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Nutritional considerations for performance and rehabilitation

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Introduction

Nutrition is a major consideration for athletes, coaches and rehabilitators and plays a crucial role in training, competition and in the prevention and management of sports injuries. *So, what is sports nutrition?* Sports nutrition encompasses what, when, and how much athletes eat. It takes account of how nutrients are digested and absorbed and how foods are metabolised for energy or assimilated into body tissues.

Correct nutrition, or more specifically the optimal balance of energy and nutrients delivered at the right time, has a range of potential benefits for the athlete. These include: recuperation from and adaptation to training; the maintenance of work-rate throughout a match, race or training session; the maintenance of concentration and coordination; the maintenance of body composition; and provision of an optimum environment for injuries to heal. Without correct nutrition, all of these processes are affected with associated detriments to training, performance, injury risk and injury rehabilitation.

During this chapter you will learn about:

- fundamentals of nutrition
- energy balance
- the nutrients and how to obtain them
- the importance of a balanced diet for health and performance
- energy requirements for specific sports
- nutritional strategies for optimal performance and the evidence to support them
- nutritional strategies for injury prevention
- nutrition for the injured athlete

Fundamentals of nutrition

Energy balance

Food and drink provide energy. Complex chemical processes break down food to provide essential fuels for a range of functions including breathing, blood circulation, chemical reactions, growth, repair, brain function and muscular activity.

Managing energy balance is a nutritional priority for athletes. Food must provide adequate energy for training and competition, but must not provide excess. An excess of energy, over and above that expended, will lead to weight gain. This may be in

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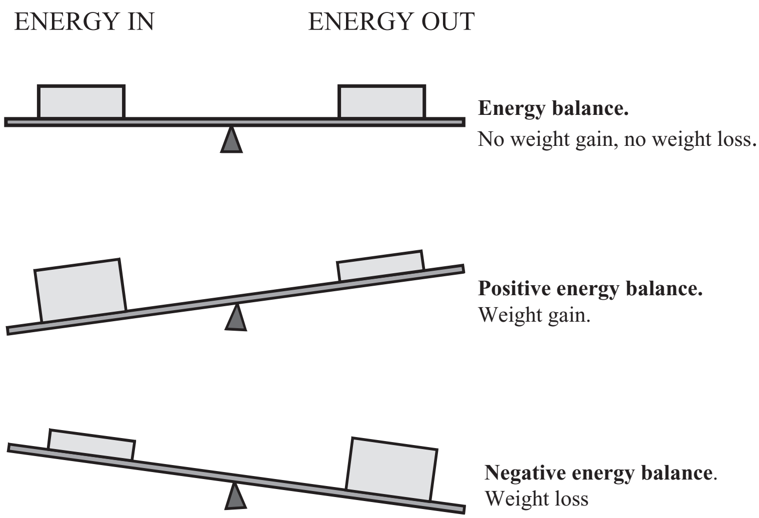

Figure 14.1 Energy balance.

the form of functional muscle tissue in the case of an athlete training for increased muscle hypertrophy, strength and power but, more commonly, may also be in the form of unwanted body fat, for example when an injured athlete is forced to stop training but maintains the same high-energy diet. By contrast, a diet that has insufficient energy will lead to weight loss. This may be the case in sports that require a high volume of training, such as triathlon, where athletes may struggle to consume enough energy to meet the demands of training.

To maintain weight and body composition at the optimal level for sport, athletes must therefore manage both the amount of energy they consume and the amount they expend. This is called managing the *energy balance*.

Energy balance can be summarised by the following: If athletes consume more energy than they use then they will gain weight – hypercalorific diet. If athletes consume as much energy as they use then they will stay the same weight – isocalorific diet. If athletes consume less energy than they use then they will lose weight – hypocalorific diet (Figure 14.1).

Energy and calories

Energy is measured in Joules, however the term most often used in dietetics and amongst athletes is the kcal (one kcal equals 4.2 kJoules). To maintain energy balance, the estimated average energy intakes required in 'healthy' adults are 2550 kcal/day for males and 1940 kcal/day for females (FSA 2008). Additional physical activity needs, however, are not accounted for in these estimated average requirements. Therefore athletes in training will have higher energy requirements and this will increase in proportion to the volume of training that the athlete performs.

Nutrients and where to get them

In addition to energy, food and drink provide nutrients. These are the raw materials, or ingredients, required by the body for optimal health and function.

There are six key nutrient classes. These are:

- carbohydrates
- fats
- proteins
- vitamins
- minerals
- water.

Each of these nutrient classes has specialised roles within the body that are essential for health and optimal performance. An inadequate intake of any of these will result in disease, or impaired physical and cognitive functioning, which can normally only be prevented by the nutrient. Of these nutrients, carbohydrates, fats and proteins provide energy. Water, vitamins and minerals provide no energy but play a vital role in the regulation of body processes. Alcohol is considered by some to be the seventh nutrient as it also provides a source of energy, but it is not essential.

The correct nutrient balance will help athletes remain healthy and perform optimally. Too much or too little of any one nutrient will affect both health and performance.

Carbohydrates

Carbohydrates are the single most important source of energy for athletes. They provide approximately four kcal per gram and are the primary fuel source for high intensity exercise (above 60% VO_2max) (Coggan and Coyle 1988; Carter et al. 2003). Carbohydrates can be classified as simple and complex.

Simple carbohydrates are found in sugary foods such as fruit, fruit juices, sugar and honey and generally provide a quick but short-lasting source of energy. These can be further divided into: monosaccharides, which are simple, one-unit sugars such as glucose, fructose and galactose; and disaccharides, which are formed from two monosaccharides. For example sucrose – or common table sugar – is a combination of glucose and fructose.

Complex carbohydrates are found in starchy foods such as pasta, rice, potatoes, bread, vegetables, cereals, beans and pulses and provide a stable supply of longer-term energy. Complex carbohydrates can be further divided into: polysaccharides (containing more than two monosaccharides), which include starch (from plant sources) and glycogen (from animals), and dietary fibre (non-starch polysaccharide), which is found in plant foods, cereal, fruit and vegetables and is crucial to optimal health.

Foods, and in particular carbohydrates, can also be classified by their glycaemic index. The glycaemic index (GI) is a measure of the extent to which a certain food raises blood glucose (Jenkins et al. 1981). High GI foods, such as white bread, potatoes, cornflakes and jelly beans, cause a sharp rise in blood glucose, which is often short lasting and followed by a rebound drop in blood glucose. Low GI foods, such as porridge, high-fibre cereal, beans, peanuts and apricots, which are high in fibre and/or protein, give a slower, but more sustained release of glucose causing a slower rise in blood glucose and no rebound drop.

For the healthy population, carbohydrates should contribute approximately 50–60% of the energy intake in the diet, with low GI, high-fibre complex carbohydrates providing the majority of this requirement (Salmeron et al. 1997; Foster-Powell et al. 2002). This should increase to approximately 60–70% in an athletic population.

Protein

Protein plays a vital role in the maintenance of all body tissues. It is used as the structural basis of all cells, forms the contractile components of muscle, and is used to synthesise haemoglobin, enzymes, hormones, neurotransmitters and antibodies, helping to maintain the immune system and regulate all essential chemical reactions. Protein, which contains approximately 4 kcal/gram, is also used as an energy source, supplying about 5–10% of energy expenditure (Dohn 1986; Brooks and Mercies 1994).

Proteins are made up of amino acids, and it is these amino acids that are the real building blocks of the body. There are 20 amino acids, 12 of which can be synthesised from other amino acids and are considered *non-essential* and, and eight (nine for children) that are considered *essential* as they cannot be made within the body and therefore must come from the diet.

Protein is found in a variety of foods, however not all foods contain all of the essential amino acids. Those that do contain all the essential amino acids are termed *complete* proteins, which can be found in animal products such as meat, fish, poultry, eggs, milk and yogurt, as well as soya. *Incomplete* proteins have one or more of the essential amino acids missing. These are usually found in plant foods such as beans, pulses, vegetables, grains and rice. In order to get all of the essential amino acids athletes should either aim to eat complete proteins, such as those gained from animal sources, or combine other proteins to ensure that their essential amino acid needs are met.

The recommended intake of protein for a healthy sedentary person is 0.75g/kg.bw/day or approximately 15% of the diet (FSA 2008).

Fat

Fat has many essential functions within the body that include: energy provision, formation of cell membranes and nerve fibres, protection of vital organs, production of hormones, storage and transport of fat soluble vitamins, insulation, suppression of hunger and adding palatability to foods.

The body can store large amounts of energy as fat, mostly in the form of subcutaneous adipose tissue, which can be mobilised and transported to the working muscles as a fuel source during exercise, but also as intramuscular fat where it is more readily utilised within the muscles.

Fat contains approximately 9kcal/gram making it a very efficient way for the body to store large amounts of energy. High fat foods are therefore considered energy dense, making it easy for athletes to inadvertently consume too much energy from these foods. Managing fat intake is therefore a primary concern for athletes to prevent any unwanted increase in body fat.

Athletes should also consider the type of fat in the diet. Naturally occurring dietary fat can be either unsaturated or saturated. *Unsaturated* fatty acids contain one (monounsaturated) or more (polyunsaturated) double bonds between carbon atoms where each double bond replaces two hydrogen atoms. *Saturated* fatty acids contain no double bonds. Unsaturated fatty acids are generally liquid at room temperature and are found in plant sources and fish. Saturated fats tend to be solid at room temperature and come from animal sources. Saturated fats are associated with increased levels of low-density lipoproteins (LDL cholesterol) (Mustad et al. 1997) and an increased risk of coronary heart disease, whereas unsaturated fats are associated with a lower risk by reducing serum LDL (Kratz et al. 2002) and increasing high-density lipoproteins (HDL cholesterol) (Karmally and Goldber 2006).

Trans-fatty acids are formed by a process called hydrogenation. Vegetable oils are chemically changed to give them a higher melting point, effectively making them more solid at room temperature, and are used in the manufacture of margarine and other spreads. When unsaturated fatty acids are altered, and acquire some of the properties of saturated fatty acids through hydrogenation, they are termed trans-fatty acids.

All fats contain a mixture of fatty acid types, but it is the proportion of different fatty acids that makes some fats healthier than others. Fats associated with raised cholesterol levels and heart disease include those high in saturated animal fats (red meat, butter, cream, lard), and trans-fatty acids from hydrogenated vegetable oils (baked goods and some margarines) (Miettinen et al. 1972; Baer et al. 2004). Fats with a greater protective effect include monounsaturated and polyunsaturated fats found in olive oil and oily fish (Bucher 2002).

While most fatty acids can be synthesised within the body, there are two that are essential. The essential fatty acids are linolenic (omega-3) and linoleic (omega-6) fatty acids. Omega-3 fatty acids, in particular, are associated with beneficial effects on the cardio-vascular system (Simopoulos 1999). Linolenic fatty acids are found in oily fish and a range of vegetable oils such as sunflower and sesame. Linoleic fatty acids are found in most plant oils, especially corn and soybean oil.

Current guidelines for fat intake in a healthy diet recommend no more than 30% of energy intake as total fat, and less than 10% as saturated fat (DoH 1991, 1994).

Athletes should aim to avoid or reduce their intake of the following high fat foods: cake, biscuits, chocolate, fat on meat, sausages, pasties, pies, beef burgers, cheese, butter and cream. Moreover, athletes should aim to get the majority of their fat intake from oily fish, white fish, vegetable seeds and oils, soya beans and nuts.

Vitamins

Vitamins are essential organic molecules that cannot be synthesised in the body. Although they are only required in very small quantities, a deficiency can lead to symptoms of disease. Vitamins have a range of specific functions that are essential for health. These include: absorption of nutrients, anti-oxidants and protection of cell membranes, energy metabolism, catalysts for and regulation of chemical reactions and collagen synthesis. There are 13 compounds commonly identified as vitamins that are broadly categorised as either *water-soluble* or *fat-soluble*. A

Table 14.1 Reference nutrient intakes for healthy adults.

Vitamin	RNI (adult male)	RNI (adult female)
A	700μg	600μg
Thiamin (B1)	1.0mg	0.8mg
Riboflavin (B2)	1.3mg	1.1mg
Niacin (B3)	1.7mg	1.3mg
Pyridoxine (B6)	1.4mg	1.2mg
B12	1.5mg	1.5mg
Folic acid	200mg	200mg
C	40mg	40mg
D	10μg (if limited exposure to sunlight)	10μg (if limited exposure to sunlight)
E*	RNI not established	
K*	RNI not established	

Adapted from DoH 1991 – requirements vary for children and pregnant women.

summary of the body's requirements of these nutrients is provided in Table 14.1.

Water-soluble vitamins include vitamin C and the B-complex. They cannot be stored within the body and must therefore be consumed regularly. Any excess intake is normally excreted in the urine.

Vitamin B refers to a host of different vitamins that play an essential role in the release of energy from carbohydrates, fat and protein, and the formation of haemoglobin. They are known as the B-complex and include thiamine (B1), riboflavin (B2), pantothenic acid, niacin (B3), piridoxine (B6), folic acid, cyanocobalamin (B12), and biotin. Deficiencies can lead to fatigue, gastro-intestinal problems, heart failure and nervous disorders (FSA 2008). Vitamin B is found in grains, milk products, eggs, green vegetables, fish, liver, nuts and wholegrain and fortified cereals.

Vitamin C (ascorbic acid) works as an antioxidant and is essential for collagen synthesis, protein metabolism, wound healing, functioning of the immune system and iron absorption. Deficiencies can lead to poor immune function, poor wound healing, and scurvy. Good sources of Vitamin C include citrus fruits, tomatoes and green vegetables.

Fat-soluble vitamins include vitamins A, D, E, and K. These are stored in the body and can accumulate in fatty tissue. Excessive intakes may accumulate to toxic levels.

Vitamin A (retinol and beta-carotene) has many roles. It is an important anti-oxidant, and is essential for vision, immune function, bone health and gene transcription. Deficiency leads to vision impairments, particularly night blindness. Excess can become toxic and lead to numerous problems that could include birth defects, kidney problems, nausea, hair loss, headache, irritability, susceptibility to infection, fissures of the lips, blurred vision, bone and joint pains, muscle pain and weakness (FSA 2003). Whilst it is not possible to establish a Safe Upper Limit for vitamin A, total intakes above 1500 micrograms should be avoided (FSA 2003). Good sources of vitamin A include liver, kidney, milk, and eggs. Good sources of beta-carotene (a precursor to vitamin A) include green leafy vegetables and carrots.

Vitamin D plays a central role in the absorption and regulation of both calcium and phosphorus and is therefore essential for optimum bone health. Deficiency can lead to rickets, osteomalacia, and osteoporosis. Vitamin D is synthesised by the skin in response to UV exposure but can also be gained from foods such as fish, eggs, fortified dairy products and breakfast cereals.

Vitamin E refers to a group of antioxidants that prevent cell-membrane damage by reacting with radicals produced by lipid peroxidation. Vitamin E is found in seeds, nuts, green leafy vegetables, avocado, olives and vegetable oils.

Vitamin K is primarily responsible for blood clotting. A deficiency is associated with severe and uncontrolled bleeding, malformation of developing bone and cartilage calcification. The main dietary sources include green leafy vegetables, avocado, and kiwifruit.

Table 14.2 Summary of the functions and sources of key minerals

Mineral	Function	Foods
Boron	Promotes healthy bones, teeth; metabolism of other minerals	Fruits and vegetables
Calcium	Blood clotting, intracellular signaling, muscle contraction	Milk, yogurt, cheese, other dairy products, sardines, bread, sultanas, vegetables
Chromium	Insulin and glucose tolerance responses	Meat, wholegrain cereals, legumes and nuts
Cobalt	Contained in vitamin B12	Meat, dairy products, eggs
Copper	Formation of haemoglobin; absorption and use of iron; skin, hair pigmentation	Shellfish, liver, meat, cereal products, vegetables
Fluoride	Prevents dental carries; crystalline structure of bones and teeth	Water (variable), tea, seafood,
Iodine	Contained in hormones thyroxine (T4) and triiodothyronine (T3)	Seafood, vegetables and cereals
Iron	Contained in cytochromes, myoglobin, haemoglobin.	Beef, liver, eggs, sardines, apricots, fortified cereals, plain chocolate, bread, vegetables
Magnesium	Mineral present mainly in the bones; maintains electrical potential in nerve and muscle cells	Cheese, milk, chicken, cod, peanuts, bread, marmite, cereal products, potatoes, vegetables
Phosphorus	Contained in bones, teeth; role in energy metabolism	Cheese, eggs, milk, chicken, beef, ham, peanuts, marmite, meat and bread
Potassium	Role in fluid and electrolyte balance; heart muscle activity; metabolism and protein synthesis	Fruit and vegetables, fruit juices, milk, fish, meat
Selenium	Helps heart function; possibly prevents certain cancers	Meat, fish and cereal products
Sodium	Present in extracellular fluid	Table salt, bacon, ham, potato crisps, cereals, marmite, soy sauce
Sulphur	Energy metabolism, enzyme function, and detoxification	Cheese, eggs, nuts, onions, green leafy vegetables, fish, wheat germ
Zinc	Contained in enzymes, transcription factors	Meat and meat products, bread, cheese and eggs, milk, cereal products

For those following a varied and balanced diet, deficiencies in the fat-soluble vitamins are rare.

Minerals

Minerals have several major roles including the formation of bones and teeth, formation of haemoglobin and hormones, muscular contractility, neural conductivity, regulation of acid-base balance, and metabolism. Some minerals occur in the body in relatively large amounts. These are known as the major minerals and include: calcium, phosphorus, sulphur, potassium, chlorine, sodium, magnesium, zinc and iron. Other minerals occur in minute quantities. These are called trace minerals and include: chromium, cobalt, copper, fluorine, iodine, manganese, molybdenum, nickel, selenium, silicon, tin and vanadium (see Table 14.2).

Deficiencies of any mineral can lead to signs and symptoms of disease. Moderate excesses of sodium, potassium, calcium and chlorine are normally excreted by the kidneys, whereas excess intakes of other minerals can be harmful or impair absorption of other micronutrients (e.g. excess calcium inhibits absorption of iron and zinc; excess zinc inhibits absorption of copper) (Fairweather-Tait and Hurrell 1996).

In general, a balanced diet that contains a variety of foodstuffs and includes plenty of fresh fruit and vegetables should provide sufficient quantities of the minerals required for optimal health.

Two of the most important minerals for athletes are iron and calcium.

Iron is an essential element, which is required for oxygen transport (haemoglobin and myoglobin) and electron transport. It is found in the diet in two forms, haem iron and non-haem iron. Haem iron is generally found in animal foods and has greater bioavailability (10–35%). Non-haem iron, generally found in plant foods, has low bioavailability (2–10%) (Zijp et al. 2000).

Low iron levels can be due to inadequate diet, malabsorption or increased iron losses. To ensure an adequate iron intake, athletes should eat a variety of foods including red meat and green leafy vegetables. Iron absorption can be enhanced by the presence of vitamin C. Excessive intakes of iron are associated with gastrointestinal disorders including constipation, nausea, vomiting and diarrhoea, whilst chronic excess may lead to high body iron stores and increased risk of cardiovascular disease or cancer (FSA 2003). The FSA Expert Group on Vitamins and Minerals (2003) suggest that, for most people, an intake of approximately 17 mg/day would not be expected to produce adverse effects.

Calcium is another essential mineral for health and sports performance. It forms an integral part of bone structure, muscle contraction, blood clotting and transmission of nerve impulses. A deficiency can lead to rickets, reduced bone mineral density and osteoporosis, and problems with blood clotting.

The best dietary sources of calcium are milk and milk products, and green leafy vegetables. Overall absorption is generally poor and requires adequate vitamin D (FSA 2003).

Summary of micronutrients

Overall, a diet that is balanced and varied should meet the needs for vitamins and minerals for a healthy population. In athletes, the question of whether vitamins and minerals are required in greater amounts is more complex, and likely to be affected by the interaction between the total volume and intensity of sporting activity and the specific energy and nutrient intakes of each individual (Volpe 2006). It does appear, however, that a deficiency will have a negative impact on performance (Volpe 2006).

Water

Water is by far the most important nutrient. It accounts for 50–75% of body weight, depending on body fat content, with fat tissue containing approximately 20% water, lean tissue approximately 75%, and blood around 95%. Water has many crucial roles including temperature control (sweating), lubrication (brain, eyes, spinal cord and digestive system), a solvent for all biochemical reactions, and the transportation of nutrients and oxygen to, and carbon dioxide and other metabolic waste products away from, the working muscles. For optimal cardiovascular and thermoregulatory function athletes must therefore maintain sufficient body fluid levels and avoid dehydration, which results in a decrease in both cardiovascular (Gonzalez-Alonso et al. 1997) and strength and power performance (Jones et al. 2008). Water is gained from drink, food and metabolic reactions and is lost through urine, faeces, expired air and sweat.

Alcohol

Alcohol is a non-essential nutrient that has a range of negative effects for athletes. It causes intoxication, affects skill and co-ordination, leads to dehydration, de-motivates, inhibits recovery, lowers testosterone and provides an energy source (7kcal/gram) that can only be utilised once it has been deposited as fat. Overall, alcohol is highly detrimental to sporting performance, significantly reducing aerobic performance capacity for several hours after consumption (O'Brien and Lyons 2000; El-Sayed et al. 2005). Alcohol also acts as a diuretic and therefore may result in dehydration.

The importance of a balanced diet

For optimal health and performance it is essential that athletes get the right quantities and balance of all the nutrients. There are several tools and guidelines to ensure the correct quantities and balance of nutrients for health. The most common tool is the reference nutrient intake (RNI), which is the amount of a nutrient required to maintain adequate health for the majority of the population. RNIs are provided for energy, protein, vitamins and minerals. The advantages of using RNIs are that they give individuals a starting point to judge their diet in relation to a

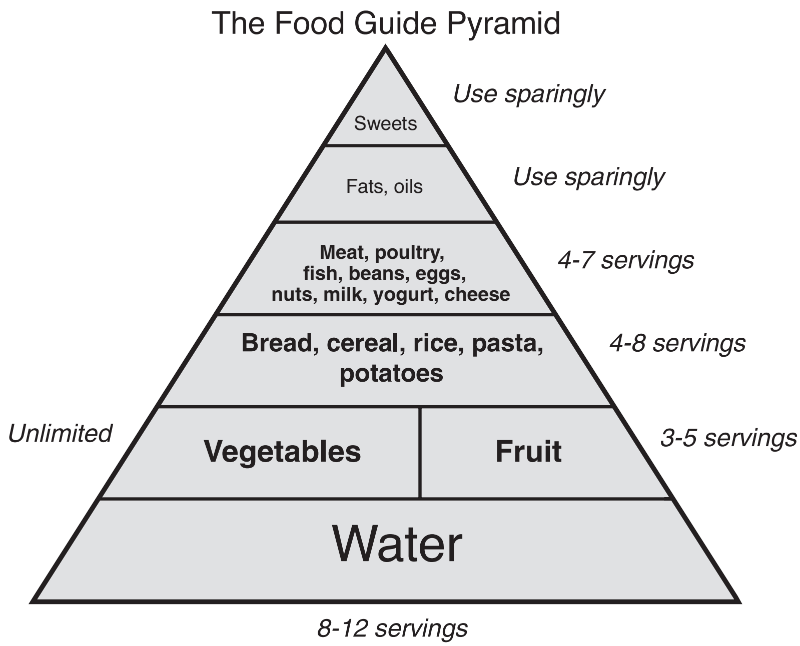

Figure 14.2 The food guide pyramid.

healthy population. RNIs, however, do not take into account the individual needs of athletes determined by the individual, the sport and the level of training. For athletes, a diet that is adequate for health may not be optimal for performance, due primarily to an increased energy expenditure.

The current UK government guidelines for health suggest a balance of approximately 55% carbohydrate, 15% protein and less than 30% fat (of which saturated fat should account for less than 10%) (FSA 2008). Again, these recommendations act as a good starting point for athletes but, as discussed later, there are a number of circumstances where these recommendations are modified. The optimal diet for an athlete will depend on the sport, activity levels, body size, weight gain or weight loss, and the type of training performed at any given time.

The food guide pyramid (Figure 14.2) is a common tool to help individuals achieve a healthy balance of foods within the diet. The pyramid shows the proportion and type of foods, which contribute to a healthy, balanced diet. At the base of the pyramid are carbohydrate-based foods, and requirements for fruit and vegetables. The pyramid reflects the percentage guidelines already outlined for the macronutrients in a healthy diet. Several alternative versions of the pyramid now exist to support specific groups (Painter et al. 2002).

Nutrition for performance

Optimal nutrition for performance is determined by what, when and how much an athlete eats. A diet that is adequate for health is not usually optimal for performance. For example, athletes will require more energy, greater quantities of certain nutrients (carbohydrates, protein) and will need to consume food at key times before, during and after training or competition.

Energy requirements for specific sports/training activities

Energy requirements for athletes are determined by their size, basal metabolic rate, the extra energy that is required for activities performed throughout the day (training and competition), recovery and adaptation from training and competition and whether the athlete is trying to gain or lose weight.

Mean total daily energy expenditures vary between different athletes. For example:

- male boxers (57Kg) expend 2900kcal; male weightlifters (110Kg), 4900kcal; female basketball players (61.4Kg), 3100kcal (Ismail et al. 1997).
- male cross-country skiers (during periods of hard training) use around 8600kcal/day (Sjodin et al. 1994).
- professional road cyclists expend over 6000kcal per day throughout the three-week Tour de France event, and use in excess of 9000kcal per day during hard mountain stages (Saris et al. 1989). This is reflected by high reported energy intakes (in excess of 5450 Kcal) during training and competition (García-Rovés et al. 2000).

In team sports, differences in activity levels will also vary with playing position, resulting in large variations in energy expenditure between individuals on the same team, which must be matched by energy intake. For example, Lundy et al. (2006) report that elite professional rugby league players consume between 2700 and 6900 kcal/day (mean 4230kcal/day) depending on size and position, although it is worth noting that this is 'normative' data and this level of consumption may not necessarily be optimal. In fact, Lundy et al. (2006) recommended that these athletes increase their energy intake through additional carbohydrate consumption.

Macronutrient requirements for performance

Energy needs are met from carbohydrate, fat and protein. The balance of use between these fuels, at any one time, depends on the intensity and duration of exercise. At the exercise intensities normally encountered during training and competition, carbohydrate is usually the primary energy substrate. To optimise performance athletes need to consume the right fuels at the right time.

Carbohydrate requirements for performance

The selection of fuel for muscular work is directly related to the intensity of effort with the higher the intensity, the greater the reliance on carbohydrate as a substrate (see Figure 14.3) (Romjin et al. 1993). As most sports are performed at high intensities carbohydrate becomes the primary source of energy.

In the body, carbohydrate is stored primarily as muscle and liver glycogen. Carbohydrate stores, however, are limited to approximately 450g of muscle glycogen (with a range from 50g after exhaustive exercise to approximately 900g in a large, well-trained, well-rested, and well-fed athlete (Jeukendrup 2003, de Jonge and Smith 2008), 100–120g of liver glycogen, and 5g of circulating blood glucose. Just 2–3 hours of high-intensity activity may be enough to completely deplete these relatively limited glycogen reserves (Coyle et al. 1986). The status of the glycogen stores before activity, therefore, will determine the duration that high intensity exercise can be maintained (Astrand and Rodahl 1986). It is therefore important that, for endurance activities (Coyle et al. 1986) and high-intensity

Calculating energy needs

Energy needs can be calculated by the following formula:

Energy EAR (eatimated average requirement) = BMR (basal metabolic rate) × PAL (Physical Activity Level).

PAL refers to the ratio of total energy required over 24 hours to the BMR over 24 hours. For example a PAL of 1.4 represents very low activity levels, 1.6 represents moderate activity levels, and 1.9 represents high activity levels. Most athletes will have a PAL of 1.9 or above.

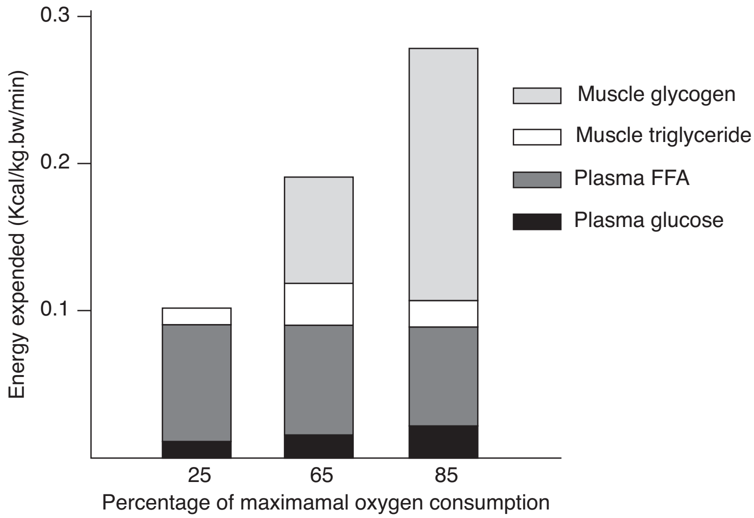

Figure 14.3 Contribution of muscle glycogen, plasma glucose, plasma FFA, and muscle triglyceride to energy expenditure after 30 min of exercise at 25%, 65%, and 85% of maximal oxygen uptake in fasted subjects (from Romjin et al. 1993).

intermittent activities (Balsom et al. 1999), athletes aim to optimise their glycogen stores. Depending on the intensity and volume of training, this is normally achieved with an intake of 5–13g/kg.bw/day(see Table 14.4) (Jeukendrup and Gleeson 2004).

Pre-exercise

To delay fatigue, and therefore enhance performance, athletes should optimise muscle glycogen stores pre-exercise (Astrand and Rodahl 1986). In short, glycogen stores must be sufficient to allow completion of the event at the highest possible intensity. It is important to distinguish between maximal and optimal storage of glycogen. For events where glycogen depletion becomes a limiting factor for performance (e.g. the marathon, a soccer match) it is clearly desirable to maximise stores prior to the race or game. For shorter events, for example, a 10K race, maximising glycogen stores may not be desirable. Every gram of glycogen is stored with approximately 2.7 grams of water so any additional weight from excess glycogen storage has the potential to inhibit performance. Athletes should therefore only seek to 'carbo-load' for sports where glycogen depletion may become a limiting factor in performance.

Carbohydrate-loading

Athletes can maximise muscle glycogen stores through a carbohydrate loading regime (see Table 14.3). There are several protocols for doing this. Early research suggested athletes should perform an exhaustive bout or bouts of exercise followed by 3-4 days of very low carbohydrate intake or very low carbohydrate/high fat intake, followed finally by 3-4 days of extremely high carbohydrate intake (Ahlborg et al. 1967; Bergstrom et al. 1967). Although this did increase muscle glycogen stores, athletes were reluctant to train so hard and felt lethargic and irritable just a few days before competition. A later and more widely adopted protocol involved tapering training over a seven day period and increasing consumption of carbohydrate for three days before the race (Sherman et al. 1981). The advantage of this method was that athletes benefited from increased glycogen stores without the negative side effects. Most glycogen loading protocols used by athletes and researchers involve the Sherman et al. (1981) protocol, or variations thereof (Madsen et al. 1990; Widrick et al., 1993; Burke et al. 2000; James et al. 2001). More recently even higher glycogen levels have been achieved by the inclusion of a 3-minute intense bout of training (150s of cycling at 130% of VO_2 peak followed by 30s of all-out cycling) 24-hours

Table 14.3 Suggested carbo-loading protocols for (1) an endurance event, and (2) a weekly match (for a team sports player)

Endurance event	
Days before the event	Action
7–10 days before the event	Start to taper training
6–4 days before	Consume 7g/kg.bw/day
From 3 days before	Consume 10–13g/kg.bw/day
Weekly match	
From 2 days before the match	Taper training
Days 7–6 before the next match	To facilitate recovery from the previous match – consume 10g/kg.bw/day
Days 5–3 before the next match	To maintain stores during training – consume 7–10/kg.bw/day
From 2 days before the match	To ensure optimal levels of muscle glycogen prior to the next game – consume 10g/kg.bw/day

before the event followed by 10.3g/kg.bw/day of high-glycaemic index carbohydrates (Fairchild et al. 2002). The main advantage of this protocol is not that higher glycogen levels are reached, but that they are achieved in a much shorter time-frame (24 hours) and do not necessarily require an extended period of tapering. Whilst there may be obvious advantages to athletes that compete on a regular basis – for example, team sport athletes – there is, as yet, little evidence to support the use of this method in a practical setting over Sherman et al. (1981), particularly as the potential negative effects of the 3-minute intense bout 24-hours before competition are not yet fully realised.

Liver glycogen stores in particular are sensitive to dietary intake of carbohydrate and can be depleted by the overnight fast. To replenish liver glycogen stores, athletes should eat breakfast and/or consume a pre-competition meal. For example, consume 150–300g of moderate GI carbohydrate three to four hours beforehand. To maintain blood glucose, smaller amounts of carbohydrate (e.g. $<$50g, of low-moderate GI) can then be consumed in the hour prior to exercise.

Fructose (the sugar often found in fruit, honey and commercial sports drinks) has been suggested as a source of carbohydrate immediately prior to exercise as the insulin response is lower than with glucose (Maughan et al. 1997), however, for many athletes fructose can lead to gastrointestinal discomfort (Murray et al. 1989; Beyer et al. 2005).

Table 14.4 Summary and practical carbohydrate intake recommendations to replenish muscle glycogen during training

Volume/intensity of training	Approximate duration	Daily carbohydrate requirements*
Moderate training	1–2 hours	5–7g/kg.bw/day
Heavy training	2–3 hours	7–10g/kg.bw/day
Very heavy training	Over 3 hours	10–13/kg.bw/day

*From Jeukendrup and Gleeson (2004).

During exercise

Whilst the benefits of pre-competition (or pre-training) carbohydrate loading are well established, there is also clear evidence for an ergogenic effect of carbohydrate feeding *during* an event (Coggan and Coyle 1991). Rather than reducing the rate of glycogen utilisation (Bergstrom et al. 1967; Tsintzas et al. 1996), carbohydrate ingestion appears to maintain blood glucose levels late in exercise, thus maintaining carbohydrate oxidation, and therefore performance, during endurance exercise (Coyle et al., 1986, Coggan and Coyle, 1991). Carbohydrate ingestion also improves endurance performance during intermittent high-intensity running in athletes with already high pre-exercise muscle glycogen concentrations (Foskett et al. 2008), and should therefore be considered an essential practice for team sport athletes.

Carbohydrate feeding during exercise is often best achieved through the use of sports drinks or carbohydrate gels. These are palatable, convenient to take, and generally tolerated well by athletes. Sports drinks typically contain around 60g of carbohydrate per litre, which is close to the maximum amount of exogenous carbohydrate that the body can absorb and oxidise per hour (1-1.1g/min) (Jeukendrup and Jentjens 2000; Wallis et al. 2007; Jeukendrup, 2008). For longer events, athletes can carry small snacks of easily digested high-carbohydrate foods (e.g. sports gels, jelly-beans, jam sandwiches). To identify what they like and what they can tolerate, athletes should practice eating and drinking during training. Depending on the priority (fluid delivery or carbohydrate delivery) athletes can vary the concentration of carbohydrate in the sports drink. For example, a 5% solution will be more appropriate for those athletes wishing to replenish both water and carbohydrate. A 10% solution will be more suited to carbohydrate delivery at the expense of gastric emptying (Maughan 1991) however, during exercise this may result in gastrointestinal distress in some individuals.

It is often difficult for team sport athletes to consume food or fluid during the game. Players and support teams must be organised and proactive during any stoppages, time-outs, injury breaks, and half-times as these breaks provide the perfect opportunity to consume an isotonic carbohydrate-based drink.

Post-exercise

To enhance recovery and provide the fuel for the next match or training session, athletes must restore their muscle glycogen stores as soon as possible post-exercise. If glycogen stores are low at the start of the next training session, muscle glycogen and overall carbohydrate utilisation will be reduced, lowering the exercise intensity that can be maintained.

The rate and extent of glycogen re-synthesis is dependent on the quantity, timing and type of carbohydrate ingestion, and on the nature of recovery (Maughan et al. 1997).

How much?

Glycogen re-synthesis depends on the quantity of dietary carbohydrate consumed. To replenish glycogen stores athletes should consume at least 1g/kg.bw immediately post-exercise (Ivy 1998) or a minimum of 1–1.85g/kg.bw of carbohydrate per hour in the first few hours post-exercise (Jentjens and Jeukendrup 2003) and maintain a daily intake of 5–7g/kg.bw/day during periods of moderate training (1–2 hours per day), 7–10g/kg.bw/day when training load is increased (2–3 hours per day), and 10–13g per kg/day during periods of hard or prolonged training (over 3 hours per day) (Jeukendrup and Gleeson 2004).

When?

Due to elevated enzyme activity (glycogen synthase) (Sherman et al. 1983; Doyle et al. 1993) and cell membrane permeability, the highest rates of muscle glycogen synthesis occur when athletes consume large amounts of carbohydrate (1.0–1.85 g/kg.bw/h) immediately post-exercise, followed by further feeding at 15–60 minute intervals thereafter for up to 6-hours post-exercise (Ivy 1998; Jentjens and Jeukendrup 2003). When carbohydrate feeding is delayed, lower rates of muscle glycogen synthesis will occur (Jentjens and Jeukendrup 2003). Therefore, to facilitate glycogen resynthesis, athletes should consume carbohydrates as soon as possible post-exercise.

What?

High glycaemic index snacks (eg. jaffa cakes, jelly beans, toast and jam) and, in particular, carbohydrate based drinks are convenient, easily and more rapidly absorbed and digested, and will provide sufficient carbohydrate until consumption of a larger meal. In order to maintain the high level of carbohydrate intake and glycogen resynthesis, the post-exercise meal should be based around complex carbohydrates such as pasta, rice or potatoes.

Type of recovery

Passive recovery appears to be a more effective strategy to optimise glycogen resynthesis, particularly in type I muscle fibres (Choi et al. 1994; Fairchild et al. 2003).

Carbohydrates and protein

Although some studies have shown enhanced glycogen resynthesis when carbohydrate feedings are combined with protein, as long as the carbohydrate feedings are adequate, and meet the recommendations, there appears to be no additional benefit on glycogen resynthesis or performance when protein is taken as well (Jentjens et al. 2001; Osterberg et al. 2008). Despite this there may be some additional benefit in terms of protein synthesis and muscle regeneration when both protein (10–20g) and carbohydrate (60–90g) are combined post-exercise (Griewe et al. 2001; Bolster et al. 2004; Dreyer et al. 2008).

Summary/Key points

- Athletes should aim to optimise glycogen levels pre-exercise via breakfast and a pre-exercise meal (low-moderate GI carbohydrates). See table below for examples.
- During exercise consume up to 70g/hour to maintain carbohydrate oxidation and exercise intensity (sports drinks, easily digestible snacks, see the table below for examples).
- Consume high glycaemic index and easily digested carbohydrates immediately post-exercise (1-1.85g/kg.bw).
- Consume 1g/kg.bw high glycaemic index carbohydrates within the next 2 hours post exercise.

Table 14.5 provides examples of carbohydrate-rich foods ideal for pre-, during and post-exercise.

Fat as a fuel for exercise

Whilst high-intensity exercise is fuelled predominantly by carbohydrate, at lower intensities, or late in prolonged exercise, fat becomes increasingly important (Klein et al. 1994; Horowitz and Klein 2000). In contrast to limited carbohydrate stores, fat stores are large, with an average person storing over 100,000 kcal of energy as fat, mainly as subcutaneous adipose tissue. Due to limits in the fat oxidation process, however, these stores cannot be fully utilised for exercise.

There are several steps involved in the oxidation of fat for energy:

1. lipolysis, where stored fat must be broken down to fatty acids for transport around the body
2. transport of fatty acids in the blood stream to the muscle cell
3. transport of fatty acids across the cell membrane and to the mitochondria for oxidation.

The slow rate at which these processes occur is a key limiting factors for athletes and why carbohydrate, which is readily available for oxidation, is the primary fuel for high intensity exercise

Table 14.5 Example carbohydrate rich foods (providing approx. 50g carbohydrate per portion) for pre-, during-, and post-exercise

Pre	During	Post
1 large bowl of cereal with milk – cornflakes, Frosties, Shreddies, branflakes, 3–4 Weetabix or Shredded Wheat	750ml sports drink	2 slices toast/bread with jam or honey
1 cup of soup and a large bread roll	1–2 gels or sports bars	2–3 crumpets with jam or banana
500ml fruit juice	500ml fruit juice	500ml fruit juice
3/4 can of baked beans on 2 slices of toast	75g jelly babies	3/4 can of baked beans on 2 slices of toast
1 bagel or 2 bread rolls with filling	6 jaffa cakes	250ml milkshake or fruit smoothie
2 slices malt loaf / 2 cereal bars		2 slices malt loaf/2 cereal bars
1 large baked potato		300g mashed potato
1 packet dried fruit		1/3 pizza with topping
1 bowl fruit salad with pot of fruit flavoured yogurt		1 can of rice pudding
2 bananas		6 jaffa cakes/1 mars bar
		1 large currant bun

The relative contribution of fat for fuel depends on both the *intensity* and *duration* of exercise and whether *carbohydrate* has been consumed.

Intensity

At rest the majority of our fuel requirements come from fat. As exercise intensity rises, the rate of lipolysis and oxidation increase to a maximum at approximately 64% VO_2 max (Achten et al. 2002). At higher exercise intensities (approximately 86–89% of VO_2 max) the contribution of fat oxidation to energy expenditure is negligible (Achten et al. 2002; Achten and Jeukendrup 2003), probably due to the restricted transport of fatty acids to the mitochondria via limited blood flow to subcutaneous tissue, and lactate accumulation (Coyle et al. 1997).

Duration

As exercise progresses, fat oxidation plays an increasingly important role. As liver and muscle glycogen stores decrease, the body's ability to oxidise carbohydrate is depleted and fat becomes the dominant fuel, with *an associated drop in exercise intensity* (not ideal during competition).

Carbohydrate intake

Carbohydrate consumption also appears to decrease fat oxidation (Horowitz et al. 1997). Therefore a pre-exercise meal that is high in carbohydrate will reduce fat oxidation. Despite this suppression of fat oxidation, the overall aim is to increase carbohydrate oxidation and therefore pre-exercise carbohydrate intake should be paramount.

Increasing fat oxidation

To enhance the use of fat as an energy source, and therefore save glycogen stores, athletes can adopt several practices. Endurance training is the most effective, increasing the rate of lipid metabolism through increased size and number of muscle mitochondria, increased activity of lipid oxidising enzymes, and increased intra-muscular triacylglycerol stores (Coyle 1995; Phillips et al. 1996). Evidence for dietary manipulation of fat intake to enhance fat oxidation, however, is inconclusive with high-fat diets and supplementation with medium-chain triglycerides failing to show any significant ergogenic benefit (Hawley et al. 1998; Hawley 2002). Whilst caffeine ingestion has been shown to increase endurance performance, usually attributed to an increased level of lipid oxidation (Ivy et al. 1979) it is still unclear whether this is due to enhanced fat metabolism (Graham 2001).

Summary/Key points

- Fat stores in humans are much larger than carbohydrate stores and provide an important source of fuel for exercise.
- Fat oxidation is limited by the steps in the oxidation process.
- Fat oxidation increases with exercise intensity up to 60–65% VO_2 max. At higher intensities fat oxidation is restricted.
- Carbohydrate feeding reduces lipolysis and fatty acid availability, which inhibits fat oxidation and increases carbohydrate usage.
- Manipulation of fat in the diet via high fat diets, or medium chain triglycerides has a limited benefit for performance.

Protein requirements for performance

Do athletes need more protein than non-athletes? Whilst the current UK RNI for protein is 0.75g/kg.body-weight per day (FSA 2008), there are several mechanisms by which athletes could require more. These include: increased oxidation of amino acids during exercise, increased proteolysis as an acute response to exercise, and increased protein synthesis as an adaptation to training.

For endurance and intermittent sprint sports, protein requirements may be increased due to increased content of mitochondrial proteins and increased involvement in oxidative metabolism. To account for this an intake of 1.2–1.4g/kg.bw/day is generally recommended for endurance athletes (Lemon 1995). Consistent levels of high intensity/high volume training where high levels of amino acid oxidation occur may increase protein requirements for endurance athletes to 1.6 g/kg.bw/day (Tarnopolsky 2004; Campbell et al. 2007), with extreme endurance

Table 14.6 Summary of protein requirements for athletes

Population	Protein requirements
Sedentary	0.75–0.8 g/kg.bw/day
Endurance athlete – moderate volume	1.2–1.4 g/kg.bw/day
Endurance athlete – high volume	1.6 g/kg.bw/day
Endurance athlete – extreme	1.6–2.0g/kg.bw/day
Intermittent sport athletes (soccer)	1.4–1.6 g/kg.bw/day
Serious resistance trained athletes	1.7–1.8 g/kg.bw/day
Novice weight trainers in first few weeks	2.0 g/kg.bw/day

From Lemon 1994, 1996; Tarnopolsky 2004; Fink et al. 2005; Campbell et al. 2007.

athletes requiring up to 2.0g/kg.bw/day (Fink et al. 2005) due to athletes' inability to consume adequate levels of carbohydrate throughout the day. Athletes engaged in intermittent sports should aim for an intake of 1.4–1.6g/kg.bw/day (Lemon 1994) (Table 14.6).

For strength and power sports, an increase in muscle mass via increased formation of actin and myosin may increase protein requirements during periods of resistance training (particularly during the initial stages of training) to 1.7–2.0g/kg.bw/day (Lemon 1996, 1997; Campbell et al. 2007) (Table 14.6). There is no mechanism for storing excess dietary proteins in the body so amino acids ingested in excess of the body's immediate requirements are oxidised and the nitrogen excreted.

In general protein intake increases in proportion to energy intake. Those consuming a balanced high-energy diet are likely to meet protein requirements with no need for supplementation. A balanced diet to meet protein needs should include meat, fish and dairy products, cereals, nuts and beans. Alternative protein sources such as Quorn™ are ideal for vegetarian athletes. Athletes who restrict their diet, however, may be at risk of insufficient protein intake, with endurance athletes (via exercise induced appetite suppression), and those competing in weight category or aesthetic sports, at greatest risk.

Timing of protein intake

Pre-exercise. The athlete should aim to create an anti-catabolic environment prior to exercise. For resistance training, Tipton et al. (2001) observed an increase in net amino acid uptake when essential amino acids plus carbohydrates were ingested pre-exercise versus post-exercise. It therefore seems prudent for athletes to consume a protein-based snack (approx. 10g) prior to resistance training. For example milk, yogurt, tuna or turkey sandwich.

Post-exercise. Results appear mixed regarding the ingestion of protein post-exercise (Roy et al. 2000; Rasmussen et al. 2000; Godard et al. 2002; Levenhagen et al. 2002; Rankin et al. 2004; Rowlands et al. 2007). Overall, however, there appears to be some additional benefit of consuming a protein and carbohydrate based snack/drink *immediately* post-exercise. It is unclear whether increases in fat-free soft tissue and strength occur as a result of the additional energy, the presence of amino acids, or both (Roy et al. 2000; Levenhagen et al. 2001, 2002; Rankin et al. 2004).

The athlete should aim to create an anabolic environment post-exercise. This is usually achieved via a protein and carbohydrate snack or drink *immediately* after exercise. For example: milkshake, yogurt and banana, cereals with milk, beans on toast, or a sandwich with a protein filling such as ham, turkey or tuna. Athletes may find that the consumption of a protein-based drink, such as a milk shake, is the most convenient and easily tolerated method to consume and absorb protein quickly post-exercise. It is essential that this drink also contains adequate (75–90g) carbohydrates, as discussed above.

Throughout the day. Increased protein intake leads to increased activity of those enzymes responsible for oxidising protein. Enzyme activity increases quickly in response to a large protein meal, but takes longer to down-regulate (van Hall et al. 1996). A large meal therefore leads to greater levels of protein oxidation (Schauder et al. 1984). To ensure that protein is constantly available for growth and repair, without being preferentially oxidised, athletes should therefore eat small quantities of protein regularly throughout the day.

Summary and practical recommendations

- Protein requirements vary depending on the sport, training, and the individual.
- *Endurance athletes* should consume 1.2–2.0g/kg.bw/day, depending on the volume of training.
- *Intermittent sport athletes* should consume 1.4–1.6g/kg.bw/day.
- *Strength athletes* should consume 1.7–2g/kg.bw/day.
- Eat small quantities at each meal, not all in one go.
- Athletes should consume protein from a variety of sources to ensure they achieve a balance between the essential and non-essential amino acids (complete proteins from animal sources will provide all of the essential amino acids).
- Prior to resistance training consume a protein-based snack.
- Immediately post resistance training consume a protein-based snack.
- Protein intake above those recommended (1.2–2.0g/kg.bw/day) is not necessary for most athletes.
- Ensure adequate carbohydrate intake – the body will use increased levels of protein in a glycogen-depleted state.

Calculating macronutrient requirements for different sports

The tables below show the different nutritional intakes by different athletes.

The examples shown in Tables 14.7 and 14.8 provide a useful reference point for athletes. The practical implications of food intake during training or competition, however, may affect the consumption of each macronutrient and also the overall balance. For example, in practice, a Tour de France cyclist may find it difficult to achieve the 13g/kg.bw/day required to maintain performance. To supply this requires large quantities of easily digestible carbohydrate that is delivered to the cyclist throughout the ride and requires considerable logistical support before, during, and after each stage.

Table 14.7 Example nutritional intake for a Tour de France cyclist

Cyclist – 75Kg – Energy requirements ~ 5500 kcal/day				
Nutrient	Quantity	Total	Energy	% daily intake
Carbohydrate	13g/kg.bw/day	975	3900	69.9
Protein	2.0g/kg.bw/day	150	600	10.8
Fat	120g /day	120	1080	19.3
		Total	5580	100

Fluid for performance

Adequate hydration, and the maintenance of fluid balance, is crucial for performance. During exercise, 75–80% of the energy used by the muscles appears as heat with the greater the intensity of exercise, the greater the heat produced. This heat is dissipated through the evaporation of sweat. It is possible to lose up to 2.5 litres per hour during intense activity

Table 14.8 Example nutritional intake for a rugby league player

Rugby league – 100Kg – Energy Requirements ~ 5000 kcal/day				
Nutrient	Quantity	Total	Energy	% daily intake
Carbohydrate	8g/kg.bw/day	800	3200	64
Protein	1.8g/kg.bw/day	180	720	14.4
Fat	120g /day	120	1080	21.6
		Total	5000	100

(Casa et al. 2000) with losses up to 3.1 litres observed during a 90-minute soccer training session in the heat (Shirreffs et al. 2005), or 2.65 litres in a cool environment (Maughan et al. 2005). The loss of fluid in sweat and associated dehydration contributes to fatigue and hyperthermia during exercise (González-Alonso et al. 1997) with distance runners (5000 and 10,000m) forced to slow their pace by more than 6% following a 2% loss of bodyweight through dehydration (Armstrong et al. 1985). This is further compounded when exercising in hot environments or during events of longer duration. Single bout sprint and power performance, however, does not appear to be negatively affected by dehydration (Watson et al. 2005).

Besides physical performance, dehydration also inhibits co-ordination and increases risk of injury. Because changes in body water content (2% of body weight) can severely impair physical performance, as well as psychomotor, and cognitive performance (Grandjean and Grandjean 2007), potentially increasing risk of injury, it is essential that athletes maintain fluid levels and avoid dehydration. The continued ingestion of fluid therefore becomes a major factor in delaying fatigue during exercise.

Fluid intake during exercise

Fluid intake during exercise has a number of benefits. These include the prevention of dehydration, the maintenance of blood volume, osmolality and viscosity (ensuring cardiac output and the maintenance of performance), and the maintenance of skin blood flow and sweat rate (reducing the risk of hyperthermia and heat stress).

Most athletes, however, do not voluntarily drink sufficient water to prevent dehydration during physical activity (NATA Position Statement: Fluid Replacement for Athletes (2000)). Shirreffs et al. (2005) observed that players only replaced between 9 and 73% (45±16%) of the fluid lost through sweat during a 90-minute training session in the heat. Thirst is a sign of dehydration but, because it is possible to dehydrate by 2% of bodyweight before thirst occurs, athletes must drink before getting thirsty.

Factors affecting fluid intake

There are several factors that affect fluid intake during training and competition. These include availability of fluid, thirst, awareness of sweat losses, opportunity to drink and the palatability of fluid.

Ideal fluid for exercise

Initially fluids should be cool (10–12 °C), palatable, not acidic or gassy and not cause gastrointestinal distress. Water fits this description and is a good place to start, however there are good reasons why drinks should also contain carbohydrate (for energy and to maintain carbohydrate oxidation), salt (0.3–0.7g/l) (to aid fluid retention and stimulate thirst) (Casa et al. 2000), and be isotonic – have an osmolality of 280–300 mOsm/kg (to aid gastric emptying). Sports drinks typically contain a mixture of water, carbohydrates and salt, and benefit athletes through quicker re-hydration after training, quicker refuelling of carbohydrates, stimulating thirst, and being convenient and readily available.

Practical recommendations

What, when, and how much athletes drink will be determined by a range of factors.

What to drink? Athletes must identify whether the priority is to supply fluid or energy. If fluid, then electrolyte solutions with 4–6% carbohydrates will work well (Murray et al. 1999). If carbohydrates are the priority then a more concentrated solution (6–10% carbohydrate) may deliver more carbohydrate. There is, however, some evidence that solutions over 8% may cause gastro-intestinal distress (Shi et al. 2004). Overall, it appears that carbohydrate solutions in the 6–8% range provide the optimal balance of gastric emptying, fluid absorption and carbohydrate delivery. Athletes should experiment with varying concentrations during training to determine what they can tolerate.

When to drink? This will largely depend on the nature of the sport and availability of fluid.

How much to drink? This will depend on whether it is before, during, or after exercise, on losses through sweat, and on how much fluid the athlete can reasonably tolerate.

Prior to exercise: athletes should drink sufficient quantities to ensure they are well hydrated before exercise, with their urine clear for several hours beforehand. As competition approaches, a drink of 500–600ml 2–3 hours before exercise followed by another 200–300 ml 10–20 minutes before exercise begins (Casa et al. 2000) will ensure athletes arrive in a well-hydrated state. Taking regular sips until, the start may be a useful way for athletes to consume these quantities. For longer events, where dehydration may inhibit performance, athletes should drink an additional 400–600ml of water (or carbohydrate solution) *immediately before exercise.* Athletes should experiment in training to ensure they can tolerate both the quantity and the type of drink.

During exercise: drink 100–300ml of water every 15 minutes as tolerated (Rehrer et al. 1990). For team sports, drink at halftime or during breaks in play. Again, athletes should practice drinking during training. Adding carbohydrates and electrolytes, as found in most popular sports drinks, will ensure delivery of carbohydrate for oxidation and glycogen replenishment (during a break), and electrolytes to aid retention.

After exercise: the priority post-exercise is to replenish what was lost (both in terms of fluid and glycogen stores). Fluid intake needs to be about 150% of weight lost during exercise to achieve normal hydration within 6 hours post-exercise (Shirreffs et al. 1996). Ingesting plain water though is largely ineffective as this dilutes plasma and inhibits the secretion of anti-diuretic hormone. Adding sodium (60–80 mmol/litre) will reduce urinary water loss, aiding fluid retention and the recovery of fluid balance (Nose et al. 1988; Sharp 2006). Moreover, adding sodium will trigger thirst and promote drinking. Cool fluids are more palatable. Therefore to promote rapid recovery of fluid balance post exercise, athletes should focus on both volume of fluid (around 150% of weight loss) and sodium content (60–80mmol/litre). The inclusion of carbohydrate (4–6%) will also help to restore glycogen stores.

Hydration for team sports

Team sports such as football, rugby, hockey and netball present another problem. Often athletes cannot consume fluid throughout the match or training session. Athletes therefore need to ensure adequate hydration on days prior to a match, follow the pre-exercise fluid intake guidelines above, aim to consume at least 500ml at half time, and try to drink during any other breaks in play such as during injury breaks. Post-match, athletes should follow the guidelines above for rehydration post-exercise.

Carbohydrate versus fluid delivery

Carbohydrates provide the substrate for glycogen resynthesis and maintenance of blood glucose, but there can be a conflict with fluid absorption at higher carbohydrate concentrations. If an athlete is dehydrated then fluid (and electrolyte) intake will be paramount. A carbohydrate concentration of no more than 4–6% will ensure that gastric emptying is not affected. If carbohydrate is the priority (either for oxidation or glycogen resynthesis) then higher levels up to about 10% may be consumed.

Summary/Key points

- Start well hydrated. Thirst is not an indicator of fluid need but a sign of partial dehydration. Athletes should consume fluids before they are thirsty.
- To avoid dehydration, drink about 500–600 ml in the hours before a race/match and 200–300 ml 10–20 minutes beforehand. Drink regularly throughout exercise (100–300 ml every 10–15 min).
- Carry fluids. This will encourage voluntary fluid consumption.
- Clear (pale yellow) urine is a sign that the athlete is well hydrated; dark urine, that the athlete is under-hydrated.
- Avoid foods and drinks that may have a diuretic effect (alcohol, strong coffee).
- Estimate sweat loss for each athlete by measuring body weight loss during training.
- During exercise, aim to drink sufficient fluids to match sweat loss.
- Combine carbohydrates with fluid ingestion to help replenish glycogen stores.

Vitamin and mineral requirements for athletes

Recommendations for micronutrient intake are largely based on the requirements of healthy, but relatively inactive people. During exercise it is likely that micronutient requirements will increase (Whiting and Barabash 2006).

Micronutrient intake varies widely between individuals and groups, with dietary surveys of athletes showing both high and low reported intakes of some vitamins and minerals, leading to the possibility of a long-term deficient diet or health problems associated with excess intakes. Athlete groups that may be at risk of insufficient micronutrient intake include those on restricted energy intakes (Haymes 1991), vegetarians, female athletes, those involved in endurance or aesthetic sports, and athletes in weight category sports. In these groups, consumption of a multi-vitamin supplement may ensure adequate intakes and avoid deficiency (Beals and Manore 1998).

There is no clear evidence that elevated intakes of vitamins or minerals will increase performance and no evidence that athletes require significantly higher levels of micronutrients than non-athletes. The priority therefore should be to avoid deficiency through the consumption of a diet that is both sufficient and balanced.

There are, however, several key micronutrients that either play a pivotal role during exercise or are particularly prone to deficiency.

Vitamin B

Because vitamin B plays an essential role in the release of energy from carbohydrates, fat and protein, and in the formation of haemoglobin, a deficiency can have serious consequences for the athlete, leading to fatigue and decreases in VO_2 max and power (van der Beek et al. 1994). Athletes at risk of possible deficiency may be those with restricted diets or vegans, whereas athletes with an energy rich diet are unlikely to be deficient. Good sources of the B vitamins include meat, fish, milk, eggs, wholegrain cereals, fortified breakfast cereals and some vegetables. Although, with a balanced and energy rich diet supplementation is generally unnecessary, a multivitamin will help meet requirements for athletes who may be unsure of their status.

Vitamin C and antioxidants

Although there is no evidence that athletes need more vitamin C than non-athletes, it is possible that antioxidant supplementation may decrease exercise-induced oxidative stress (Ji 1999; Morillas-Ruiz et al. 2006). Overall, athletes should avoid deficiency and obtain antioxidants via increased consumption of fruit and vegetables. Large doses of single antioxidant compounds are not recommended.

Minerals and exercise

Exercise is associated with increased losses of minerals in sweat and urine. Iron, calcium, magnesium and zinc may be a cause for concern in some athlete groups due to insufficient intakes and increased losses in sweat and urine. Of these, calcium and iron have the biggest impact on health and performance.

Iron

Iron depletion (low iron stores: low serum ferritin) is common in athletes (26% women, 11% men-Malczewska et al. 2001) but does not necessarily affect performance (Risser et al. 1988). Iron deficiency without anaemia may, however, impair adaptation to endurance training (Brownlie et al. 2004) in previously untrained women, but can be corrected with iron supplementation. Iron deficiency with anaemia (low haemoglobin) can impair work capacity and decrease exercise performance (Haas and Brownlie 2001).

Athletes at risk of iron deficiency include young athletes, female athletes (Beard and Tobin 2000; Gropper et al. 2006), athletes on low energy intakes (less than 300kcal/day), athletes in weight category sports, endurance athletes (Spodaryk 1993), vegetarians, and athletes training in hot climates or at altitude.

There are a number of ways to increase iron:

1. Athletes should eat foods rich in haem-iron at least four times per week (e.g. liver, lean red meat) as iron from these foods is readily absorbed.

2. Vegetarians should aim to eat iron-fortified foods (e.g. breakfast cereal) and other non-haem iron food sources (e.g. dried fruit, legumes, green leafy vegetables).

3. Athletes can increase the absorption of iron from non-haem iron foods by consuming them with vitamin C-rich foods (e.g. orange juice) and avoiding tea at meals.

Calcium

Athletes with low energy intakes and who avoid dairy products may not meet their calcium requirements. This is a particular problem for female athletes on low energy intakes (Clarkson 1995) as amenorrhea may further hinder bone development and increase the risk of osteoporosis. The current UK recommended daily intake of calcium is 700mg, with an upper safe limit of 2500mg. Calcium cannot be absorbed without Vitamin D (FSA 2008).

There are a number of ways to increase calcium:

1. Athletes should include three servings per day of low-fat dairy foods. Include these in high carbohydrate meals (e.g. skimmed milk on cereal).

2. Eat fish with bones (e.g. sardines, tinned salmon).

3. If athletes cannot tolerate dairy products then consider calcium-enriched soy products.

4. Eat green leafy vegetables (cabbage, broccoli, spinach).

5. Supplementing calcium to 125% RNI helps maintain bone density when amenorrhea is present.

Summary

Maintaining adequate intakes of vitamins and minerals is essential for health and performance. This can be achieved through a varied and balanced diet. Athletes who consume sufficient energy from a balanced diet are unlikely to have vitamin and mineral deficiencies (Armstrong and Maresh, 1996), however, the use of a multi-vitamin and mineral supplement for groups at risk or on low energy intakes may be appropriate.

Nutrition for injury prevention

Delaying fatigue

The most important nutritional consideration for injury prevention is in delaying the onset of fatigue. If an athlete is fatigued, there is a change in running mechanics (Gerlach et al. 2005; Kellis and Liassou 2009), landing mechanics (King et al. 2005), a decreased ability to maintain joint alignment, control and appropriate muscular activation patterns during potentially risky manoeuvres (Wojtys et al. 1996; Chappell et al. 2005), an increased incidence of high-risk actions (Rahnama et al. 2002), and an actual increase in injury occurrence towards the end of a match or phase of play (Hawkins et al. 2001). To limit fatigue, athletes should consume a diet that allows them to maintain optimal performance throughout the duration of a race, match or training session. The two most important nutrients to prevent fatigue are carbohydrate and water.

Carbohydrate

One of the primary factors linking fatigue and injury is the level of muscle glycogen (Sherman and Costill 1984; Costill and Hargreaves 1992). If muscle glycogen is low, athletes will not be able to maintain exercise intensity, muscles will fatigue and lose strength along with the ability to protect joints, coordination will suffer, protective motor programmes will be replaced by less efficient and more risky movement patterns, awareness of the game and environment will decrease, and reactions will slow (Schlabach 1994). These are the circumstances when injury is most likely to occur.

Therefore the primary nutrient that is required to avoid fatigue is carbohydrate. Athletes who are maintaining high-volume high-intensity exercise are most at risk and must optimise carbohydrate intake. Athletes should aim to consume 5–13g/kg.bw per day (depending on volume and intensity of exercise) by eating pre, during and post exercise (Jeukendrup and Gleeson 2004).

Long-term fatigue

Athletes that are in heavy training for prolonged periods are at risk of progressively depleting glycogen stores leading to a drop off in performance, increased risk of injury, compromised immune system and increased risk of illness, and ultimately overtraining syndrome (Kirwan et al. 1988).

Fluid

Fluid intake is the other primary factor in reducing signs of fatigue. The effects of dehydration largely mimic those of fatigue and can therefore contribute to injury risk. There is also a greater risk of heat injury when dehydrated, as the body is unable to thermo-regulate effectively. Glycogen use increases when dehydrated, further compounding the problems.

Athletes should be aware of and look out for the effects of dehydration. Initially these may include thirst, dark urine, tiredness, lack of concentration, dry skin and headache. Fluid intake should be monitored and matched to sweat losses. Fluid replacement strategies should be in place before, during, and after the game or training (Rehrer et al. 1990; Shirreffs et al. 1996; Casa et al. 2000; Sharp 2006).

Other factors to consider in injury prevention

Iron

Low iron intakes have the potential to affect injury risk through fatigue. In a study on female cross-country runners, over the course of the season, there were 71 injuries that caused a loss of training time. The 34 runners with the lowest ferritin concentrations had twice as many injuries as the 34 runners with the highest ferritin (Loosli et al. 1993). As iron plays a crucial role in the transport of oxygen to muscles, it is likely that athletes with low haemoglobin (caused by iron deficiency) have decreased oxygen delivery to tissues, reducing work capacity (Viteri and Torun 1974), and therefore fatigue more easily.

Bone health

Nutrition can affect bone health in several ways. First, low fat and low energy intakes are associated with an increased risk of stress fractures particularly in physically active women (Frusztajer et al. 1990; Nattiv 2000). Supplementation with calcium (2000mg) and Vitamin D (800IU), however, has been shown to decrease the incidence of stress fractures in female navy recruits by 20% compared with a placebo (Lappe et al. 2008).

In the longer term, a diet that is deficient in energy, fat, calcium or vitamin D may lead to osteoporosis. Moreover other nutrients, such as magnesium and potassium, along with an adequate protein intake, also appear to play a significant role in preventing the loss of bone mineral density (Hannan et al. 2000; Tucker et al. 2001).

Athletes, and in particular female athletes, should therefore ensure they consume a balanced diet containing sufficient energy, protein, fat, calcium and vitamin D with plenty of fresh fruit and vegetables to ensure a balanced micronutrient intake (Tucker et al. 2001).

Nutrition during injury

Injury can lead to a range of complex nutritional issues for some athletes. Body mass management (preventing weight gain during injury, restoration of muscle mass post injury) is crucial for effective rehabilitation. For example, if the athlete has a significant reduction in activity levels as a result of injury, then the diet will need to change to reflect the drop in energy expenditure. Moreover, athletes with poor diets, who have previously avoided weight gain through training, or those who turn to food for comfort, are likely to put on weight when injured, making it harder for them to return to full fitness. If, however, the athlete can maintain energy expenditure through other forms of exercise, then diet may not need to change.

Education is a priority. Athletes must aim for a nutrient rich and healthy diet that is sufficient to maintain energy balance. Athletes should focus on low-fat, low-sugar, high-fibre foods that provide sufficient carbohydrate, protein and fat, and which provide optimal vitamin and mineral intakes.

Despite lower activity levels when injured, athletes who are hospitalised, or subject to long-term incapacity, may still require increased protein (approx 1.4–1.7g/kg/day) to prevent loss of lean tissue, and maintain immune function (Bucci 1994). This can be met through the selection of low-fat protein options such as lean meat, fish and skimmed milk.

Supplements

The use of supplements by athletes requires caution. Whilst there is a substantial body of evidence that some substances found in the diet have an ergogenic or anabolic effect under certain conditions – for example, caffeine for endurance and power performance, and creatine for increasing short-term high-intensity exercise and muscle mass (Birch et al. 1994; Williams and Branch 1998; Greenhaff 2000; Graham 2001; Maughan et al. 2004; Doherty and Smith 2005; Hespel et al. 2006 – many of the elaborate claims made for supplements by manufacturers do not stand up to scientific scrutiny. Moreover, many supplements contain substances not declared on the label and in some cases these substances contravene IOC or WADA doping regulations and would cause an athlete to fail a drugs test (Geyer et al. 2004; Maughan 2005). For example, in an IOC funded study of 634 products labelled as non-hormonal nutritional supplements from 13 countries and 215 different suppliers, 14.8% contained anabolic steroid *precursors* not declared on the label (Schanzer 2002; Geyer et al. 2004). For products purchased in the UK this figure rose to 18.8% (Schanzer 2002; Geyer et al. 2004).

It appears that, for those athletes who may be required to take a drugs test, supplements are another potential source of contamination. It is therefore possible that an athlete could fail a drugs test due to the unintentional ingestion of prohibited substances present in dietary supplements (Maughan 2005). It is simply impossible to know for sure that any given supplement is pure and not contaminated by some substance that may be prohibited.

The principle of strict liability present in the World Anti-Doping Code means that athletes are ultimately responsible for any prohibited substances found in their system (UK Sport (2008) position statement on the use of supplements – July 2008). The unintentional ingestion of prohibited substances is not considered an acceptable excuse and athletes should therefore exhibit extreme caution when deciding on the use of dietary supplements. Moreover, supplements should not be considered a solution to a poor diet and athletes should strive to optimise their nutritional intake before considering the need for supplements.

The full position statement of UK Sport (2008) concerning the use of supplements appears below.

Position statement of UK Sport, Version 5, issued in July 2008.

There is an array of supplements available for athletes to purchase through a range of retail sources that have no prohibited substances listed as ingredients. Despite this there have been several cases whereby supplement products have been contaminated with prohibited substances as defined by the World Anti-Doping Code (WADC) Prohibited List.

UK athletes are advised to be vigilant in their choice to use any supplement. No guarantee can be given that any particular supplement is free from Prohibited Substances.

Athletes should be aware that any product that claims to restore, correct or modify the body's physiological functions should be licensed as a medicine, according to current legislation (for further information visit the Medicines Healthcare products Regulatory Agency website at www.mhra.gov.uk).

Diet, lifestyle and training should all be optimised before considering supplements and athletes should assess the need for supplements by always consulting an accredited sports dietician and/or registered nutritionist with expertise in sports nutrition and a sports and exercise medicine doctor before taking supplements.

An important principle of the World Anti-Doping Code (WADC) is that of strict liability stating athletes are ultimately responsible for any Prohibited Substances found in their system or for the use of any Prohibited Method. Therefore before taking supplements athletes must assess the risk and understand their personal responsibility.

In an attempt to support athletes a number of initiatives have been created globally to identify whether a prohibited substance can be identified within a supplement. As such, supplements may claim to be drug free or safe for drug tested athletes. It is not possible to guarantee that specific supplements will be free of prohibited substances but only to reduce the risk of inadvertent doping by making informed decisions.

In the UK HFL Sports Science has taken the initiative to create a scheme to support athletes in assessing the risk. The Informed-Sport programme is designed to evaluate supplement manufacturers for their process integrity and screening of supplements and ingredients for the presence of prohibited substances that are present on the WADC Prohibited List. The supplements industry has been consulted on this approach and supports its development.

UK Sport believes this risk minimisation service to be a positive step and welcomes the approach being taken by industry and the HFL owned Informed-Sport programme.

Ultimately we wish to remind athletes that strict liability will still apply and the appropriate sanctions provided to any athlete returning an adverse analytical finding from any supplement product as with all other anti-doping case.

Athletes who are subject to drug testing need to ensure that any commercial sports drink or food is legal. If in doubt, it is very easy to produce a home-made alternative.

For further reading and up to date information on supplements go to: www.uksport.gov.uk and www.100percentme.co.uk

Make your own sports drink

For training

1 litre of water

60g table sugar (or ideally powdered glucose/dextrose)

pinch of salt

diet cordial (to taste).

Add contents together. Shake.

For recovery

500ml skimmed milk

banana

2 heaped tablespoons of malted drink powder (Horlicks, Ovaltine, Nesquick)

Add contents together. Blend.

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