CHAPTER 7

Diet for Sport and Exercise

OBJECTIVES

By the end of this chapter you should:

- understand the basic physiology of muscle contraction
- appreciate how fuels are used for different types of exercise
- understand feeding strategies for optimum physical performance for different situations
- know of the ergogenic aids in current usage

7.1 INTRODUCTION

Much of the daily energy and nutrient requirements for a healthy adult is for the maintenance of basal metabolism, which accounts for an average of 60–75% of daily energy expenditure (see chapter 2). Requirements increase incrementally with increased energy expenditure, however modest, and whether incorporated into a normal working day or as part of a fitness regimen. However, although the principles of energy and nutrient requirements do not change, people engaged in recreational or competitive sports may find that a particular dietary regimen improves performance. Some individuals strive to enhance their performance through the use of foods and supplements targeted for the competitive sportsperson, with a variable evidence-base for their efficacy.

Physical fitness need not be the exclusive domain of the sportsperson and there is now a wealth of evidence that exercise makes an important contribution to good health and helps to reduce the risk of chronic disease such as cardiovascular disease and cancer.

This chapter considers the relationships between diet, exercise and fuel metabolism.

7.2 MUSCLE STRUCTURE AND FUNCTION

To perform physical exercise our bone structure needs to be moved by muscle force, which is generated when chemical energy is transformed to
mechanical energy within the muscle. Skeletal muscle consists of an outer layer of connective tissue covering small bundles of muscle fibres. A muscle fibre represents the individual muscle cell and usually extends the entire length of a muscle. At both ends the muscle fibre fuses with a tendon, which is attached to the bone. The muscle fibre contains numerous myofibrils, which represent the contractile elements of the muscle. There are two types of muscle fibres, slow twitch fibres (also called type I), which are particularly important for aerobic exercise and are well suited for prolonged endurance exercise like marathon running and cycling, and fast twitch fibres (also called type II), which are more important for anaerobic work such as in short-term high intensity activities like weight-lifting or sprinting (see chapter 2). Interestingly, fibre composition differs considerably between individuals, which is largely determined by genetic background. Individuals seem therefore to have a genetic disposition towards high performance in some sports.

A single motor nerve innervates several muscle fibres, and together they are referred to as a single motor unit. Muscle contraction is preceded by a series of events. First, a motor nerve impulse is generated and conducted through the motor neuron towards its nerve endings. There, an electrical charge can be generated and conducted throughout the entire muscle fibre. Muscle contraction is dependent upon the presence of calcium ions in the muscle fibre and requires energy, which is provided by adenosine triphosphate (ATP), the universal energy donor in the living cell. An extremely complex, well-orchestrated series of muscle contractions within numerous muscle fibres from various muscle groups are needed to enable even the simplest of movements.

7.3 SKELETAL MUSCLE SUBSTRATE UTILIZATION

The immediate source of chemical energy required for skeletal muscle to contract is provided by the hydrolysis of ATP. Because intracellular ATP stores are small, metabolic pathways for ATP synthesis need to be activated directly in response to an increase in ATP demand. The transition from rest to exercise is associated with an increased demand for ATP, which, at the muscular level, can increase more than 100-fold. ATP can be generated during anaerobic metabolism in all cells, through the glycolytic pathway (chapter 4), but muscle cells can also rely on creatine phosphate. Creatine phosphate is a high-energy compound stored in the muscle, the hydrolysis of which generates energy for ATP synthesis. A high rate of synthesis of ATP can be achieved through these routes but substrates are rapidly depleted. The majority of ATP required for muscle contraction is generated through oxidative phosphorylation, primarily from the oxidation of fat and carbohydrate.

Fuel storage

Muscle contraction occurs continuously and therefore the body needs to ensure a continuous supply of ATP. It does this through the use of fuels made available through diet and from stores (Table 7.1). Carbohydrate is stored as glycogen in skeletal muscle and in the liver. A normal healthy adult stores about 100g glycogen in the liver and about three times this in skeletal muscle. Fat is stored in adipose tissue; stores are generally between 9 and 15kg in
the non-obese adult male weighing about 70 kg but can be a great deal more. Additionally, the energy provision from fat is 39 kJ/g, more than twice that from carbohydrate.

### Exercise intensity and duration

Fat and carbohydrate are the main substrates that fuel aerobic ATP synthesis during prolonged exercise. Though both substrates will always contribute to total energy provision, their relative utilization has been shown to vary with the intensity and duration of exercise.

During low intensity exercise (less than 30% of maximum oxygen consumption, $V_{O2\text{max}}$), most of the energy requirement comes from the oxidation of fat, principally from fatty acids in the circulation. During moderate intensity exercise fat and carbohydrate each contribute about half of the energy requirement. At high exercise intensity muscle glycogen becomes the most important source of energy. However, muscle glycogen stores are limited, and cannot sustain exercise of long duration; this is a reason behind the onset of fatigue during prolonged endurance exercise. This means that pre-exercise muscle glycogen concentration is a determinant of the time of onset of exercise fatigue.

### Effects of training on fuel use

The relative contribution of fat and carbohydrate oxidation to total energy expenditure during exercise is also determined by training status. Endurance training leads to an increased capacity to utilize fat as a substrate source and reduces the reliance on the limited endogenous carbohydrate stores during exercise. Evidence suggests that the increase in fat oxidation is accounted for by an increase in the concentration of intramuscular triacylglycerol and an increased rate of utilization.

### 7.4 NUTRITIONAL STRATEGIES FOR OPTIMUM PERFORMANCE

Increased physical activity, however modest and through whatever means, will increase the requirement for energy. Exercise training or competition can
increase the daily energy expenditure by 2–4 MJ/hour (500–1000 kcal) of exercise, depending on physical fitness, duration, type and intensity of sport. For this reason, athletes must increase food consumption to meet their energy needs, according to the level of daily energy expenditure. This increased food intake should be well balanced with respect to macronutrient and micronutrient composition.

It can be difficult to maintain the required increment in energy intake associated with high intensity exercise, especially during competition events. A professional cycling race, such as the Tour de France, can cost an athlete up to 40 MJ/day (9,550 kcal). And there is a practical limit to ingesting this amount of energy through solid meals. Some athletes resolve the problem by consuming specially-formulated fluids.

In contrast, some athletes with high profiles, such as gymnasts and ballet dancers, are known to reduce their energy intake, despite their high rate of energy expenditure. This leads inevitably to low BMI and fat mass with associated effects on performance.

**Carbohydrate**

Endurance performance capacity is often limited by the availability of endogenous carbohydrate. For this reason athletes involved in moderate to high intensity exercise lasting more than 45–60 min may adopt strategies to increase muscle glycogen concentration prior to competitive events. Increases in muscle glycogen can be achieved through carefully-regulated exercise and carbohydrate-feeding regimens (carbohydrate loading) and it seems that this practice is commonly employed by endurance athletes throughout the world.

Endurance exercise performance has also been shown to benefit from the consumption of carbohydrate during exercise itself. In this case carbohydrates are best provided in combination with water. Studies indicate that although monosaccharides and disaccharides are absorbed and oxidized at similar rates, exercise inhibits oxidation of carbohydrate, so no more than ~60–70 g of carbohydrate should be ingested per hour. Additionally, sports drinks should not have a high osmolality as this would result in impaired gastric emptying. Following prolonged endurance exercise the restoration of muscle glycogen is slow. Muscle glycogen synthesis rates are highest during the first two hours after exercise and this offers an opportunity for the use of carbohydrate-rich sports drinks immediately post-exercise, to aid in recovery. Thereafter, moderate-to-high glycaemic index foods (cakes, biscuits, white bread) should be consumed rather than low glycaemic index foods (brown bread, fruit, pasta).

**Fat**

Far less information is available on the role of fat compared with the role of carbohydrate as a fuel during exercise. However, as endurance training increases fat oxidative capacity, there is interest in the potential for nutritional interventions to increase fat oxidative capacity. Interest has focused on the use of medium chain triacylglycerols, as these are relatively water soluble and less likely to inhibit gastric emptying than long chain triglycerides.
Furthermore, medium chain fatty acid oxidation is not as limited by transport into the mitochondria as long chain fatty acids are. However, performance studies have failed to show effects greater than carbohydrate feeding.

As well as the use of fat supplements during exercise, research has also focused on the effect on performance of using high fat diets over a long term. The use of such diets provokes adaptive responses, leading to an increase in the capacity to oxidize fat as a fuel and the sparing of endogenous carbohydrate stores during exercise. However there is little evidence that such diets improve exercise performance, and from a general health perspective such diets cannot be encouraged.

**Protein**

Evidence shows that according to the type and duration of exercise there is an associated increase in protein requirement. This has been explained by the need to repair exercise-induced muscle damage, as an additional substrate source during prolonged exercise, and to support training-induced muscle reconditioning with an associated increase in lean tissue mass. However, there is a strong relationship between energy and protein intake in athletes and increased protein needs are likely to be covered by the increase in overall food intake that is usual in athletes. Nevertheless, protein requirements may not be met by normal dietary intake in athletes who are trying to lose weight, as is reported in some gymnasts, and female long distance runners. Resistance training is thought to increase protein requirements more than endurance exercise, and it is recommended that experienced male bodybuilders and strength athletes consume up to 1.6 g/kg body weight per day.

The use of protein and/or free amino acid supplements is currently popular in both strength and endurance athletes, as a means of supporting post-exercise recovery. The combined ingestion of carbohydrate with protein and/or specific free amino acids in the post-exercise phase has been shown to increase post-exercise insulin production, accelerate muscle glycogen synthesis, decrease muscle proteolysis and stimulate protein synthesis, leading to net protein anabolism. Besides providing ample substrate for protein synthesis and increasing insulin and/or growth hormone levels the ingestion of protein and/or free amino acids may also directly stimulate muscle protein synthesis. Research is currently underway to investigate the properties of individual amino acids to directly stimulate muscle protein synthesis.

**Fluids and electrolytes**

Most of the energy required for intensive endurance exercise is produced by oxidative metabolism, with an associated heat production. Much of this heat will be lost in sweat and at maximal sweat rates a 70kg male athlete may lose >30ml/min or >1800ml sweat/hour. Dehydration substantially impairs exercise performance, with a ~10-15% decrease in performance capacity with each degree increase in body temperature. With sweat loss, electrolytes are also excreted but because sweat has a lower mineral content than plasma and water intake is inadequate to fully compensate the losses, the electrolyte
concentration in blood normally increases as a result of intense endurance exercise.

Restoration of fluid balance after exercise is an important part of recovery. Rehydration after exercise can be achieved effectively only if both electrolyte as well as water losses are replaced. An ideal post-exercise rehydration drink should contain around 1100 mg/L sodium to optimize water retention. In comparison, ordinary soft drinks contain virtually no sodium and are therefore less suitable as a rapid rehydration solution.

**Micronutrients**

Vitamin supplements are widely used by both professional as well as recreational athletes but there is little evidence that this is either necessary or beneficial. Athletes who achieve an increased energy intake to address their increased requirements will generally do so with an associated increase in micronutrients. An exception may be athletes who have extremely high energy requirements and who choose to consume very high energy dense foods, which can be of low nutrient density, such as cakes and carbohydrate-rich fluids. Those sports men and women consuming diets of low energy content may also be prone to a marginal vitamin intake. However, vitamin supplements in individuals showing no biochemical evidence of inadequacy have not been shown to improve performance.

A specific role for antioxidant micronutrients might be argued for people who exercise regularly. Exercise has been associated with increases in free radical production in skeletal muscle, with potential for tissue damage. However, there is also evidence that athletes may compensate by increasing the intracellular activities of antioxidant enzymes and the benefit to be gained from antioxidant supplements is doubtful.

There may be a stronger case for the use of iron supplements by some athletes. Iron loss is increased in athletes, partly due to loss in sweat, increased gastrointestinal and/or urinary blood loss and foot strike haemolysis, but is usually well compensated for by the increased dietary intake associated with the higher energy expenditure. Female athletes are more likely to be iron depleted than their male counterparts, but iron deficiency anaemia is seldom reported. A lower than average haemoglobin concentration sometimes seen in athletes can be a training-induced physiological condition, caused by an increase in plasma volume, so-called ‘athletes’ anaemia’. This physiological condition does not respond to iron supplementation. Iron supplements have only been shown to enhance performance capacity in situations in which iron deficiency anaemia exists.

### 7.5 ERGOGENIC AIDS

Sports men and women the world over, seeking to enhance their performance, have turned to the wide range of heavily-marketed sports supplements now available. These products range from sports drinks, high-energy bars and protein-shakes to a multitude of nutrient supplements containing vitamins, minerals and free amino acids. Additionally, some products, marketed as ergogenic aids, contain active ingredients other than nutrients, or nutrients
to be consumed in pharmacological amounts and may be marketed as functional foods. Evidence for their efficacy is generally lacking.

**Caffeine**

Caffeine has been used as an ergogenic aid but is currently included on the banned substances list used by the IOC (International Olympic Committee). Several studies have provided evidence for the ergogenic properties of caffeine ingestion during prolonged endurance exercise tasks. An effective ingestion dose lies between 2–5 mg/kg body weight, equivalent to about 2–6 cups of coffee. Its efficacy has been ascribed to a stimulating effect on the central nervous system, through the release and/or activity of adrenaline. Side-effects associated with caffeine use include gastrointestinal distress, decreased motor-control, shivering, headache, dizziness, and minor elevations in blood pressure and resting heart rate.

**Creatine**

In healthy individuals, the total endogenous creatine pool is approximately 120 g, most of which is located in skeletal muscle. It is replenished by endogenous synthesis and dietary intake (meat and fish). Studies have shown that oral creatine supplementation increases total creatine and creatine phosphate concentrations in human skeletal muscle and can enhance performance in repeated high-intensity, short-term exercise tasks, during which energy transfer is primarily derived by the ATP-creatine phosphate system. Consequently, creatine supplementation has become a common practice in both professional and amateur athletes.

**Carnitine**

Carnitine plays an important role in the transport of long chain fatty acids across the mitochondrial membrane, for oxidation. It has been suggested that increasing the intramuscular carnitine pool by using carnitine supplements could improve fatty acid import into the mitochondria and increase fat oxidative capacity. Carnitine is present in the diet (red meat and dairy products) and can be synthesized endogenously. Studies have generally failed to show that supplements can raise the concentration of carnitine in muscle or improve exercise performance.

**Sodium bicarbonate**

Sodium bicarbonate (NaHCO₃) better known as ‘baking soda’ has also been used as an ergogenic aid, on the basis that it will correct a fall in intracellular pH associated with anaerobic glycolysis. The accumulation of lactate in the anaerobic muscle leads to muscular pain and fatigue and the inability to maintain exercise intensity for a more prolonged period. Bicarbonate loading in athletes can improve performance in exercise tasks lasting between 0.5–6.0 min of near-maximal performance. Gastrointestinal distress and hyperosmotic diarrhoea have often been reported following bicarbonate loading.
KEY POINTS

- Quantitatively, muscle glycogen stores are the most important energy source during moderate to high intensity exercise.
- Endogenous carbohydrate stores are relatively small and usually limit endurance performance capacity.
- Carbohydrate loading in the days preceding endurance competition represents an effective means to optimize pre-exercise glycogen content.
- During prolonged endurance exercise carbohydrate ingestion can significantly improve performance capacity.
- Depending upon intensity and duration of exercise, people who exercise regularly may need to increase their energy and nutrient intakes.
- Under most circumstances, increased protein requirements in athletes are provided by a general increase in energy intake.
- Studies have failed to show that supplements of medium chain triacylglycerols enhance physical performance over carbohydrate feeding.
- Fluids and electrolytes need to be supplied during prolonged exercise to compensate for sweat loss.
- Vitamin and/or mineral supplementation does not improve performance capacity when no deficiencies are present.

FURTHER READING