BODY FUEL

food for sport

A SPECIAL REPORT FROM

PEAK PERFORMANCE

The research newsletter on stamina, strength and fitness

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A CIP catalogue record for this book is available from the British Library.

Printed by: Baskerville Press Ltd
6-8 Newton Road, Salisbury, Wiltshire SP2 7QB

Published by Peak Performance Publishing

Peak Performance Publishing is a trading name of Electric Word plc
Registered office: 67-71 Goswell Road, London, EC1V 7EP
Tel: 0845 450 6402
Registered number: 3934419

ISBN: 1-905096-14-3

Publisher Jonathan A. Pye
Editor Isabel Walker
Designer The Flying Fish Studios Ltd

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From the editor

An engine, however finely tuned and carefully maintained, will only ever be as good as the fuel it is given to run on. And so we make no apology for producing a second special report on nutrition, although the first of these focused mostly on the benefits of supplementation, whereas this one concentrates more on what can be achieved by means of dietary manipulation.

PP's expert team of regular writers on nutrition start by examining aspects of the three major nutrients: protein (quality as well as quantity), carbohydrate (absolutely pivotal to successful sport performance) and fat (quite unjustifiably demonised by nutritionists and health professionals).

Next minerals – and a searching re-examination of the role of magnesium (crucial for energy production) and calcium (a new aid to weight maintenance?) in the athletic diet.

Then a first-person account of the trials of being a football team nutritionist (was he wise to drop fish-and-chips from the post-match menu?) and new thoughts on the so-called 'post-exercise window of opportunity for muscle recovery' (maybe it's not so important after all).

Finally our 'What the scientists say' section, with brief reports on carbo-loading for women (not as easy as for men), carbs and perceived exertion (supplementation doesn't make running feel easier) and post-exercise supercompensation (sadly it doesn't work after repeated bouts).

We hope you enjoy reading this special report and find it helpful in putting together the best diet plan for your particular sport.

Isabel Walker
Editor

How much protein do athletes need – and how safe are high-protein diets?

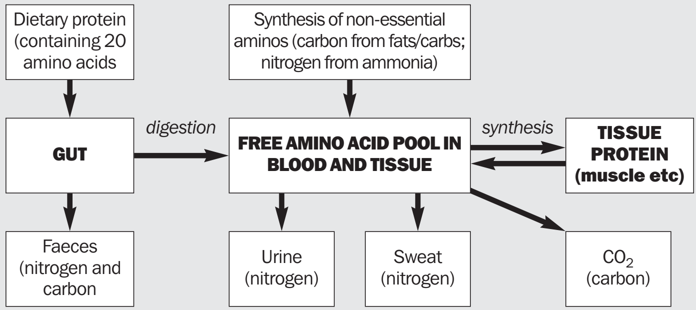
Protein is not just an essential nutrient, but the largest component in the body after water, typically representing about 15% of body weight. Most of this protein mass is found in skeletal muscle, which explains the importance of protein to athletes. However, proteins also play an important role in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

Figure 1: overview of protein metabolism



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. 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 controlled 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.

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

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.

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?

Until recently the protein requirements of athletes were thought to be 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, research over the past decade 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 3-4 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].

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, especially 'if you're trying to build muscle'. It goes on to advise: 'Try not to eat more protein than you need because your body won't use it to build muscle. Instead it converts excess protein to fat, which is then stored, so try to make sure your protein intake is just right for your needs.' However, it never actually states what those needs are!

'Protein insufficiency may be a problem for certain athletes, including runners, cyclists, swimmers, triathletes, gymnasts, skaters and wrestlers'

Meanwhile, the EU's Scientific Committee on Food recently 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].

Forty 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.

Fierce debate about high-protein diets

However, the recent meteoric rise in popularity of high-protein diets, such as Zone and Atkins, for slimmers has 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 recent meta-review of the literature, Finnish scientists searched for any evidence supporting the hypothesis that high protein diets, containing 2-3 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.

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 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.

‘It seems likely that high-protein diets have something to offer athletes seeking a reduction in body fat while conserving muscle tissue’

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 2-

‘Athletes can rest assured that high-protein diets containing up to thre times the current RDA for protein are perfectly safe’

3 times the RDA (0.8-1.0g per kg per day) yet with a sufficiently high protein content to exert an increased satiation effect.

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 for nitrogen balance, unless this extra protein is consumed as a protein/ carbohydrate drink before, during or after training – something we'll tackle in the next article starting on page 21. 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

References

1. *J Appl Physiol 1992;73(2):767-75*
2. *J Appl Physiol 1988;64(1):187-93*
3. *J Appl Physiol 1992;73(5):1986-95*
4. *Curr Opin Clin Nutr Metab Care 1999;2(6):533-7*
5. *Sportscience 1999. Available: www.sportsci.org/jour/9901/rbk.html;3(1)*
6. *Butterfield G (1991). Amino acids and high protein diets. In Lamb D, Williams M (editors), Perspectives in exercise science and sports medicine, vol 4; Ergogenics, enhancement of performance in exercise and sport (pages 87-122). Indianapolis, Indiana: Brown & Benchmark*
7. *EU Scientific Committee on Food, 2004, Working Document – 20 April. Available: www.food.gov.uk/multimedia/pdfs/foodsportworkdoc.pdf*
8. *Sports Nutrition Review Journal 2004; 1(1):1-44*
9. *Circulation 2001; 104:1869-74*
10. *Sports Nutrition Review Journal 2004; 1(1):45-51*
11. *Presentation by WF Martin at Experimental Biology meeting, April 2002 New Orleans, USA*
12. *Am J Clin Nutr 1996; 63, 174-178*
13. *Diabet. Care 2002; 25, 652-657*
14. *N Engl. J. Med 2003; 348, 2074-2081*
15. *Eur J Clin Nutr 1996; 50, 418-430*
16. *Int J Obes Relat Metab Disord. 1999; 23, 528-536*
17. *Int J Obes Relat Metab Disord. 1999; 23(11), 1202-6*

Optimum nutrition: it's about much more than simply eating the right amount

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.

The role of carbohydrate in enhancing endurance during long events and accelerating post- exercise recovery is undisputed, and recent research 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.

Post-exercise protein feeding

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 just a few months ago, 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 minutes 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 very recent 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 consensus of scientific opinion is that athletes should ingest a carbohydrate and protein mix after intense exercise’

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.

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].

‘Ingesting fast-releasing proteins mid- or post-exercise may be more important for older athletes’

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 recent study, examining 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 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.

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.

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].

These findings suggest that BCAA supplementation may have some impact on body composition. Moreover, some recent 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]. More research is needed, therefore, before firm conclusions can be drawn.

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 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.

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

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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? Recent 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 recent 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.

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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. 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.

'Essential amino acids have to be obtained from the diet because they can't be synthesised in the body'

In recent 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 (essential and non-essential) 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'.

A comprehensive protein strategy

Given the above findings, what reasonable steps can an athlete take to optimise his or her protein nutrition? They would be well advised to follow the advice in this checklist:
- 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.

Andrew Hamilton

References

1. *J Appl Physiol, 2003; 548P, 98*
2. *J Appl Physiol, 2003; 94:1917-25*
3. *J Appl Physiol, 1994; 76:839-45*
4. *Eur J Appl Physiol Occup Physiol, 1992; 63:210-5*
5. *Am J Physiol Endocrinol Metab 2004; 287:E712-E720*
6. *Sports Med 1999; 27(2):97-110*
7. *J Appl Physiol 1992; 72(5):1854-9*
8. *J Appl Physiol 1997; 83(6):1877-83*
9. *J Appl Physiol 1998; 85(4):1544-55*
10. *Eur J Appl Physiol Occup Physiol 1992; 64(3):272-7*
11. *Eur J Appl Physiol Occup Physiol 1991; 63(3-4):210-5*
12. *Med Sci Sports Exerc, 2004; 7:1233-8*

13. Proc Natl Acad Sci USA, 1997; 94:14930-35

14. J Nutr 2003, 133:1308-1315

15. Am J Physiol Endocrinol Metab, 2001; 280:E340-348

16. J Physiol 2003, 549.2:635-644

17. Eur J Appl Physiol Occup Physiol, 1992; 65(5):394-8

18. Minerva Endocrinol 1995; 20(4):217-23

19. J Sports Med Phys Fitness 2000; 40(3):240-6

20. Acta Physiol Scand 1997; 159(1):41-9

21. Nutrition 1994; 10(5):405-10

22. Metabolism 1992; 41(6):643-8

23. Am J Physiol 1992; 263:E928-E934

24. Nutr Rev 1987; 45:289-298

25. Sports Med 1990; 9, 23-35

26. Med Sci Sports Exerc 2000; 32(12):2109-15

27. Med Sci Sports Exerc 2000; 32(12):2116-9

28. J Appl Physiol 1996; 81(5):2095-104

29. Nutrition 2000; 16(9):734-9

30. Sports Med 2000; 30(2):105-16

31. Nutr 2000; 130(8):1937-45

32. J Nutr 2001; 131(7):2049-52

33. J Appl Physiol 2000; 89: 1340-1344

34. Int J Sports Med 1999;20(8):503-9

35. Int J Sport Nutr Exerc Metab 2001;11(3):384-96

36. Strength Cond Res 2003;17(1): 34-9

37. Am J Physiol Endocrinol Metab 2003;284(1): E76-89.

38. J Nutr 2002;132(10):3219S-24S

39. J Appl Physiol 2000; 88:386-392

40. Am J Physiol Endocrinol Metab 1999; 276:E628-E634

Forget fancy supplements – carbs are even more important than you'd thought, for strength as well as endurance

The role of carbohydrate in sports performance might be one of the most thoroughly researched topics in the field of sports nutrition, but that doesn't stop it constantly throwing up new surprises! Read any biochemistry textbook on carbohydrate nutrition and you will find no mention of variation in carbohydrate metabolism between different groups of people. But now new research indicates that both gender and age can affect the way our bodies utilise this vital fuel.

And just in case you have any lingering doubts about the crucial contribution of carbohydrate to optimum performance, scientists have also been busy investigating the link between low carb intakes and exercise-induced free radical damage, leading to impaired muscle function.

According to evolutionary theory, one of the reasons the average female carries more fat than the average male is because of her role in child rearing. More fat stores and a more efficient fat metabolism add up to an enhanced ability to survive a period of famine – crucial for the survival of any infant, born or unborn. This difference in fat metabolism is thought to underlie the observation that females are able to oxidise proportionately more fat and less carbohydrate during long periods of endurance exercise, when normal fuel reserves run low, and also why women perform proportionately better at ultra-distance events than their male counterparts.

‘Ingested carbohydrate may be a particularly beneficial source of fuel during endurance exercise for females’

Until recently, these gender differences in carbohydrate metabolism have been thought to be minimal. But recent research seems to throw this assumption into doubt[1]. In this study, 14 healthy but untrained volunteers were split into two equal groups of men and women. Each group completed two exercise trials in which they pedalled on a stationary bike for 90 minutes at 60% of VO_2max.

In the first exercise trial, both groups were given a sweetened placebo drink to consume during the session. In the second, carried out a week later, they were given an 8% carbohydrate drink, supplying carbohydrate at a rate of 1 gram per kg of body weight per hour. This drink contained radio-labelled glucose which, when metabolised for energy, breaks down to form radio-labelled carbon dioxide and water, both of which can be distinguished from ordinary carbon dioxide and water (the breakdown products from fat metabolism and any stored carbohydrate). The more carbohydrate used from the drink to supply energy, the higher the ratio of labelled expired carbon dioxide and water to the unlabelled variety.

During the placebo drink trial, fat oxidation (‘burning’ to produce energy) was higher in females than in males when measured at 30 minutes of exercise. But, when averaged out over the final 60 minutes of exercise, the relative contributions of fat, total carbohydrate and protein to energy were similar for both groups.

However, clear differences emerged during the carbohydrate drink trial. At 75 and 90 minutes, both the ratio of labelled-to-unlabelled carbon dioxide and the proportion of energy derived from the carbohydrate relative to lean body mass were higher in the women than the men. Moreover, when averaged over the final 60 minutes of exercise, the contribution of ingested carbohydrate to the total energy used tended to be higher in the female group – 14.3% compared with 11.2% for the males.

This finding is rather surprising because it is counter-intuitive; in other words, one might expect that women, being more efficient at burning fat than men, might derive less energy from ingested carbohydrates during exercise.

Nevertheless, the researchers concluded that: ‘compared to males, females may oxidise a greater relative proportion of ingested carbohydrate during endurance exercise which, in turn, may spare more endogenous fuel [ie fat]. Based on these observations, ingested carbohydrate may be a particularly beneficial source of fuel during endurance exercise for females’.

This study was small and there was no suggestion that the two groups were matched for aerobic fitness/training levels (remember that high aerobic fitness levels and training volumes increase the efficiency of fat metabolism). This means that further studies are required before firm conclusions can be drawn. However, the notion that carbohydrate replenishment for female endurance athletes may be less important than for men because of their inherent advantage with fat metabolism is certainly going to need revising!

Age effect on carbohydrate usage

In a related study, researchers set out to see what effect age might have on carbohydrate usage during exercise[2]. This time, 12 boys aged just under 10 on average were compared with 10 adult men (average age 22.1 years). As in the previous study, both groups completed two exercise trials on a stationary bike, consuming a placebo drink with the first and a radio-labelled carbohydrate drink with the second. However, this time the trials lasted only 60 minutes and were performed at 70% VO_2max, while the carb drink was of 6% concentration, given at the rate of 24ml per kg of body weight over the hour (just over a litre for a 50kg subject).

In both exercise trials, the researchers measured the rate of ingested radio-labelled carbohydrate utilisation over the final 30 minutes and compared it with that of other fuels (primarily fats and stored carbohydrates).

In both trials, total fat oxidation was higher and the total ingested carbohydrate oxidation lower in the boys than in the men. But in the carbohydrate drink trial, the rate of carbohydrate oxidation was increased and made a relatively greater contribution to total energy in the boys – 21.8% compared with 14.6% for men.

These results suggest that, although stored carbohydrate utilisation during exercise is lower, the relative oxidation of ingested carbohydrate is considerably higher in boys than in men. The researchers concluded that the greater reliance on ingested carbohydrate in boys may be an important mechanism in preserving stored fuels and may also be related to pubertal status.

To put it another way, there may be biochemical/ physiological mechanisms operating in children that are designed to conserve stored glycogen and body fat. If you consider these results in relation to those of the male-female study, it begins to look like a carbohydrate-rich diet may be more important for young female athletes than has previously been realised.

Free radical damage and carbs

High-carbohydrate diets are associated with reduced secretion of the immune-suppressing stress hormones cortisol and the catecholamines, and it is known that the latter can undergo a biochemical transformation in the body known as 'auto-oxidation', forming highly reactive oxygen species (ROS), more commonly known as 'free radicals'.

The obvious question, therefore, is whether the ingestion of carbohydrate during intense exercise can diminish the production of ROS, thereby reducing oxidative stress.

In a bid to answer this question, researchers at the University of Montana studied 16 experienced marathon runners, who ran on treadmills for three hours at approximately 70% VO_2max on two separate occasions under the following conditions[3]:

- with a carbohydrate beverage taken throughout the run;
- with an identical-tasting placebo beverage containing no carbohydrate.

Blood samples were taken before and after training and analysed for isoprostanes and lipid hydroperoxides (both markers of free radical damage within the body), levels of the stress hormone cortisol and the so-called 'ferric reducing ability of plasma' (FRAP), which is basically a measure of the body's ability to neutralise free radicals.

As expected, the pattern of change in cortisol levels was significantly different between trial conditions, with higher post-exercise levels recorded after the placebo trial. The researchers then went on to examine the markers of free radical damage and demand on the antioxidant defence systems of the body.

Although these markers were increased after both exercise trials, there was no significant difference between trial conditions. In other words, the excess stress hormone secreted in the placebo condition did not lead to a significant increase in oxidative stress.

'There may be mechanisms operating in children that are designed to conserve stored glycogen and body fat'

We cannot conclude from this that stress hormones do not aggravate oxidative stress. The effect may be small, for example, and submerged in the overall increase in oxidative stress induced by the exercise alone. Also, these results were obtained at a training intensity of 70% VO_2max and it is not possible to extrapolate these results to other intensities. It may be a cliché, but more research will be needed before we can draw definite conclusions!

Central nervous fatigue and carbs

Every athlete knows that ingesting carbohydrates during prolonged exercise can improve endurance, while an insufficiency of carbs reduces glucose availability to the muscles which, in turn, leads to hypoglycaemia and fatigue.

Fatigue, normally defined as a loss of force-generating capacity, may set in for a variety of reasons, but in long bouts of endurance exercise it is generally believed to occur principally as a result of reduced availability of muscular adenosine triphosphate (ATP), the high-energy molecule that fuels muscle contraction and is generated by the oxidation of glucose. However, some exercise physiologists have questioned whether this is the whole story, arguing that the central nervous system (CNS) may also play a role in fatigue.

The CNS is responsible for sending the electrical signals required to 'fire' muscle fibres, thereby releasing the stored energy of ATP to produce muscular contraction. However, the CNS itself also requires carbohydrate, in the form of glucose, to function, and the key question is whether the reduced levels of blood glucose typically present after long bouts of exercise can impair the efficiency of the CNS, thereby reducing the firing ability of the muscles, regardless of ATP levels.

To resolve this question, a study was recently carried out to examine the degree of CNS activation before and after three-hour cycling sessions performed with and without supplemental carbohydrate [4].

Eight endurance-trained male cyclists were randomised to one of two groups, one given a carbohydrate beverage to take throughout the bike ride and the other a no-carb placebo.

Before the trial, all the cyclists completed a two-minute sustained maximal knee extension session during which voluntary force production and central nervous activation ratios were assessed by means of a technique known as 'twitch interpolation', which measures the efficiency of the CNS in sending electrical impulses to the muscle fibres.

'Latest research continues to emphasise the absolutely pivotal role of carbohydrate nutrition in sports performance'

Blood glucose concentrations were monitored in both groups. In the placebo trial, these fell from 4.5mM (moles) per litre before the ride to around 3.0mM per litre afterwards. By contrast, blood glucose concentrations were maintained in the carbohydrate trial.

After the ride, both groups were reassessed for knee extension force and CNS activation. Before the ride, the average force during sustained maximal voluntary muscle contraction was 248 newtons (N). This force fell to an average of 222N in the carbohydrate group and 197N in the placebo trial group.

However, this result could not simply be attributed to reduced muscle stores of glycogen (and therefore reduced ATP availability) because in the placebo group the lowered force production was accompanied by a significantly reduced level of CNS activation, which remained stable in the carbohydrate group.

The researchers concluded that exercise-induced hypoglycaemia can reduce CNS activation during sustained muscle contractions, but that this effect can be mitigated by ingestion of a suitable carbohydrate drink.

This latest research continues to emphasise the absolutely pivotal role of carbohydrate nutrition in sports performance. Forget fancy supplements: the most useful performance-enhancing change any athlete can make to his or her dietary regime is to ensure a plentiful carbohydrate intake, before, during and after exercise!

This may be particularly critical for young and female athletes, because it appears that their bodies may be 'preferentially programmed' to conserve stored body fat and carbohydrate by comparison with other groups.

The work on CNS activation also has implications for power and strength athletes, who have traditionally been less assiduous in maintaining optimum carbohydrate intakes.

The fact that reduced blood glucose appears to reduce CNS activation, thereby reducing the peak power of sustained muscle contractions, means that these athletes, too, neglect carbohydrate nutrition at their peril!

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References

1. Int J Sport Nutr Exerc Metab, 13(4): 407-21, 2003

2. J Appl Physiol, 94(1): 278-84, 2003

3. Free Radic Res, 37(8): 835-40, 2003

4. Med Sci Sports Exerc, 35(4): 589-94, 2003

High-fat diets and endurance performance: is it time for a rethink?

The F word! The very mention of fat can send athletes and non-athletes alike running for cover. As a food, fat has gained a bad reputation and become something to be eliminated from our diet as completely as possible. Athletes tend to avoid fat because they believe it will lead to an increase in body fat levels, which they see as having an adverse effect on performance. But is this really the case? Or could it be that fat is actually an important ally to athletes in some events.

Fat derives much of its bad press from the concerted efforts of nutritionists and health professionals to reduce the nation's intake to within what constitutes healthy limits. These concerns are justified to some extent since high-fat diets have a well-established association with cardiovascular disease – especially in combination with inactive lifestyles.

However, the general demonisation of fat is quite unjustified since, as any nutritionist will tell you, fat has a valuable place in a well-balanced diet.

Apart from its role as an energy source, fat has other important functions in the body. Indeed, the famous Omega 3 and Omega 6 fatty acids, found in oily fish like tuna and mackerel, are essential to human health. Some fats also act as carriers of micronutrients, particularly vitamin E.

The key dietary recommendation on fat is that it should constitute 35% of total energy intake, although 25% is a healthier target. This works out at around 70 grams a day for women and 95g for men. Recommendations on carbohydrate intake range from 60-70% for athletes to 50% for the general population, while protein should make up around 15% of total energy for both groups [1].

Before considering the pros and cons of high-fat diets, it is useful to remind ourselves of the contribution fat makes to athletic performance. In well-nourished individuals, carbohydrates and fats are the two main sources of energy, with protein making only a minor contribution. The actual percentage contribution each of these makes to energy production is dictated, for the most part, by two main factors:

1. *Intensity of activity.* As we move from sitting to standing to walking to running, the contribution fat makes to energy production is gradually reduced. This is because the physiological pathways involved in obtaining energy from fat use more oxygen than can be supplied by the body during higher intensity exercise. When oxygen supply is limited, the body has to rely more on carbohydrate to fuel its exercising muscles;
2. *Training status.* To put it simply, the higher your fitness level the greater the percentage fat used for any given activity. This is because the physiological adaptations that go with endurance training – including increased blood supply to muscles and a rise in the number of oxidative enzymes – all tend to enhance fat usage during exercise.

'The higher your fitness level the greater the percentage fat used for any given activity'

For the endurance athlete, this last factor can open up a number of advantages, since the ability to use fat for energy clearly enhances endurance capacity. Convention tells us that carbohydrate levels are among the main determining factors in athletic performance. However, endurance athletes will tell you that one of the major problems they face, particularly in longer events, is a fall-off in performance associated with the depletion of carbohydrate reserves. A greater utilisation of fat during exercise has the effect of sparing important carbohydrate stores in the muscles and liver for later use [2].

If we think about the tactical aspects of distance races like the marathon, where runners don't get down to the serious business of racing until past the halfway point, using more fat during the early stages, and so saving energy for the business end of the race, seems to make perfect sense.

This physiological adaptation has led to the development of a number of training and nutritional strategies aimed at increasing fat utilisation during exercise, including use of high-fat, low-carbohydrate diets.

Research on diet, training and performance has tended to focus on the role of carbohydrates. But the known glycogen-sparing effects of high-fat diets have led some sports scientists to investigate the possibility that boosting the fat content of an athlete's diet could in someway boost endurance performance. Has this possibility been borne out? And what, if any, are the health risks for athletes attempting to follow a high-fat diet?

Most research in this area has focused on two types of dietary intervention: short-term diets, lasting less than seven days, and those lasting longer. The fat content of the diets studied has accounted for anything up to 90% of energy intake. The table below summarises some of the most recent findings on the effects of high-fat diets. Although it includes only a small number of studies, a recent overview reinforces the general trend, with short-term diets having either no effect or a negative effect on endurance performance and only long-term diets tending to show positive results [3].

Each of the trials summarised in the table attempted to manipulate the ratio of fat to carbohydrate used as fuel during low-to-moderate intensity exercise. If we focus in on two of these trials in more detail, we should be able to get a feel for the methods used to test the effectiveness of high-fat diets.

Table 1: Impact of short- and long-term high-fat diets on performance

Duration	Fat %	CHO%	Exercise	+/- difference
7 days [4]	34	50	70-75% VO_2max	none
14 days [5]	64	15	70% VO_2max	positive
6 days [6]	69	16	65% VO_2max	positive
1 day [7]	85	5	55-85% peak power	negative

The third investigation listed in the table looked at the effects of short-term high-fat diets on elite ultra-endurance triathletes [6]. For the six days the trial lasted, the athletes were asked to follow diets made up of 2.5g carbohydrate, 4.6g fat and 2.2g of protein per kg of body weight per day. Then the ratio of fat-to-carbohydrate usage was measured during a 20-minute bout of cycling at 65% of VO_2max. Analysis of the results revealed that fat made the highest contribution to energy production.

The first investigation listed in the table also looked at the potential for high-fat diets to alter substrate utilisation [4]. In this seven-day study, 34% of energy intake was derived from fat and 50% from carbohydrate, with measurements of usage taken while subjects ran for 40 minutes on a treadmill at 70%-75% of VO_2max. However, in this trial the researchers were unable to detect any changes to fuel usage during exercise.

Longer-term diets have produced positive results

In terms of impact on endurance performance, it is not really surprising that short-term dietary manipulation has shown high-carbohydrate diets to be superior to high-fat versions. After all it is the amount of carbohydrate stored in muscles that is the key determinant.

‘High-fat diets are not only of uncertain efficacy but could also have adverse effects on health in the long term’

What is interesting, however, is the fact that longer-term dietary intervention with high-fat diets has produced some positive results.

What seems to happen during the longer trials is an enhancement of the normal endurance adaptation to energy pathways which can increase the use of fat as fuel at low-to-moderate exercise intensities, so boosting endurance capacity.

Now for a reality check: can these positive results be transferred from the laboratory to the track, road or trail? In my view the answer is almost certainly ‘no’, for the following reasons.

- While there is overwhelming evidence to suggest that high-carbohydrate diets have a positive impact on performance, high-fat trials have produced inconsistent results.
- For optimal training and performance, athletes need to be able to work at high intensities. Fat doesn’t allow them to do

this because the metabolic processes that break down fat for energy require large amounts of oxygen, which the body is unable to supply during high-intensity exercise.
- Carbohydrate, by contrast, can supply energy without oxygen.

As a nutritionist, my recommendation is that athletes should stick to high-carbohydrate diets during training and competition. While fat has an important place in a well-balanced diet, high-fat diets are not only of uncertain efficacy but could also have adverse effects on health in the long term.

Ian Carlton

References

1. *Dietary Reference Values for Food Energy and Nutrients for the United Kingdom, pp1-40, 1991*
2. *International Journal of Sports Nutrition and Exercise Metabolism, vol 5, ppS1-S12, 1995*
3. *International Journal of Sports Medicine, vol 19, pp371-379, 1998*
4. *International Journal of Sports nutrition and Exercise Metabolism, vol 12, pp480-489, 2002*
5. *International Journal of Sports nutrition and Exercise Metabolism, vol 11, pp209-225, 2001*
6. *International Journal of Sports nutrition and Exercise Metabolism, vol 11, pp273-286,2001*
7. *International Journal of Sports nutrition and Exercise Metabolism, vol 12, pp318-335, 2002*

Why magnesium matters to athletes

Ask most athletes to name some key minerals for human performance nutrition and you'll probably find calcium, iron, zinc and even chromium popping up in their lists. But they are unlikely to mention magnesium. Despite this mineral's pivotal role in energy production, many coaches and athletes remain unaware of its critical importance in maintaining health and performance. Indeed, dietary intakes of magnesium in the West have declined to less than half of those recorded 100 years ago, and are still falling.

Yet many scientists believe that the amount of magnesium required for optimum health has been underestimated in the past, and recent research suggests that even small shortfalls in magnesium intake can seriously impair athletic performance. Clearly, magnesium nutrition is an area that no serious athlete can afford to overlook!

Pure magnesium is a silvery-white metal, which burns with a dazzling brilliance – something you've probably seen demonstrated by your science teacher at school! It is the second most abundant mineral in cells after potassium, but the two ounces-or-so found in the typical human body is present not as metal but as magnesium ions (positively-charged magnesium atoms found either in solution or bound to other tissues, such as bone).

Roughly one quarter of this magnesium is found in muscle tissue and three-fifths in bone; but less than 1% of it is found in blood serum, although that is used as the commonest indicator of magnesium status. This blood serum magnesium can be further subdivided into free ionic, complex-bound and protein-bound portions, but it is the ionic portion that's considered most important in measuring magnesium status, because it is physiologically active.

Magnesium is well supplied in unrefined whole grain cereals, such as wholemeal bread, and also in green leafy vegetables, nuts and seeds, peas, beans and lentils *(see table opposite)*. Fruit, meat and fish supply poor levels, as do refined foods. Contrary to common belief, milk and dairy products are not particularly rich sources of magnesium

The magnesium content of plant foods tends to reflect soil magnesium concentrations and growing conditions, especially as magnesium is not routinely added to soils by farmers during intensive fertilization [1].

Magnesium is a fairly soluble mineral, which is why boiling vegetables can result in significant losses; in cereals and grains, it tends to be concentrated in the germ and bran, which explains why white refined grains contain relatively little magnesium by comparison with their unrefined counterparts.

‘Contrary to common belief, dairy products are not particularly rich sources of magnesium’

Magnesium plays a number of roles in the body, being required for more than 325 enzymatic reactions, including those involved in the synthesis of fat, protein and nucleic acids, neurological activity, muscular contraction and relaxation, cardiac activity and bone metabolism.

Even more important is magnesium’s pivotal role in both anaerobic and aerobic energy production, particularly in the metabolism of adenosine triphosphate (ATP), the ‘energy currency’ of the body. The synthesis of ATP requires magnesium-dependent enzymes called ‘ATPases’. These enzymes have to work extremely hard: the average human can store no more than about 3oz of ATP, yet during strenuous exercise the rate of turnover of ATP is phenomenal, with as much as 15kg of ATP per hour being broken down and reformed (from adenosine diphosphate and phosphate)!

In normal adults, a magnesium deficiency results in altered cardiovascular function, including electrocardiographic abnormalities [2,3], impaired carbohydrate metabolism, with insulin resistance and decreased insulin secretion [2,4], and high blood pressure [5].

Table 1: the magnesium content of common foods

Food	Magnesium content (milligrams per 100g)
Pumpkin seeds (roasted)	532
Almonds	300
Brazil nuts	225
Sesame seeds	200
Peanuts (roasted, salted)	183
Walnuts	158
Rice (whole grain brown)	110
Wholemeal bread	85
Spinach	80
Cooked beans	40
Broccoli	30
Banana	29
Potato (baked)	25
White bread	20
Yoghurt (plain, low fat)	17
Milk	10
Rice (white)	6
Cornflakes (‘Frosties’ or ‘Honeynut’)	6
Apple	4
Honey	0.6

Source; USDA Nutrient Database

Disease states that have been associated with magnesium imbalances and deficiencies include coronary heart disease, neuromuscular disorders, kidney diseases, asthma[6], migraines, premenstrual syndrome, pre-eclampsia and eclampsia (both potentially serious complications of pregnancy), menopausal bone problems[3] and even obesity!

The UK recommended intake for magnesium (the daily amount deemed adequate to prevent deficiencies in 97.5% of the UK population) is set at 300mg for men and 270mg for women[7]. The US has recently revised its figures upwards and now recommends an intake of 400mg per day for men aged 19-30 and 420 for those over 30; the figures for women under and over 30 are 300 and 310mg per day respectively[8]. However, some investigators believe these should be set even higher at 450-500mg/day[9].

Dietary intakes of magnesium in the United States have been declining over the last 100 years from about 500mg/day to 175–225mg/day [10] and a recent national survey suggested that the average magnesium intake for women is as low as 228mg per day [11]. But since this figure is derived from a one-day diet recall method, it may represent an overestimate of actual magnesium intakes [12]. Meanwhile, the UK's Food Standards Agency estimates that the average daily intake of magnesium in Britain for both men and women is just 227mg – only two thirds of the US recommended daily amount (RDA).

Many people go short of magnesium

These figures suggest that many people fall short of optimum magnesium intakes, a supposition which has been confirmed by a number of studies. For example, American researchers found that more than 60% of US adults were failing to meet even the previous (lower) RDA for magnesium [13]. Even athletes, who might be expected to take greater care with their diets, are not immune from magnesium deficiency; for example, studies carried out in 1986/87 revealed that gymnasts, footballers and basketball players were consuming only around 70% of the RDA [14], while female runners fared even worse, with reported intakes as low as 59% of the RDA [15].

Given magnesium's vital role in energy production, two key questions emerge:

1. Can these all-too-common sub-optimum dietary magnesium intakes impair athletic performance?
2. Could extra magnesium intake, over and above RDA levels, enhance performance?

While there is plenty of evidence that oral magnesium therapy improves cardiac function and exercise tolerance in coronary heart disease patients [16, 17], until recently, there has been little hard evidence about the effects of sub-optimum magnesium intakes in healthy exercising adults.

However, in a very tightly controlled three-month US study carried out in 2002, the effects of magnesium depletion on exercise performance in 10 women were observed – and the results make fascinating reading [18]. In the first month, the women received a magnesium-deficient diet (112mg per day), which was supplemented with 200mg per day of magnesium to bring the total magnesium content up to the RDA of 310mg per day. In the second month, the supplement was withdrawn to make the diet magnesium-deficient, but in the third month it was reintroduced to replenish magnesium levels.

At the end of each month, the women were asked to cycle at increasing intensities until they reached 80% of their maximum heart rate, at which time a large number of measurements were taken, including blood tests, ECG and respiratory gas analysis. The researchers found that, for a given workload, peak oxygen uptake, total and cumulative net oxygen utilisation and heart rate all increased significantly during the period of magnesium restriction, with the amount of the increase directly related to the extent of magnesium depletion. In plain English, a magnesium deficiency reduced metabolic efficiency, increasing the oxygen consumption and heart rate required to perform work – exactly what an athlete doesn't want!

‘Magnesium deficiency reduces metabolic efficiency – exactly what an athlete doesn't want!’

The researchers concluded: ‘This report provides the first evidence that low dietary magnesium, in amounts consumed by some groups of physically active individuals, impairs function during exercise.’ The mechanisms behind this effect are unclear, but it seems likely that a magnesium shortfall can cause a partial uncoupling of the respiratory chain, increasing the amount of oxygen required to maintain ATP production. There is also evidence that a magnesium shortfall boosts the energy cost, and hence oxygen use, of exercise because it reduces the efficiency during exercise of muscle relaxation, which accounts for an important fraction of total energy needs during an activity like cycling [19].

While many studies on magnesium supplementation and exercise have been carried out, the results have been inconsistent and may indicate that there is nothing to be gained by supplementing an already magnesium-sufficient diet.

One study of male athletes supplemented with 390mg of magnesium per day for 25 days resulted in an increased peak oxygen uptake and total work output during work capacity tests [20]; in another, on sub-maximal work, supplemental magnesium elicited reductions in heart rate, ventilation, oxygen uptake and carbon dioxide production [21]; in a third, physically active students, supplemented with 8mg of magnesium per kg of body weight per day, experienced significant increases in endurance performance and decreased oxygen consumption during standardised, sub-maximal exercise [22].

However, other studies carried out on physically active people with 'normal' serum magnesium and muscle magnesium concentrations have found no functional or performance improvements associated with supplementation [23, 24].

On the evidence available so far, the scientific consensus is that extra magnesium can enhance performance when (as is all too often the case) magnesium intakes fall below optimum levels. But in subjects already consuming magnesium at or above this optimum level, there is little hard evidence to suggest that taking more confers extra benefits.

Testing for magnesium status

Given the growing body of evidence pointing to the need for optimum magnesium nutrition in athletes, what tests are available to coaches for determining magnesium status? Muscle magnesium (obtained through a needle biopsy) is one of the most accurate methods of assessment, but it is time-consuming, very invasive and can cause discomfort. Magnesium status can also be measured by means of a 'magnesium load' test, followed up with measurement of urinary excretion. However research suggests that urinary magnesium is too variable to accurately evaluate magnesium status [6].

Total blood magnesium (TMg) is the most widely used assay, but this has the disadvantage of including complex and protein-bound magnesium, whereas it is the ionic portion that is physiologically active. This test is also insensitive to the movements of magnesium that occur within the body as a result of exercise.

However, the recent introduction of ion-selective electrode (ISE) technology now enables scientists to measure ionic magnesium directly, and this is considered one of the best methods. But even then it's not all plain-sailing, since ionic magnesium levels tend to fluctuate significantly according to the time of day, with higher values recorded in the morning and lower values in the evening. This 'circadian magnesium rhythm' is believed to be linked to changes in physical activity levels through the day, but the whole subject of 'intra-body' magnesium fluctuations remains poorly understood. Nevertheless, the best results seem to be obtained when ionic magnesium is sampled from fasting, non-exercised subjects first thing in the morning[25].

So what's the take-home message for athletes? First, it's all too easy to go short of magnesium, especially if your diet is light on foods like whole grains and cereals, green leafy vegetables, pulses (peas/beans/lentils), nuts and seeds. To make matters worse, excessive sugar intake, alcohol consumption and diets high in fats, protein and calcium have all been shown to impair magnesium absorption and/or increase excretion. And even when the quality of food is good and the diet carefully balanced, diets containing fewer than 2,000 calories per day often struggle to meet magnesium needs, placing those on weight loss or maintenance régimes at added risk.

'Diets containing fewer than 2,000 calories per day often struggle to meet magnesium needs'

The box overleaf summarises the kinds of dietary habits that can lead to low magnesium intakes and also some of the sub-clinical symptoms that can be signs of a sub-optimum intake (although clinical tests such as muscle magnesium or ionic magnesium are better at establishing actual magnesium status).

Given the potential for impaired performance on a sub-optimum magnesium intake, any athlete not already doing so should make a conscious effort to increase the proportion of magnesium-rich foods in his or her diet. Even a simple change like eating more whole grain products and boosting your intake of vegetables, nuts and seeds can make a big impact.

Magnesium intakes above the RDA are unlikely to boost performance further, but supplements are cheap and non-toxic, so can safely be used as an insurance policy. Most forms of supplemental magnesium are well-tolerated but it is inadvisable to supplement more than 400mg per day. Some forms, such as

Risk factors and signs of low magnesium intake

Eating habits associated with low magnesium intake

- You tend to eat white flour products instead of wholemeal
- You have a low intake of green leafy vegetables
- You don't eat much in the way of nuts and seeds or beans and lentils
- You regularly consume sugar or sugary products
- You drink alcohol regularly
- You follow a calorie-restricted or high-protein, low-carbohydrate diet

Possible symptoms of sub-optimal magnesium intake

- Muscle cramps, twitches or tremors
- Regular or excessive fatigue
- Feelings of irritability and/or lethargy
- Frequent mood swings, including depression
- Pre-menstrual bloating
- Restless legs at night

magnesium oxide, are quite alkaline forming and can have the side effect of neutralising stomach acid and interfering with digestion. These should not be taken with meals.

Finally, magnesium is best absorbed in small, frequent doses; so, for example, it is better to take 100mg three times a day than 300mg in one go!

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References

1. *National Research Council of Canada: Ottawa, ON: NRCC Publications (1979)*
2. *Hypertension 21:1024-1029. (1993)*
3. *Endocrinol Metab Clin N Am 22:377-395 (1993)*
4. *Diabetologia 33:511-514 (1990)*
5. *Magnesium and Trace Elements, 10:Measurement 1991-90 (1992)*

6. *Scandinavian Journal of Clinical and Laboratory Investigation, 55:549-558 (1995)*
7. *UK Food Standards Agency/COMA*
8. *US Institute of Medicine and National Academy of Sciences*
9. *Scandinavian Journal of Clinical and Laboratory Investigation, 56 (Supplement 224): 211-234 (1996)*
10. *Scandinavian Journal of Clinical and Laboratory Investigation, 54(Supplement 217):5-9 (1994)*
11. *Clinical Nutrition of the Essential Trace Elements and Minerals:49-67 (2000)*
12. *J Am Diet Assoc 93:462-464 (1993)*
13. *Institute of Medicine, Food and Nutrition Board, Washington, DC: National Academy Press, (1997)*
14. *J Am Diet Assoc;86: 251–3 (1986) and Nutr Res;7:27–34 (1987)*
15. *Med Sci Sports Exerc; 18(suppl):S55–6 (1986)*
16. *Am J Cardiol, 91(5): 517-21 (2003)*
17. *Cardiovasc Drugs Ther, 12 Suppl 2: 153-6 (1999)*
18. *J Nutr 132:930-935 (2002)*
19. *J Appl Physiol 65:1500-1505 (1988)*
20. *Endocrinol Metab Clin N Am 22:377-395 (1993)*
21. *Magnesium and Physical Activity:227-237 Parthenon Publishing Group London, UK (1995)*
22. *Med Exerc Nutr Health 4:230-233 (1995)*
23. *Sports Nutrition: Minerals and Electrolytes:179-187 CRC Press Boca Raton, FL, USA (1995)*
24. *Int J Sports Nutr 2:154-164 (1992)*
25. *Critical Reviews in Clinical Laboratory Sciences, 27:409-437 (1989)*

Could calcium be the new Holy Grail of sports nutrition?

Unless you're a cross-channel swimmer or sumo wrestler, it's almost certainly true that you'll perform better without excess body fat. Surplus fat acts as dead weight, increasing the load on your muscular system and demands on your oxygen transport system. So it's hardly surprising that the search for an effective fat loss supplement is a Holy Grail of sports nutrition. Very few of the various potions and lotions on the market stand up to scientific scrutiny. But the real answer could be right under our noses in the form of one of the most familiar nutrients in our everyday diet.

Mention calcium and most people think of bones and teeth. But, while it's true that 99% of the 1.2kg of calcium in the average human body goes to make up bone tissue (which itself acts as a 'calcium reservoir'), the remaining 1% is vitally important. Calcium is needed to switch muscles on and off – without it no muscular contraction would be possible – and is also vital to the release of neurotransmitter chemicals, such as serotonin, acetylcholine and norepinephrine. Calcium is also an important co-factor for blood clotting and activates numerous enzyme systems in the body.

However, recent research has hinted at a more intriguing function of calcium in the body. Although it has long been known that all cells require calcium to function, and that calcium also regulates the transport of other nutrients in and out of cells, there is growing evidence that calcium plays an important role in the regulation of energy metabolism and body composition and, in certain circumstances, may help reduce body fat and prevent weight gain.

The first indications that calcium might play a key role in metabolism came from two animal studies carried out in the late 1980s. In the first, two strains of rats prone to high blood pressure were placed on dietary regimes containing three different levels of calcium (2%, 1% or 0.1% by weight of the food consumed)[1]. After 15 weeks, both strains of rats on the high calcium diets (2% and 1%) showed favourable improvements (*ie* reductions) in blood pressure. But the benefits didn't stop there; rats on the high calcium diets also weighed less and had less body fat, with those on the 2% calcium diet showing the greatest changes. The second study found that increasing calcium in the diet from 0.1 to 2% led to reduced weight gain in both lean and fatty rats[2].

The first suggestion that this effect might apply to humans arose 12 years ago from a study of 11 obese African-American men, randomised into one of the following trial conditions:

- a high-calcium intake, using supplementary yoghurt to raise calcium intakes to 1,000mg/day;
- a yoghurt-free low calcium diet, containing only 500mg of calcium/day[3].

By the end of the intervention period, the men on the high-calcium diet had significantly lower body fat levels than those on the lower calcium intake. However, these results remained unpublished until recently because, at the time, scientists weren't aware of a link between calcium intake and body composition and it was just assumed that these results were a 'statistical blip'.

Initially, these early results stirred little interest within the scientific community, but a group of American scientists who had been studying the effects of calcium intake on bone mass in young women decided to investigate further and revisited the data from a two-year study published in 2001[4], this time focusing on the link between calcium intake and body composition[5]. The resultant data, collected from 54 women, were extremely intriguing. Although they observed no direct relationship between calcium intake and body fat levels, there was a very clear relationship between body fat and the calcium density of the diet.

The term 'calcium density' simply refers to how much calcium is consumed as a proportion of total calorie intake. For example, a diet containing 1,000mg of calcium per day and a total intake of 1,000kcal per day has a calcium density of 1mg per kcal. A diet containing 1,000mg of calcium and a total intake of 2,000kcal may have the same calcium content but has only half the calcium density. The results of this study showed that the density of the diet was inversely linked to changes in body weight and body fat – *ie* a high calcium density predicted weight loss and body fat reductions, and *vice versa*.

'Researchers observed a very clear relationship between body fat and the calcium density of the diet'

In order to further study the link between calcium, calorie intake and weight/fat changes, the scientists then split the women into two groups: those women who consumed more calories per day than the group average of 1,876kcal, and those consuming less. This produced two important findings:

1. In the high-calorie group, it was overall calorie intake rather than calcium intake that predicted changes in weight/fat mass;
2. However, in the low-calorie group, it was calcium intake rather than calories that predicted these changes, with a higher calcium intake producing more weight and fat loss! This effect was not small either, with calcium intakes of 1,000mg per day predicting a body fat loss of 2.6kg over two years compared with a gain of 1.8kg with calcium intakes of 500mg per day!

These results made nutritional scientists sit up and take notice and further investigations into calcium intake and body composition soon followed. In one of these studies, the dietary intakes of 53 children aged 2-5 were analysed in relation to body fat mass measured at 5 years, 10 months [6]. A clear relationship between calcium and body fat was observed; the higher the dietary intake of calcium, the lower the body fat mass.

These results seemed to confirm those of a meta-analysis of five separate studies on calcium intake and body composition, involving a total of 780 women of all ages [7]. In each of these studies, the calcium-to-protein ratio of the diet was inversely linked to either body mass index (BMI) or weight change – *ie* a high calcium-to-protein ratio predicted a lower BMI or weight loss, and *vice versa*. In fact, a difference of 1,000mg per day of calcium intake was associated with an average difference in body weight of 8kg!

The growing body of evidence in support of calcium as a modulator of body composition was given added weight by the 'Quebec Study' – another piece of research originally designed to assess the impact of calcium intake on bone mass [8]. A total of 235 men and 235 women were split into three groups according to their average daily calcium intake, as follows:

1. Low – less than 600mg per day;
2. Medium – 600-1,000mg;
3. High – more than 1,000mg.

The researchers found that women in the low calcium group had significantly higher body weight, percentage body fat, total fat mass, BMI, waist circumference and total abdominal adipose (fatty) tissue than those in the other two groups. The same overall trend was observed for men, although the differences were less significant.

'Women in the low calcium group had significantly higher body weight'

Yet another study originally designed to assess the impact of calcium intake on bone mass in young women examined the impact of calcium supplementation [9]. In this three-year double blind study, 52 young women were split into two groups: a calcium group, supplemented with 1,500mg per day of calcium, and a control group on placebo. Analysis showed that women in the calcium group gained less fat over the study period than the controls, further supporting the relationship between calcium and body weight.

Humans require over 40 nutrients for health, of which calcium is just one. And because body composition is affected by numerous (often more significant) factors, such as activity levels and total calorie intake, discerning the individual effect of a single nutrient is fraught with difficulty. Hardly surprising, then, that some studies on the link between calcium and body composition have drawn a blank!

WHAT'S GOING ON?

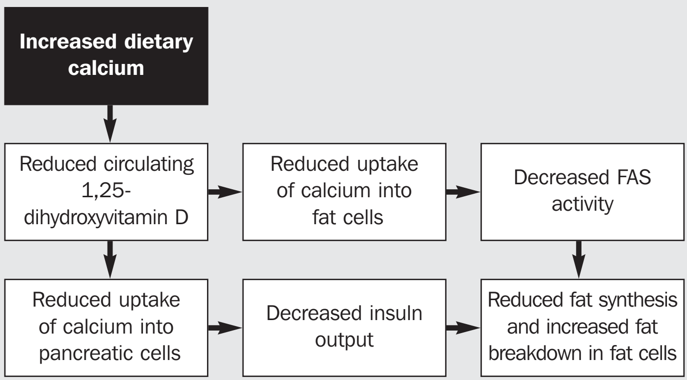
How is it that increasing calcium intake seems to exert a weight/fat loss effect? Vitamin D acts as both a vitamin and chemical messenger, and one of its jobs is to stimulate calcium uptake into the cells of the body when blood calcium levels are low. However, when blood calcium levels are high (for example on a high-calcium diet), levels of a particular metabolite of vitamin D (1,25-dihydroxyvitamin D) fall, and this in turn reduces the rate at which calcium is transferred into cells, including fat cells and pancreatic cells.

A reduced calcium level in fat cells decreases the activity of a fat storage enzyme called fatty acid synthase (FAS), which in turn leads to reduced fat synthesis and subsequent storage. Reduced FAS activity also leads to increased lipolysis (the breakdown of fat for energy).

At the same time, reduced calcium concentrations in pancreatic cells lead to lower insulin output which, in turn, results in reduced fat synthesis and enhanced fat breakdown in fat cells.

In combination, these processes – expressed in graphic form in the flow chart (below) – would help reduce fat deposition into (and storage in) fatty tissue. However, further research is needed to confirm this effect.

Flow chart: the link between calcium and fat reduction



For example, a meta-analysis of nine trials on the effects of dairy produce supplementation on body weight/composition found no differences between supplemented and unsupplemented groups in seven of the trials, while the remaining two (carried out on older adults) actually demonstrated a weight gain in the supplemented groups [10]! However, these results need to be interpreted with caution since it was not clear how many extra calories the dairy supplemented groups were consuming on account of the extra dairy produce.

The same researchers then carried out a meta-analysis (overview) of calcium supplementation trials and body composition, remembering that supplements provide more calcium without extra calories. Of the 17 trials analysed, only one found greater weight loss in the supplemented group than the controls, while in the remaining studies, the changes in body weight and/or body fat were strikingly similar between groups.

HOW MUCH CALCIUM?

Food	Portion size	Calcium content (milligrams)*
Cheddar cheese	100g	720
Milk (all varieties)	Pint	620
Canned fish with bones (sardines, salmon, pilchards etc)	100g	550
Sesame seeds	100g	420
Watercress	100g	170
Low-fat yoghurt (fruit)	100g	150
Spinach	100g	136
Fromage frais (plain)	100g	89
Peas (frozen, cooked)	100g	59
Wholemeal bread	100g	54
Baked beans	100g	53
Broccoli	100g	47
Oranges	100g	40
Iceberg lettuce	100g	20
White rice (boiled)	100g	18
Lean beef	100g	15
Avocado	100g	11
Potatoes (boiled)	100g	5
Apples	100g	4

*Figures supplied by the USDA Nutrient Data Laboratory and UK Food Standards Agency

Once again, caution is required when considering these results. For one thing, many of these studies were not specifically designed to investigate the link between calcium and body composition; for another, there is speculation that other compounds found in dairy products may act in concert with dietary calcium to produce weight loss effects, including whey proteins, conjugated linoleic acid (CLA) and branched-chain amino acids (BCAAs). These substances would not have been present at higher levels when just calcium supplements were given.

The importance of correct trial design when assessing the effectiveness of calcium supplementation and weight loss is illustrated by a study carried out in 2004 on 100 obese women[11]. All the subjects followed a weight-loss diet for 25 weeks, but one group received 1,000mg per day of supplementary calcium throughout this period, while the controls were given a placebo. Although the calcium-supplemented group lost more weight than the controls (7.0kg and 6.2kg respectively) and also lost more fat, the differences were deemed too small to be significant.

However, the study was not specifically designed to detect changes in body weight and fat mass between groups, and statisticians pointed out that as many as 500 subjects per group would have been required to reliably detect a difference of just 1kg. The researchers went on to suggest that, had the study run for longer with more subjects, it might well have been possible to conclusively demonstrate a weight loss effect of calcium, even without other dairy components.

Another study carried out in 2004 lent concrete support to the idea that calcium supplementation can help reduce fat[12]. In this trial, 32 subjects were placed on a calorie-controlled diet designed to promote weight loss on an individual basis by supplying each subject with 500kcal less per day than the amount calculated to keep them at a constant weight. The subjects were also randomly assigned to one of three groups:

1. *Control* – consuming 0–1 servings of dairy products per day while taking a 400–500mg calcium supplement and a placebo pill;

2. *High-calcium* – with the placebo replaced by 800mg per day calcium carbonate;
3. *High-dairy* – as group 1 and with the same total calorie intake (*ie* maintaining a 500kcal per day deficit) but consuming three servings of dairy products per day as part of the diet.

After 24 weeks, subjects in the control, high-calcium, and high-dairy groups lost 6.4%, 8.6%, and 10.9% of body weight respectively. Fat mass followed the same trend, with respective losses of 8.1%, 11.6%, and 14.1%. Intriguingly, fat loss from the abdominal region represented just 19% of total fat loss in subjects in the control (low-dairy) group but 50.1% and 66.2% for those in the high-calcium and high-dairy groups respectively. (Fat carried on the abdominal region is associated with a higher risk of illness, including coronary heart disease, so a greater fat loss from this region is significant.) These findings suggest that, while calcium seems to offer weight loss benefits, there may indeed be other co-factors in dairy produce which enhance this effect.

‘If you do decide to bump up your calcium intake, don’t go overboard’

Implications for athletes

To date there have been no studies specifically considering the effect of high calcium diets on fat reduction in athletes. However, we can be cautiously optimistic that the same principles would apply; positive results have been obtained in studies on men and women, young and old, although the indications are that the effects may be more significant in women than men.

There is also evidence that any fat loss effect is stronger when an increased calcium intake is provided in the form of dairy produce rather than calcium supplements, possibly because of other nutrients present in milk products. But it’s important to realise that any fat loss effect provided by an increased calcium intake will be undermined by the fat gain effect of consuming surplus calories!

It’s also worth emphasising that the ‘scientific jury’ has yet to deliver its final verdict on this issue; as I was finishing this article, the results of a new large-scale one-year study on 155 young women were published, showing no differences in body weight change between low, medium and high dairy diets containing the same number of calories[13]. This study doesn't negate the others, of course, but it does indicate that more research will be needed before we can draw definitive conclusions.

The key, therefore, for those who want to go down this route, is to replace low-calcium foods with high-calcium foods *(see table on page 64)* while maintaining roughly the same calorie intake. And since most calcium-rich foods are proteins, it makes sense to replace non-dairy proteins with dairy proteins, which will also ensure you maintain your intake of workout-fuelling carbohydrate.

If you do decide to bump up your calcium intake, don’t go overboard. Although excess dietary calcium can be excreted quite easily, very high calcium intakes, combined with high vitamin D or low magnesium intakes, have been linked with soft tissue calcification, whereby excess calcium is dumped in body tissues, leading to joint problems and kidney stones.

The Food Standards Agency recommends a maximum level of calcium supplementation of 1,500mg per day, and it would seem wise not to exceed a combined food/supplement calcium intake of 2,000mg per day[14]. Given that the recommended daily amount (RDA) for calcium is set at around 800mg per day for adults, and that most of the studies referred to above showed the greatest effects on weight loss at calcium intakes of 1,000mg per day or more, a sensible strategy might be to increase your intake of calcium-rich dairy produce by around 50% (to produce a food calcium intake of around 1,200mg per day) in the first instance!

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References

1. *Am J Hypertens 1988 Jan; 1(1):58-60*
2. *FASEB J 1989, 3137:A265(abs.)*
3. *FASEB J 2000, 14:1132-1138*
4. *Med Sci Sports Exerc 2001, 33:873-880*
5. *J Nutr 2003 Jan; 133:249S-251S*

6. *Int J Obes 2001; 25:559-566*
7. *J Clin Endocrinol Metab 2000; 85:4635-4638*
8. *Am J Clin Nutr 2003; 77:1448–52*
9. *J Bone Miner Res 2001; 16:S219*
10. *J Nutr 2003; 133:245S-248S*
11. *J Clin Endocrinol Metab 2004; 89:632–7*
12. *Obes Res 2004; 12:582–90*
13. *Am J Clin Nutr 2005; 81:751-756*
14. *UK Food Standards Agency Expert Group on Vitamins and Minerals 2003 (www.food.gov.uk/multimedia/pdfs/evm_calcium.pdf)*

'Your role is to make sure there are no fat b******s in my team'

That may not be the most scientifically precise instruction a person in my position can receive, but it is a familiar refrain in many football clubs and it has the value of letting you know where you stand! Frustrating? Perhaps. But, on a broader level, the role of sports nutritionist in professional football is seen as one of manipulating carbohydrate, protein, fat, fibre, fluid and micronutrient intake to maintain health, promote adaptation to training and, ultimately, enhance or – in our particular sport – maintain performance over the course of a season.

The role of the nutritionist in football has evolved over the last five years. Compared to some practitioners, I am new in the sport (one dietician at a top Premier League club has been employed continuously for 13 years!), but I am sufficiently long-in-the-tooth to have detected significant change over this period. At the time of writing, 19 out of 20 Premier League teams employ someone specifically to take care of the nutritional requirements of their players. This role is not always performed by a nutritionist or a dietician: in many teams the responsibility for implementing a nutritional support strategy falls on the shoulders of the sports scientist, conditioning coach, or physiotherapist.

Nutrition in football – a brief history

Football was for a long time classed as an endurance sport, due largely to the fact that a football match lasted at least 90 minutes. As a result, the nutritional requirements of football players were extrapolated from early scientific research carried out in relation to other 'endurance sports', such as running and cycling.

‘Daily energy expenditure of professional football players may not be particularly high’

Yes, it is true that the duration of a football match is normally 90 minutes; however, the training loads associated with these sports are vastly different. On closer inspection it becomes clear that daily energy expenditure of professional football players may not be particularly high. Football players are generally inactive when not training and training load will vary, depending on such factors as the stage of the season and whether tactical or fitness drills predominate in training.

Ron Maughan of Loughbrough University assessed the dietary intakes of two Scottish Premier League teams (he managed to get 51 players to perform seven-day weighed intakes) and found average daily energy intake to be approximately 2,620kcal and 3,050kcal respectively[1]. This is the only published data available on football players in this country and, notwithstanding a recent finding that Japanese football players under-reported their dietary intakes[2], this work does highlight lower energy requirements than were perhaps originally recommended for professional football players.

If football players were to consume 7-10g of carbohydrate per kg body weight each day (a recommendation found in many a textbook) then a quick calculation that included reasonable amounts of protein and fat would generate a daily energy intake closer to 4,200kcal. In Scandinavia this may be closer to the truth *(see table 1, opposite)*. Once the playing season gets under way, the Scandinavian subjects typically train seven times per week compared with roughly four sessions in this country. So it is not surprising that energy intakes will exceed 4,000kcal in a country like Sweden.

Not only were early dietary recommendations for professional football players slightly misjudged; a number of other problems existed in the delivery of nutritional support. Football was flooded with science and its analytical techniques, and experts employed by clubs exploited the ‘measure everything’ approach. Blood, saliva, urine, lactate and expired air were all being indiscriminately extracted from players, often with very little feedback offered in return. In the world of nutrition and football, science was calling the shots.

Table 1 – Energy and macronutrient intakes of elite international football players [3]

Nationality	Sample Size	Energy (kcal)	Carbohydrate (%)	Fat (%)	Protein (%)
Swedish	15	4,929	47.0	29.2	13.6
Danish	7	3,738	46.3	38.0	15.7
Italian [1]	33	3,066	56.0	28.0	14.0
Italian [2]	20	3,650	55.8	28.3	15.9
Junior Canadian	5	3,619	48.0	39.0	13.0
Puerto Rican	8	3,952	53.2	32.4	14.4
Total	88	3,682	52.9	30.1	14.5

A new climate prevails

'An athlete's diet must be high in carbohydrate, moderate in protein, low in fat, include sufficient vitamins and minerals, and plenty of fluid.' This was the original model with which many football nutritionists used to work. Although very simple, much of it still holds true today. However, as our understanding of the game in this country has improved, nutritionists have been able to tease out strategies from each of the model's sub-sections that more closely match the requirements of our sport. What is different is that science no longer holds all the cards. Football has caught up with science and is now dictating where our efforts are directed.

For, example, the glycaemic index of foods, a ranking of foods based on their immediate effect on blood glucose, has become a particularly useful tool in football. Five years ago the approach in football was to advocate a high carbohydrate, low fat diet at all times. Any food that at all met these requirements would be recommended to players in a bid to maximise muscle glycogen storage for training and competition. Now a more measured approach is employed with the glycaemic index and, to a lesser extent, the insulin index utilised in a bid to control body composition as well as carbohydrate provision. Emphasis is now placed more on achieving optimum carbohydrate intake before matches and during the recovery period after matches, particularly when some clubs find themselves involved in up to three games per week in the busiest part of the season.

Good attitudes to reducing fat intake are now commonplace in the modern player. Emphasis is placed on increasing intake of certain fatty acids that are found to be lacking in players' diets. When performing dietary analyses of players, low intakes of essential fatty acids (eicosapentaenoic acid, EPA; docosahexenoic acid, DHA) are consistently reported. Despite the appearance of oily fish in the canteens of football clubs, there may be a case for blanket supplementation in this particular group of sportsmen.

There is growing evidence that protein supplementation after training can promote protein synthesis and adaptation of muscle. The type, timing and amount of protein can be manipulated to enhance the adaptive response. The work of researchers such as Bob Wolfe and Kevin Tipton in Texas, and Mike Rennie in Dundee (whose primary interest has been likened to 'preventing older people falling down') has enabled us to design strategies for protein intake that may promote better adaptation to training.

The free radical damage theory

Interest in micronutrients has historically been associated with the free radical muscle damage hypothesis. In fact, there is now some suspicion that the release of free radicals associated with exercise is necessary for adaptation of the cell to subsequent stressful events. It is entirely feasible, although not proven, that free radicals play an important part in the adaptation of the muscle to hard exercise, and that increased consumption of some antioxidant nutrients might interfere with these necessary adaptive responses. Practitioners now warn against the use of mega-dose antioxidants.

Many indices have been investigated to establish their potential as markers of hydration status. Body mass changes, blood indices, urine indices and bioelectrical impedance analysis have been the most widely investigated. Current evidence tends to favour urine indices, and in particular urine osmolality (concentration), as the most promising marker available. Five years ago urine colour charts were commonplace on the walls of clubs' changing room toilets. Nowadays osmometers can be found at Premier League clubs. Urine samples provided by players can be analysed in approximately 30 seconds and the machines quickly identify dehydrated subjects.

A recent preliminary report has suggested that American football players who repeatedly suffer muscle cramping in training and competition have greater sweat losses and a higher sweat sodium content than players matched for fitness and other factors but who do not suffer from muscle cramps (4). Data on sweat electrolyte losses in football players in training are now being collected in a bid to identify those players at risk of potentially debilitating muscle cramp.

Assessment of body composition plays an important role in nutritional evaluation, particularly in a sport obsessed with body image. Along with body mass, an estimation of body fat percentage (or sum of skinfolds) has traditionally been the requisite regular test demanded by football managers. In addition to the usual body composition assessment methods, a number of other techniques are being utilised in the modern game. The evaluation of skeletal muscle mass can contribute important information to the assessment of nutritional status because it reflects the body protein mass.

A major impediment to determining muscle mass is the lack of suitable, easy and non-invasive methods for doing so. Lee and others (5) have developed anthropometric prediction models validated against the 'gold standard' method of magnetic resonance imagery to estimate total body skeletal mass using skinfold thickness and limb circumferences. These have proved useful in tracking changes in muscle mass associated with inactivity or resistance training protocols.

Although expensive, dual-energy X-ray absorptiometry (DEXA) is proving a valuable tool for body composition assessment, particularly with injured players recovering from a period of inactivity. If you are lucky enough to have access to

'It is entirely feasible that free radicals play an important part in the adaptation of the muscle to hard exercise'

DEXA at a university or hospital, this technology is able to identify accurately fat and lean tissue and can be used both for whole-body measurements of body composition and for providing estimates of the composition of specific sub-regions (*eg* trunk or legs). The DEXA instruments differentiate body weight into the components of lean soft tissue, fat soft tissue and bone.

A technique known as indirect calorimetry is used to estimate daily energy expenditure of individual players, particularly those who are undergoing a period of inactivity through injury. Measuring a person's oxygen consumption and time spent on different activities allows a picture of energy expenditure to be created. This information can then be used to prescribe eating and drinking plans that match more precisely players' energy requirements.

These are just a few examples of how science and football have worked together to develop player- and sport-specific nutritional support programmes. Science should be committed to meeting the demands of football, and not *vice versa*. It may sound obvious, but it wasn't always so.

The challenge ahead

Despite the progress that has been made in our understanding of the demands of football, there is a need for continued improvement. No other sub-discipline of sports medicine comes with so many contrasting views of what is right and wrong. The Zone diet, the Atkins diet, mass supplementation, the concept of the 'nutritional guru' – all are still prevalent in the modern game. Meanwhile, players are becoming more demanding and those from overseas bring their own ideas (nearly always related to vitamin intake), which are very often lacking in scientific support.

In addition, at present there is a fundamental mismatch between what players and practitioners view as important. Players believe in supplements, extra vitamins and minerals: anything that involves increasing muscle mass, and reducing energy intake to achieve 'lean' body composition. Scientific research, on the other hand, demonstrates that players should concentrate more on appropriate energy intake, with high carbohydrate and fluid intake.

Football is steeped in tradition, which many people wrongly write off as Luddite-type conservatism, or little better than old wives' tales passed around the old boys' network. It is true that many coaches and support staff are employed from within, but it is also true that these people know the sport and its peculiarities better than anyone. Furthermore, the practice of employment from within will eventually spawn a new breed of coaches that have had, one hopes, more positive and enlightened experiences of sports nutrition.

Back to the fish and chips?

Of course, providing a cutting-edge nutritional support programme has no value unless appropriate education (one that is both stimulating and imaginative) is implemented. In a world dominated by R'n'B, fast cars and Louis Vuitton washbags, it is important to pitch your educational material appropriately. 'Healthy eating' on its own just does not wash with Premier League football players. Science and technology, pitched correctly, most definitely do. For all the advances science has made, the most important lessons that nutritionists have had to learn are 'respect the sport' and 'know your place'. It is sobering to note that Real Madrid, arguably the world's best football team, employ no fewer than nine masseurs but do not employ anyone to take care of the players' nutritional requirements.

Finally, my personal working title for this article was: 'The role of fish and chips in modern football'. Five years ago I walked into a football club and one of the first changes I made was to remove the fish and chips from the post-match menu. This wasn't a popular move and it would be dishonest to say that anything offered to the players since has been received with anything like the same enthusiasm. Should I go back to fish and chips?

Well, potato is a high glycaemic index carbohydrate food, thought to be preferable for the recovery of muscle glycogen stores, and fish is a complete protein source possessing essential amino acids that are ideal for stimulation of muscle protein synthesis. Most importantly, most players will definitely eat this dish. OK, the high fat content will probably interfere with the glycaemic response of the potato and, of course, there are other health promotion issues.

In actual fact, I probably won't return to post-match fish and chips for the players, however popular this move would be, but this real-life example does highlight the fact that, for all the rewards that science and nutrition has to offer, effective change can only be achieved if we respect the traditions of the sport and take the players along with us.

Nick Broad

References

1. Br J Sports Med, 31:45-47.

2. J Sports Sci, 20:391-7

3. Int J Sport Nutr, 8:230-240.

4. Med Sci Sports and Exerc, 35:S48

5. Am J Clin Nutr, 72:796–803.

The post-exercise window of opportunity: why we need to start drawing the curtains

Since the dawn of sports nutrition as a scientific discipline, one issue has consistently dominated practitioners' attention – the post-exercise 'window of opportunity' for muscle recovery. So entrenched is this concept in recovery culture that it barely needs an explanation, but for the uninitiated here is a brief description of how it works.

Traditionally two nutrients have grabbed most of the muscle-recovery headlines: carbohydrate and protein. The drive to consume carbohydrate as early as possible after activity derives from the early work of Louise Burke, head of the Australian Institute of Sport's nutrition department [1,2], and John Ivy in Texas [3,4], whose primary concern (and this is the important point) was to maximise the rate of glycogen synthesis. They were hell bent on recovering muscle glycogen as fast as possible so that performance in an event or training session occurring up to 24 hours later did not suffer.

Protein was then added to the carbohydrate for two reasons:

1. To improve glycogen accumulation beyond what could be achieved by consuming carbohydrate alone;
2. To stimulate muscle protein synthesis.

The need to consume both these nutrients as soon as possible after exercise – during the so-called 'window of opportunity' – has become the central plank of most post-exercise recovery strategies.

Those responsible for giving nutritional advice to sportsmen and women have used the window of opportunity as their most potent weapon, regularly assaulting their ears with terms like ‘glycogen synthase’ (the enzyme considered for a long time to be the most important step in glycogen accumulation) and ‘high glycaemic index’ carbohydrates (the sort that break down quickly during digestion).

Only recently I was witness to a conversation between a football manager and one of his most senior players directly after a pre-season friendly match. Due to a mix-up at the stadium there was no post-match food available, and the player in question was furious, informing the manager that he must eat within 20 minutes.

Was he right to be so vociferous when in fact he had a day off scheduled for the next day and was not due to play another match for a week? Could he have waited a little more time to eat without prejudicing his recovery? Read on…

Since as long ago as 1983, Professor John Holloszy and his colleagues have been conducting a series of experiments investigating glycogen metabolism, insulin resistance and its association with type 2 diabetes and obesity, much of which has been overlooked by the exercise community.

Preventing glycogen supercompensation

Using animal models, Holloszy has found that preventing glycogen supercompensation by not feeding carbohydrate after exercise leads to a persistent increase in insulin-stimulated glucose transport.

After glycogen-depleting exercise, it would appear that muscle cells maintain the adaptations that make possible faster and greater glycogen accumulation until glycogen accumulation actually occurs. The window of opportunity, so long the key tool of the sports nutritionist, is starting to show some cracks!

The results from Professor Holloszy’s most recent study indicate that this increased capacity for muscle glycogen accumulation after exercise lasts for at least three days (5)! Muscle glycogen accumulation was as great in rats maintained in the glycogen-depleted state for 66 hours and then fed a high-carbohydrate diet as in those fed the high-carb diet for 18 hours immediately after exercise.

The mechanism responsible for this phenomenon appears to be the action of a muscle glucose transporter called GLUT 4 protein. Exercise training induces an increase in the GLUT4 glucose transporter in muscle, leading to a proportional increase in glucose transport and a consequent enhancement of the rate and magnitude of muscle glycogen accumulation.

'Rapid muscle glycogen repletion can be essential for survival in a fight-or-flight situation that calls for vigorous activity'

It would appear, therefore, that the importance of post-exercise carbohydrate feeding to promote maximal rates of muscle glycogen depends largely on the length of time between exercise bouts. And in many sporting situations this period is quite extended.

Why should this adaptation exist? Holloszy *et al* point to the fact that muscle glycogen is necessary for strenuous exercise, and depletion of glycogen stores results in fatigue that makes vigorous exercise impossible. Therefore, rapid muscle glycogen repletion can be essential for survival in a fight-or-flight situation that calls for vigorous activity. In this context, the rapid exercise-induced increase in GLUT4 expression could provide a survival advantage during prolonged emergency situations by facilitating faster and greater glycogen repletion between bouts of activity.

What about the role of protein? It seems that a similar, although less important, mechanism is at work here. A recent study of elderly people has provided us with some very interesting insights into the nutritional control of muscle mass (6). Birgitte Esmarck and her colleagues found that it mattered considerably when they consumed a protein meal after exercise.

Delaying the consumption of a meal for two hours after exercise limited the increase in muscle-fibre growth after a programme of progressive resistance exercise in elderly men (mean age 74 years). But when the meal was taken immediately after exercise, muscle growth, measured as increases in muscle fibre and whole muscle cross sectional area, was considerably enhanced.

‘The appropriate time for post-exercise feeding will depend largely on the time available before a subsequent bout’

However, other research on young subjects has shown little difference in the stimulation of muscle protein synthesis (and no difference in the inhibition of muscle protein breakdown) when a protein–carbohydrate meal was given either one hour or three hours after strenuous exercise [7].

This apparent contradiction may be explained by the relative sensitivity of elderly muscle to contractile activity and dietary amino acids. Further research has suggested that elderly subjects exhibit what we might call ‘nutrient resistance’ of protein synthesis, in that they show a diminished response to dietary amino acids-plus-carbohydrate by comparison with young subjects [8]. It could be that, while elderly muscle is stimulated by contractile activity, the effect wears off faster than in youthful muscle.

If all these findings were replicated in humans, would they consign a whole host of sports nutritionists to the dole queue? Not quite: but they would give athletes a bit more freedom and flexibility to design their own specific recovery strategies, plan meals accordingly and decide whether it is worth investing in expensive recovery products.

Many of us do not need to replenish muscle glycogen stores immediately. If we had a couple of days in hand before our next planned exercise bout, that would allow for sufficient accumulation of muscle glycogen. On the other hand, those with demanding training and competition regimes would need to restore muscle glycogen pretty quickly. As with everything in life, there is no one-size-fits-all approach.

Of course, in many situations it is convenient to start the process of muscle recovery early – in the changing room after a team event, for example. But if there are individuals on the team who find it difficult to consume food or drink straight after training or competition, should we really castigate them? Wouldn’t it be better to encourage them to choose appropriate times for eating and drinking that will not put them at a disadvantage?

The message is simple: the appropriate time for post-exercise feeding will depend largely on the time available before a subsequent bout. Maybe you can allow yourself a little extra time to get those essential amino acids and carbohydrates on board – unless, of course, you are collecting your pension!

Perhaps at last it is time to draw the curtains, at least in part, on that celebrated window of opportunity.

Nick Broad

References

1. J Appl Physiol, 75: 1019-1023, 1993

2. Am J Clin Nutr, 64: 115-119, 1996

3. J Appl Physiol, 93: 1337-1344, 2002

4. J Appl Physiol, 64: 1480-1485, 1988

5. Am J Physiol Endocrinol Metab, 285: E729-E736, 2003

6. J Appl Physiol, 535: 301-311, 2001

7. J Appl Physiol, 88: 386-392, 2000

8. J Clin Endocrinol Metab, 85:4481-90, 2000

WHAT THE SCIENTISTS SAY

Reports on recent nutrition-related studies by Isabel Walker, Claire Whitehead and Andrew Hamilton

When carbo-loading works best for women

Carbohydrate-loading before endurance events, which has a well-established performance-enhancing effect in men, appears less effective in women. Even when muscle glycogen levels have increased and performance times have improved, the changes have tended to be of a lesser magnitude than those observed in men.

Carbohydrate supplementation during prolonged exercise is thought to enhance time to fatigue by maintaining blood glucose levels, thus facilitating a high rate of carbohydrate oxidation during the latter stages of exercise.

Many women have drawn encouraging conclusions from results of male-only trials of carbo-loading and tried to apply the principles to their own diet, with a frustrating lack of success.

One suggested explanation for this apparent discrepancy is that women have a lower respiratory exchange ratio (RER) than men, with men tending to use carbohydrate for energy and women tending to prefer lipids, possibly on account of hormonal differences. Another possibility is that women don't ingest carbohydrate in sufficient quantities to facilitate muscle glycogen storage.

A frustrating lack of research into the effects of carbo-loading and supplementation on endurance-trained women was the stimulus behind a recent study in which US and Chinese researchers examined the metabolic and performance effects of augmented carbohydrate intake in a group of female athletes (1).

The study participants were eight well-trained endurance athletes, who performed three 24.2k treadmill performance runs under three different trial conditions, spaced one month apart and performed 5-10 days after the first day of each subject's menstrual cycle, to minimise the effects of hormones on fuel metabolism. The trial conditions were as follows:

1. Placebo (P) – no carbohydrate loading and no supplementation;

2. Carbohydrate loading and supplementation (L+S);
3. Carbohydrate supplementation only (S).

Supplementation (conditions 2 and 3) consisted of a 6% carbohydrate-electrolyte solution, given at 20-minute intervals during the treadmill run. Carbohydrate loading (condition 2) comprised a diet in which carbs made up 75% of total energy intake. In the non-loading conditions (1 and 3), carbs made up 50% of energy intake, with total energy intake the same in each condition.

The results of the study were as predicted by the researchers: no significant change in performance time for the 24.2k run, despite an increase in carbohydrate oxidation in the two active treatment conditions. Blood glucose and lactate levels were highest in the loading and supplementation condition, next highest with supplementation-only and lowest in the placebo condition, in which blood glycerol levels were highest.

In addition to the lack of performance effect with carbo-loading and/or supplementation, there was no indication that the runners had to work any harder in the placebo condition.

There were no differences in heart rate, VO_2 or perceived rate of exertion between the trial conditions, suggesting that no advantages were gained by loading or supplementation.

Nevertheless, there was evidence that carbohydrate utilisation increased and blood glucose levels were maintained in the carbohydrate trials, suggesting that when carbohydrate levels are increased, female athletes will burn it preferentially. The higher glycerol levels observed with placebo indicate that fat was employed to a greater extent than in the other two conditions.

Interestingly, the combination of carbo-loading and supplementation was not much better than supplementation alone. The performance time for the run was no faster for L+S, and there was no difference between the two conditions for any other measurements except blood lactate, which was significantly higher in the L+S trial, suggesting a greater use of muscle glycogen following carbo-loading.

The carbo-loading women consumed on average 335g (5.5g/kg body mass) of carbohydrate for four days before the trial run, compared with 238g (3.9g/kg BM) and 214g (3.5g/kg BM) during supplementation only and placebo respectively. And the point is that this may not be an adequate amount to raise muscle glycogen levels sufficiently to improve performance.

Failure by women to consume as high an absolute amount of carbohydrate as men has been put forward as one of the reasons why women do not manage to improve their performance by means of carbo-loading. Previous studies on carbo-loading have shown that carbohydrate intake must reach 500g per day to optimally fill the muscle and liver glycogen stores in men, and it could be that the same principle holds for women. In most successful carbo-loading studies, men have been consuming more than 8g/kg BM per day.

The theory that it is the absolute amount – rather than the proportion – of carbohydrate in the diet that is key to performance improvement was borne out by the results of a previous trial comparing carbo-loading and the relationship to energy intake in both men and women [(2)]. The researchers measured muscle glycogen content following a high-carbohydrate diet (75% of total normal energy intake) and a high-carbohydrate diet plus 34% extra total energy, which increased both energy and carbohydrate intake by comparison with their normal diets (comprising 58% carbs).

While the men increased their total glycogen concentration following both the high-carb and the high-carb-plus diets, women failed to increase muscle glycogen simply by boosting the proportion of carbohydrate in their diets. Only by raising their overall energy intake by 34% and maintaining a 75% carbohydrate intake did they manage to increase their muscle glycogen concentration.

The results of both these studies suggest that for women to successfully increase their muscle glycogen levels prior to an endurance event, they must consume at least 8g/kg/day. For an average 60kg female to achieve this on a total energy intake of 2000kcal/day, carbs would need to account for more than 90% of total energy intake. A more practical solution would be to increase not just the proportion of carbs in the diet but also the total energy intake.

Strong evidence links increased muscle glycogen stores with improved endurance capacity, and efforts to boost carbohydrate intake should be considered an important part of pre-race preparation for any serious female endurance athlete.

Given that carbo-loading is a strategy likely to be employed only once or twice a year, this should not pose major problems for athletes who are dedicated to improving their race times.

However, since carbohydrate supplementation during exercise failed to make up for lack of adequate carbo-loading, it should not be considered a viable alternative.

1. Journal of Applied Physiology, vol 95, pp584-590, 2003
2. Journal of Applied Physiology, vol 91, pp225-230, 2001

Carbohydrates and perceived exertion in marathon running

Does carbohydrate supplementation exert an ergogenic effect during marathon running? That is the question US researchers set out to answer in a study of 98 male and female entrants to the 1999 Charlotte Marathon and the 2000 Grandfather Mountain Marathon in Boone, both in North Carolina.

The highly experienced (but non-elite) participants, ranging in age from 21 to 72, underwent a series of blood and anthropometric tests on the morning of the race and were then randomly assigned to one of two conditions:

- supplementation with a 6% carbohydrate drink, with each runner ingesting 650ml about 30 minutes before the start of the race and approximately 1,000ml at hourly intervals during the event;
- the same amounts of an inactive placebo drink, identical in appearance and taste to the carbohydrate solution.

A chest heart rate monitor was attached to each runner, and research assistants, positioned every 3.2k along the racecourse to deliver the drinks, recorded heart rates and ratings of perceived exertion (RPE) at the same time. After runners crossed the finish line, blood samples were collected from each within five minutes.

Key findings for the two races combined were as follows:

- Race times for both the carbohydrate and the placebo group were slower than their personal bests of the previous year due to the hilly terrain of both these marathons. Although race times did not differ significantly between the groups, the placebo group was about 15 minutes slower by comparison with these earlier PBs than the carb group;

- RPEs during running did not differ significantly between the two conditions, although there was a non-significant trend towards a higher RPE during the later portion of the race with placebo;
- Runners in the carbohydrate group were able to run at a higher intensity – *ie* at a higher percentage of their maximum heart rate – particularly during the final 10k;
- Despite the similarity in RPE between the two conditions, there was a significant decrease in plasma glucose and insulin, concomitant with an increase in plasma cortisol and growth hormone, with placebo compared with the carbohydrate condition.

Based on the evidence of their previous laboratory-based studies, the researchers had hypothesised that RPE would be lower – *ie* running would feel easier – with carbohydrate supplementation. A possible explanation for their failure to replicate this finding 'in the field' is that experimental outcomes during an actual race can be easily affected by many extraneous variables, including weather, terrain and motivation as well as variations in the intensities at which the runners were performing from point to point.

'These findings suggest,' they conclude, 'that the attainment of a greater percentage of maximum heart rate at a given RPE can be attributable to a sustained supply of carbohydrate energy substrates to the exercising muscle.'

But they add: 'During prolonged strenuous exercise, where intensity varies from point-to-point as in marathon running, it appears that factors other than carbohydrate energy substrate availability play an important role in mediating the strength of perceived exertion.'
Med Sci Sports Exerc 2002 Nov; 34(11): pp1779-84

It's not just what you eat…

…but how and when you eat it, according to UK research. For most athletes, maintaining optimum weight is vital to performance, especially as excess weight in the form of fat is an instant recipe for slower times. Although maintaining a daily calorie balance (calories consumed equal to calories expended) plays a major role in weight maintenance, other mechanisms are also important, including thermogenesis, whereby small amounts of excess calories are burned off as heat, rather than stored as fat.

Thermogenesis is thought to explain why, for example, an athlete in hard training, burning anything up to 6,000kcal per day, who consumes an extra 100kcal per day (the amount contained in a banana) beyond his or her daily calorie expenditure figure, doesn't gain the extra weight that the simple calorie balance theory would predict!

Now researchers in Nottingham studying the thermic effect of food (whereby the digestion, absorption and metabolism of food acts to raise metabolic rate and calorie expenditure) have discovered that the regularity of meals affects the rate of thermogenesis and subsequent calorie 'burn' [1].

Nine healthy lean women were asked to continue consuming their normal diet for 14 days in one of two patterns:

- Taken as six small meals per day, eaten at regular intervals (A);
- Taken as three to nine meals per day, eaten at irregular intervals and varied at random throughout the 14-day period (B).

After 14 days, all the women resumed their usual eating patterns for two weeks, then switched to the other group for a further two weeks (*ie* those in A switched to B and *vice versa*).

The women underwent a variety of tests at the beginning and end of each study period, including an overnight fast to determine resting metabolism and measurement (for three hours) of metabolic rate following consumption of a milkshake test meal, containing 50% of calories as carbohydrate, 15% as protein and 35% as fat.

The researchers found that while the average daily calorie intake remained the same, regardless of eating pattern, and resting metabolism after an overnight fast remained unchanged, the overall thermic effect of the milkshake meal was significantly higher following a regular meal pattern (A) than an irregular one (B).

And they went on to conclude that the reduced thermic effect associated with irregular eating might be significant enough to lead to weight gain in the long-term!

These findings may help to explain what many bodybuilders striving for reduced body fat while maintaining sufficient calorie intake to train and recover have known intuitively all along: that several small meals consumed at evenly-spaced intervals throughout the day are preferable to irregular and variable consumption.

The same research group went on to analyse the health implications of irregular v regular eating patterns by measuring circulating glucose, lipids, insulin and uric acid in blood samples taken over a three-hour period following the consumption of a high-carbohydrate test meal [(2)]. They found that peak insulin levels were significantly higher after irregular eating, as were markers of total insulin secreted, indicating a degree of insulin resistance. Moreover, levels of LDL cholesterol (the 'bad' sort, associated with heart disease) were also raised by irregular eating patterns.

The researchers concluded: 'An irregular meal frequency appears to produce a degree of insulin resistance and higher fasting lipid profiles, which may indicate a deleterious effect for cardiovascular risk factors. Quite apart from the health implications, optimum insulin function is vital for recovery, growth and regulation of energy in hard-working bodies.

The message for athletes seems to be that careful forward planning of meals and snacks is more important than we had previously realised; the evidence suggests that it's not just what and how much we eat that matters, but also when and how we eat it!

1.International Journal of Obesity, vol 28, no, 653-660
2. International Journal of Obesity, vol 58, no 7, 1071-1077

Post-exercise supercompensation only works once

The 'supercompensation' of muscle glycogen stores that is known to occur as a result of carbo-loading following exhaustive exercise cannot be relied on after successive bouts, according to a fascinating study from Australia.

The research team set out to discover whether it is possible to repeatedly supercompensate muscle glycogen stores after repeated exercise bouts undertaken within several days.

Six well-trained subjects completed an intermittent exhaustive cycling protocol on three occasions separated by 48 hours (days 1, 3 and 5) in a five-day period. Twenty-four hours before day 1, they consumed a moderate carbohydrate diet (6g per kg of body weight) followed by five days of a high-carb diet (12g per kg). Biopsies to measure muscle glycogen levels were taken at rest, immediately after exercise on days 1, 3 and 5 and after three hours of recovery on days 1 and 3.

The researchers, who had hypothesised that these highly trained subjects would be able to supercompensate their glycogen stores more than once, were surprised to find themselves wrong. Compared with day 1, resting muscle glycogen was elevated on day 3 but not on day 5.

'We feel confident,' the researchers note, 'that our high-CHO diet would have provided ample substrate for glycogen resynthesis: subjects consumed [12g per kg of body weight] for four successive days: such an amount is 20-35% more than typical glycogen-loading protocols.

'Accordingly, the failure of muscle glycogen stores to reach supercompensated values on day 5 compared with day 3 of the experimental protocol strongly suggests an impairment in one or more of the mechanisms responsible for glycogen storage, possibly as a direct consequence of the cumulative effect of repeated exhaustive exercise.'

The good news was that, despite this failure to supercompensate, exercise capacity, which was improved on day 3 by comparison with day 1, was maintained on day 5. The researchers find it difficult to explain this phenomenon but suggest it is due to a substantial increase in the contribution to total energy requirements from lipid (fat) oxidation.

Whatever the reason for this continued increase in exercise capacity, it suggests, they conclude, 'that glycogen supercompensation may not be required in the trained athlete during successive days of competition'.
Med Sci Sports Exerc, vol 37, no 3, pp404-411, 2005

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