would respond similarly to the untrained subjects used in those studies. BCAA supplementation may therefore be potentially beneficial when returning from a period of rest or injury, or when starting a new training programme, but only in regard to reduced soreness.

Claim #3: *BCAAs reduce central fatigue and enhance mental performance*

Fatigue during very prolonged exercise such as ultramarathons and Ironman distance triathlons may be centrally mediated, as well as or instead of peripherally mediated. In other words, fatigue is due to changes in the **central nervous system (CNS)** and not the muscles.

Of specific interest with regard to feelings of lethargy and fatigue during prolonged exercise is a connection with increases in brain levels of the brain **neurotransmitter** serotonin. This mechanism was proposed by a biochemist from London many years ago. We have illustrated the proposed mechanism for central fatigue and the potential impact of BCAA supplements in figure 2.

Briefly, serotonin is made from the amino acid tryptophan. Prolonged exercise leads to elevated levels of tryptophan in the blood; this in turn means more tryptophan transport into the brain, more serotonin production and thus – because serotonin causes lethargy and drowsiness – central fatigue.

The rationale for BCAA supplements has to do with competition for transport into the brain. Tryptophan enters the brain via the same transporter as other large amino acids, including the BCAAs. These amino acids compete for transport across the blood-brain barrier. Supplemental BCAAs increase

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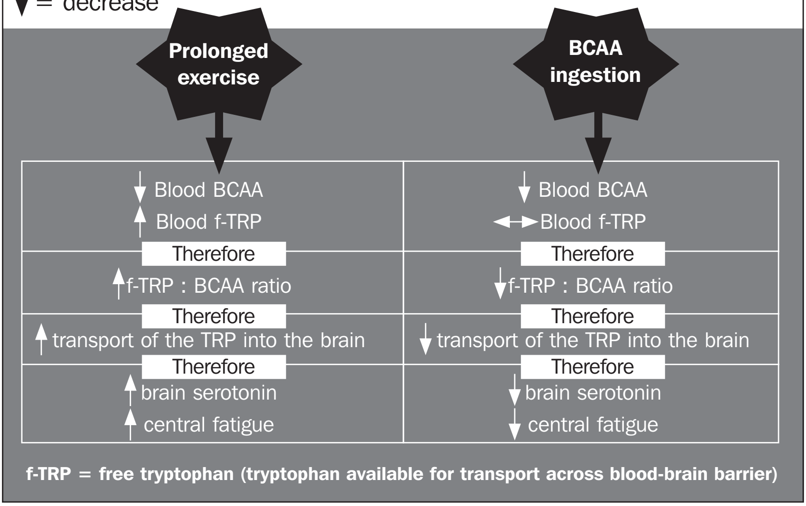
Eccentric
Muscle contraction involving the application of force while the muscle is lengthening. Often called 'negatives' in the gym

Central nervous system (CNS)
Part of the nervous system consisting of the brain and spinal chord

Neurotransmitter
A chemical substance in the body involved in communication between nerve cells

Figure 2: Summary of the Central Fatigue Hypothesis and the hypothesis by which BCAAs are proposed to counter central fatigue; ↑ = increase; ↓ = decrease



blood levels of BCAAs, which results in greater competition for this transporter. This in turn means less tryptophan gets transported into the brain, hence less serotonin is produced – so helping to stave off lethargy and fatigue.

Consistent support for this theory can be found in animal studies, but not studies involving humans. Support comes largely from one early field trial on BCAA supplementation during marathon running(11). However, the lack of control and questionable use of statistics makes it difficult to accept these findings.

Since then no study in humans at moderate temperatures has demonstrated an impact of BCAA supplementation on performance(12,13,14).Researchers in New Jersey reported that time to exhaustion during exercise in the heat was extended with supplementation of BCAAs(15), but subsequent studies failed to replicate this finding (16,17).

Similarly, mental performance can suffer during prolonged exercise. Improved mental performance from BCAA supplementation has been suggested with a rationale similar to that of central fatigue. Unfortunately, there are few studies examining the relationship between BCAA supplementation and improvements in mental performance. Some studies found that when BCAA ingestion was compared with a placebo, mental performance was improved[18,19,20]. However, follow-up studies failed to replicate these results[15,16]. At the moment therefore, no definitive conclusions can be drawn in relation to BCAA supplementation for improved CNS function during prolonged exercise.

Claim #4: *BCAAs spare glycogen during exercise*

It has long been recognised that muscle glycogen levels are critical for athletic performance, particularly in moderate- to high-intensity events. Glycogen is the main source of fuel for the muscles during exercise and low levels contribute to fatigue. Therefore if BCAAs can be used in preference to glycogen at early stages of exercise, glycogen can be spared and used later. Thus exercise performance may be enhanced.

Claims related to BCAA ingestion and glycogen sparing are primarily based on animal studies[21,22]. All information related to this issue has come from studies which were designed for other purposes. There is an indication that BCAAs reduce glycogen use during exercise from a couple of studies performed in Sweden[23,24,25]. However, the changes are small and unlikely to be physiologically relevant. Others have clearly demonstrated no glycogen sparing during exercise with BCAAs ingestion[26,27]. We conclude that, at least for now, there is no evidence to suggest that if BCAA supplements are taken they will help to spare glycogen.

Claim #5: *BCAAs improve immune function*

Intense exercise training can result in **immunosuppression** and athletes often report increased illness during intense training. **In vitro** evidence suggests that BCAA supplementation may help prevent immunosuppression. Immune cells oxidise BCAAs for energy and BCAA supplementation increases

Table 1: Claims related to BCAA supplementation and the conclusions based on scientific evidence

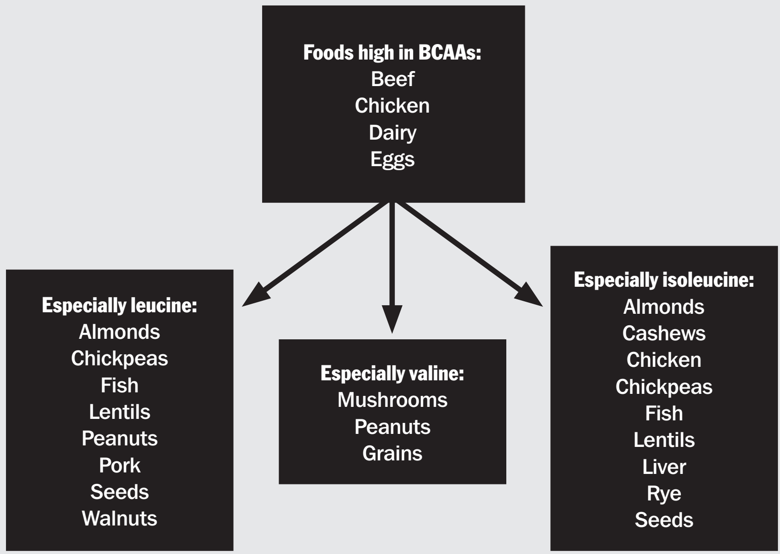
Claim	Conclusion
Improve muscle mass	Insufficient evidence
Reduce central fatigue	Insufficient evidence
Reduce peripheral fatigue	Insufficient evidence
Improve mental performance in exercise	Insufficient evidence
Help reduce muscle breakdown during exercise	Promising rationale but limited evidence
Increase protein synthesis following exercise	Promising rationale but limited evidence
Improve immune function	Promising rationale but limited evidence
Decrease muscle soreness following intense exercise in untrained individuals	Consistent evidence
Decrease loss of muscle function following intense exercise	Insufficient evidence
Decrease myofibre protein in the blood following intense exercise	Insufficient evidence
Enhance weight loss (maintain lean mass and lose fat mass)	Promising rationale but limited evidence
Increase growth hormone release	Insufficient evidence

blood levels of the amino acid glutamine(28,29). In response to heavy training, glutamine levels fall, which is believed to be related to immunosuppression.

In humans there are only two papers investigating the effect of BCAA ingestion and the immune system in exercise. Both were field-based trials using triathletes and runners(28,29). The data suggest that BCAA supplementation maintains blood glutamine levels, increases **lymphocyte** (immune cells) function and decreases reported incidence of illness in these athletes with 15-30 days of supplementation.

Whereas these data seem to strongly support the use of BCAAs with prolonged, intense training caution is warranted; these studies were field-based from only a single laboratory and it is difficult to adequately control field-based trials. More stringently controlled studies are needed to follow up these intriguing findings, and the jury is out until more studies from other laboratories confirm these findings.

Figure 3: Food items with relatively high BCAA content



Claim #6: *BCAAs help with weight loss*

Many athletes are very concerned with body composition. If dieting is used to lose fat, both fat and muscle will be lost. For many athletes, loss of muscle is undesirable. So, if energy intake can be reduced, but muscle mass maintained, then a more desirable body composition may be attained.

There is now ample evidence that increasing the protein content of the food during low-calorie dieting will maintain muscle while weight is lost(30).The rationale for maintenance of muscle during weight loss with high protein intakes is often attributed to the increased intakes of BCAAs that occur(30). The idea is that BCAA ingestion during weight loss increases protein synthesis, which helps maintain muscle.

Studies in rats have shown a decrease in body fat with chronic leucine supplementation(31). However in lean, active humans there seems to be only one study addressing this issue at this time. French researchers measured body composition in wrestlers during 19 days of low energy intake(32).The group with high BCAA intake seemed to lose the most fat but all groups lost equal amounts of muscle. So, these results are not exactly in line with the theory.

Summary

There are many, many claims for the effectiveness of BCAA supplements related to athletic performance and exercise training; but while some have a solid theoretical rationale, most of these claims are dubious at best. Even where claims have a promising rationale, the actual evidence from well-controlled studies in humans is limited (*see table 1 for a summary*).

To complicate the situation further, most studies demonstrating a beneficial role of supplemental BCAAs used untrained individuals; the implications of these findings to athletes are therefore currently unknown. Moreover, BCAAs can be found in a number of foods in relatively high amounts (*see figure 3*), and so supplements may not be necessary.

For all these reasons, more studies are needed to determine the effectiveness of BCAA supplements for sportsmen and women and thus caution is warranted before accepting the vast majority of the claims on websites, advertisements and labels!

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Rapid recovery – why you can't afford to ignore protein!

At a Glance

- The benefits of post-exercise protein supplementation using milk and sports-specific drinks are discussed;
- New findings on the use of protein during exercise are presented and recommendations given.

As we seen earlier in this special report, the timing of protein intake is important as it plays a vital role in recovery from exercise. And now some very recent research not only confirms this fact, but also suggests that the right kind of protein taken at the right time can actually enhance performance. Andrew Hamilton explains

Low-fat milk and muscle gains

Elsewhere in this issue, Amanda Carlson has looked recent research on the virtues of milk as a post-exercise recovery drink to maximise muscle mass gains. Until recently, the consensus has been that drinks containing rapidly digesting proteins are superior to those with slower digesting proteins as they provide a more rapid delivery of amino acids to 'hungry' muscles.

However, although the major protein in milk (casein) is a relatively slow digesting protein, new Canadian research has compared the effects of post-exercise milk and soy protein drinks on muscle accretion and come up with some surprising results(1). In the study, 56 young healthy men trained five days per week for 12 weeks on a rotating split-body resistance exercise program. The subjects were randomly assigned to consume one of three drinks immediately and again one hour after exercise:

- Fat-free milk (18 subjects);
- Fat-free soy protein (19 subjects);
- Maltodextrin (carbohydrate – no protein) (19 subjects – control group).

The drinks were carefully matched so that each contained the same number of calories and also so the two protein drinks contained the same total protein and macronutrient content. Before and after the study, the subjects' muscle fibre size, maximal strength and body composition (determined by dual energy X-ray absorptiometry (DXA)) were measured. DXA was used to specifically determine fat and bone-free muscle mass (*ie* lean muscle mass).

After the 12-week training period, there were no differences in strength between the three groups; however, (as might be expected) the increase in cross-sectional area of type 2 muscle fibres (fast twitch) was greater in the milk and soy groups, but there was a significantly greater increase in the milk group than in both the soy and control groups.

A similar pattern was also observed with the type 1 (endurance) muscle fibre cross-sectional area. Moreover, DXA measurements showed that while lean muscle mass increased in all groups, the milk group showed a greater increase than both the soy and control groups. The researchers concluded that post-exercise consumption of fat-free milk promotes greater muscle-growth in the early stages of resistance training than soy or carbohydrate consumption.

These results are perhaps surprising because milk proteins are known to digest less rapidly than soy proteins. Although small amounts of whey protein (quick digesting) are present in milk, these results may indicate that fat-free milk can provide some as yet undetermined additional nutritional advantage.

Protein, recovery and performance gains

More muscle tissue is one thing but can protein-enhanced recovery actually produce improved performance? Some very recent research by Australian scientists indicates that it can[2].

The researchers set out to discover whether whey protein hydrolysate (fragments of protein produced by the partial chemical breakdown of whole whey protein) can speed muscle tissue repair following exercise-induced damage from eccentric exercise, and therefore accelerate recovery from exercise.

In the study, 28 sedentary males had muscle soreness, markers of muscle damage and peak force production capacity assessed at baseline and then after 100 maximal eccentric contractions of their knee extensors muscles (quadriceps). Eccentric contractions involve lengthening the muscle under load and are were used because they readily produce muscle damage and soreness. The subjects then consumed 250mls of either:

- Flavoured water (control condition);
- Flavoured water containing 25g of whole whey protein
- Flavoured water containing 25g of whey protein hydrosylate (*ie* partially broken down whole whey protein).

The assessments above were then repeated 1, 2, 6 and 24 hours later.

The researchers discovered that the levels of subsequent muscle soreness recorded were the same for all three groups the average peak force. Intriguingly however, although the peak force capacity was decreased by around 23% for all groups after the eccentric exercise, in the whey protein hydrosylate group, it recovered fully within six hours post-exercise whereas it remain depressed in the control and whole whey groups.

The researchers concluded that *'whey protein hydrosylate may be a useful supplement for assisting athletes to recover from fatiguing eccentric exercise'*. The obvious implication here is that the advantage conferred by the whey hydrosylate was due to its extremely rapid uptake into the muscles; the process of hydrosylation (where it is broken down into very fragments) means that the amino acids from the whey can be transported out of the gut, into the blood and then into muscle cells extremely rapidly!

'More muscle tissue is one thing but can protein-enhanced recovery actually produce improved performance? Some very recent research by Australian scientists indicates that it can'

More evidence for performance gains

The study above using untrained subjects is encouraging, but can trained athletes expect to obtain similar benefits from protein supplementation? Moreover, are these benefits any greater than those that could be expected with a normal high-carbohydrate recovery regime?

To answer this question scientists from New Zealand examined the effect of post-exercise dietary protein content imposed over a high-carbohydrate background on subsequent performance in highly trained cyclists and come up with some intriguing results[3].

Twelve cyclists completed three high-intensity rides over four days as follows:

- Day 1 comprising of a 2.5-hour high-intensity ride;
- Days 2 and 4, comprising of repeated sprint performance tests, 15 hours and 60 hours after the initial session respectively;
- Day 3 as a rest day.

'A delayed performance benefit (at 60 hours) was observed following protein-enriched high-carbohydrate diet'

During a 4-hour recovery on days 1 and 2, the cyclists ingested one of two diets:

- **Protein-enriched** – 1.4 grams per kilo per hour of carbohydrate, 0.7 grams per kilo per hour of protein and 0.26 grams per kilo per hour of fat;
- **Control** – 2.1 grams per kilo per hour of carbohydrate, 0.1 grams per kilo per hour of protein and equal fat.

At all other times, the cyclists ingested a standardised high-carbohydrate diet.

A number of assessments were made during the study including muscle growth/breakdown (by measuring nitrogen balance), the degree of muscle stress and inflammation (by measuring cortisol and cytokines), skeletal-muscle membrane disruption (by creatine kinase), and muscle damage from oxidative stress (by measuring malonyldealdehyde).

The results showed that although mean sprint power was not clearly different on day 2, on day 4 it was 4.1% higher in the protein-enriched condition relative to control. Moreover, overnight nitrogen balance was positive in the protein-enriched condition on day 1 (indicating muscle growth) but negative in the control condition. The effects on oxidative stress, inflammatory markers, and cortisol were considered inconclusive or trivial.

The researchers concluded that a delayed performance benefit (at 60 hours) was observed following protein-enriched high-carbohydrate diet and that athletes involved in several consecutive bouts of hard exercise over a period of a few days could benefit from an increased protein intake.

Protein during exercise

The traditional and proven approach to sports nutrition supplementation is to supply carbohydrate to maximise endurance performance during exercise, and both carbohydrate and protein during the post-exercise recovery period to maximise recovery. But while studies above provide solid evidence that protein supplementation following exercise can lead to real and tangible gains in performance, very recent research now suggests that protein supplementation *during* exercise can produce real performance gains.

For example, Brazilian scientists have been studying the effects of protein supplementation in the form of peptide glutamine on soccer performance4. In the study, scientists from the University of São Paulo compared the performance of nine trained soccer players who drank either a pure carbohydrate drink (maltodextrin) or a combined carbohydrate/peptide glutamine drink. Peptide glutamine is produced by the partial chemical breakdown of wheat protein, which is naturally rich in glutamine, containing around 30g of glutamine per 100g. The turnover of glutamine during and after exercise is very high, which explains the popularity of glutamine supplements among some athletes. A claimed advantage of peptide glutamine is that it is more stable and absorbable than pure L-glutamine and also supplies other important amino acids.

The soccer players underwent an exercise test and then followed an exercise protocol that simulated the movements of a soccer game in order to evaluate their tolerance to intermittent

'Drinking a protein/ carbohydrate beverage during resistance training exercise enhanced muscle synthesis, even when subjects have been consuming regular meals during the day before training'

exercise. The players consumed either carbohydrate with peptide glutamine (50g of maltodextrin + 3.5g of peptide glutamine in 250ml of water) or carbohydrate alone (50g of maltodextrin in 250ml of water). The drinks were consumed 30 minutes before beginning each of two tests, which were performed with a 1-week interval between, and the subsequent performance measured.

The results showed that compared to the carbohydrate-only drink, the combined carbohydrate/peptide glutamine drink produced a significant increase in exercise tolerance; the total distance covered was 12,750m when taking the carbohydrate-only drink and 15,571m when using the carbohydrate/peptide glutamine drink. Moreover, the total duration of exercise tolerance was 73 minutes and 88 minutes for the two drinks respectively. The researchers also noted that the carbohydrate/ peptide glutamine drink also reduced feelings of self-reported fatigue in the players compared with the use of the carbohydrate-only drink. However, it should be noted that the carbohydrate/peptide glutamine drink contained approximately 7% more calories than the pure carbohydrate drink, but these results were nevertheless striking and at the time of writing, more research in this area is currently underway.

More research

More research demonstrating the benefits of protein consumption during exercise has also come from a study by Dutch scientists who studied the effects of combining a protein hydrosylate/carbohydrate drink during exercise on strength gains in men who were undergoing resistance training5. Importantly, this research indicated that drinking a protein/ carbohydrate beverage during resistance training exercise enhanced muscle synthesis, even when subjects have been consuming regular meals during the day before training.

Ten healthy males participated in two experiments, in which they ingested either carbohydrate-only or carbohydrate with a protein hydrolysate (a pre-digested form of protein) during a two-hour resistance-training session, after consuming a standardised diet throughout the day.

The results showed that compared to a carbohydrate-only drink, consuming a protein/carbohydrate drink lowered whole-body protein breakdown rates by 26% and raised protein synthesis by 33%. As a consequence, whole-body net protein balance was negative when consuming a carbohydrate-only drink, whereas a positive net balance was achieved in the protein/carbohydrate trial.

The researchers were keen to emphasise the implications of this study; namely that even when subjects had eaten normally through the day, taking a protein/carbohydrate drink significantly boosted muscle protein synthesis. If these results are confirmed by other studies, the use of protein/carbohydrate drinks during sprint/power/strength training sessions could be a valuable tool for athletes seeking to gain or maintain muscle mass.

Summary and practical advice

Once upon a time, carbohydrate supplementation during and after exercise was considered all that was needed to address the nutritional needs of the athlete. However, over time, there's been a growing realisation that protein supplementation immediately following exercise can enhance recovery and even boost subsequent performance.

The evidence presented here indicates that protein (when taken combined with carbohydrate) taken immediately post-exercise not only helps recovery but also appears to enhance subsequent performance and should therefore be considered as an essential part of any nutritional strategy. Moreover, new research indicates that protein replacement during exercise may result in additional performance benefits; athletes may therefore wish to consider using carbohydrate drinks with added protein.

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Notes