Position of the New Zealand Dietetic Association (Inc): Nutrition for exercise and sport in New Zealand

POSITION PAPER

Statement of purpose

New Zealand is a successful sporting nation that consistently produces world-lass athletes. In addition to the elite, many New Zealanders are involved in recreational sports and exercise. Nutrition plays a major part in exercise performance by contributing to good health, enabling the athlete to train and compete optimally, and by enhancing recovery. This paper provides the stand of the New Zealand Dietetic Association (NZDA) on nutrition advice for athletes to follow in everyday training and at times of competition.

Statement of position

It is the position of the NZDA to:

1. Support the availability of, and access to, appropriate and accurate information for those individuals and groups who regularly engage in sport and exercise.
2. Make available more specific nutritional advice to committed athletes.
3. Educate coaches, health professionals and others who support athletes.
4. Correct and counteract nutritional misinformation relating to sport.

Summary of main points

The key points below summarise the main points of the technical support document. The reader is advised to consult this document for more information.

- Athletes and people who exercise frequently are advised to follow the Food and Nutrition Guidelines for Healthy New Zealanders.
- Athletes use more energy than the average person and meeting energy needs is the number one priority. Failure to do so is likely to decrease athletic training and performance.
- Body composition (ratio of fat and muscle) can affect sporting performance. Low body fat is important in weight-bearing sports, such as running, or in sports with a focus on appearance, such as gymnastics.
- Body composition is most commonly assessed by trained technicians using height, weight and skinfold measurements. The percentage body fat is derived from prediction equations using these data. The sum of skinfolds is preferred for estimating body composition of athletes.
- Attempts to alter body composition should be made outside the competition season, when possible. To increase muscle mass, the individual requires an increase in energy intake combined with appropriate strength-type training and recovery. To lose weight, an energy deficit of 2100–4200 kJ/day should lead to safe weight loss without compromising training and adequacy of nutrient intake.
- Carbohydrate, stored as glycogen in liver and muscle, is the most important fuel for exercise. Maintenance of glycogen stores and blood glucose levels are important in endurance exercise and can be achieved by consuming a diet rich in high-carbohydrate foods. Daily needs range from 5 to 10 g carbohydrate/kg body mass (BM).
- Protein is important for athletes; however, most consume sufficient protein in their regular diet. Protein recommendations are 1.2–1.7 g/kg BM/day for adult athletes, and 2 g/kg BM/day for adolescent athletes.
- Fat is secondary to carbohydrate and protein needs. Depending on total energy needs, fat should make up approximately 25–30% of total energy, and be mainly from mono- and polyunsaturated fats for health reasons. A fat intake under 15% of total energy is not recommended.
- Athletes are likely to meet their vitamin and mineral needs if their energy intake is adequate and the Food and Nutrition guidelines are followed. However, the main micronutrients of concern for athletes are calcium and iron.
- Sweat losses in exercise mean that athletes have greater fluid needs than non-athletes. Losses often range from 0.5 to >1 L/hour and losses of >2 L/hour are not uncommon in hot and humid conditions. To determine fluid requirements in a particular setting, athletes should weigh themselves before and after training; losing 1 kg of bodyweight equates to slightly less than 1 L of sweat loss, as some weight loss is due to substrate metabolism. In longer events (e.g. 42 km marathon run or ultra-events), a 1–2% bodyweight loss can reflect euhydration. Weight gain during an event reflects overhydration and can result in hyponatraemia.
- For long and intensive training and racing sessions, particularly in warm climates, it is necessary to consume fluids to prevent hypohydration. Water is typically sufficient in exercise less than one hour, but there are several advantages of adding carbohydrate and electrolytes (sports drinks). Glucose or glucose-containing carbohydrates increase net fluid absorption (as well as giving fuel), and sodium facilitates retention of the fluid. Sports drinks should contain 0.5–0.7 g/L (20–30 mmol/L) sodium and 4–8% glucose or glucose-containing carbohydrates. However, increases in either may be appropriate in extreme situations.

- Alcohol does not improve most sports performance and excessive alcohol consumption can impair performance and recovery. Binge drinking practices should be actively discouraged.
- Athletes are advised to trial their competition eating strategies in training sessions to determine what works for them within the advice/framework provided below.
- An increased carbohydrate intake ('carbohydrate loading') on the days prior to endurance competition, particularly in events lasting longer than 90 minutes, can enhance performance. However, if enough carbohydrate is consumed in the pre-race meal, this may have a similar effect.
- Consumption of 200–300 g carbohydrate three to four hours before exercise increases muscle glycogen and enhances performance. Carbohydrate in the hour before competition may have benefits, especially in the early morning, compared with consuming no food.
- For endurance exercise lasting >90 minutes, carbohydrate consumption during the session can enhance performance. Up to 60–70 g/hour can be oxidised by the body, but the general recommendation is between 30 and 60 g/hour consumed at regular intervals in the form of sports drinks, carbohydrate gels or solid foods.
- Athletes should consume carbohydrate (1.2 g/kg BM) immediately after training sessions for improved recovery. This is particularly important when recovery time is short, for example, when training twice daily. High glycaemic index (GI) carbohydrate foods may be useful, and inclusion of protein in the recovery snack/meal can enhance recovery.
- Energy and nutrient needs change through the life cycle. Child athletes have higher energy, protein, and calcium needs compared with adults and need supervision with attention to fluid consumption. Older athletes need to ensure that energy and protein intake is adequate and be aware of interactions between medication and nutrients.
- Vegetarian athletes typically meet energy and carbohydrate needs but need to ensure that adequate amounts of protein, iron, zinc, vitamin B_{12} and calcium are consumed by eating a wide variety of grains, legumes, nuts, vegetables, eggs and dairy products. Those who consume no animal products must take a vitamin B_{12} supplement and be particularly mindful of meeting essential amino acid needs.
- Excellence in sports performance is achieved through the combined effects of genetic potential, quality training and recovery, and targeted nutrition, and not through the use of isolated nutritional supplements. Appealing marketing of these products makes it hard for athletes to obtain objective advice on supplement matters. The reality is that for the vast majority of supplements, evidence of performance enhancement is lacking, and that taking supplements carries a small, but real risk of having a positive drug test.
- Pressures to improve performance can predispose athletes to eating disorders. Women are more likely to develop anorexia nervosa or anorexia athletica, and bulimia nervosa, whereas male athletes are more likely to develop muscular dysmorphism. Women athletes are at risk of the female triad of disordered eating, menstrual dysfunction and osteopenia.

TECHNICAL SUPPORT DOCUMENT

1. Introduction

Nutrition plays a major role in exercise performance, through its effect on energy stores, hydration status, post-exercise recovery, body composition, immune system function and general health. The main impact of diet is likely to be on supporting the athlete's daily training programme, and on recovery, particularly at the elite level, when training volumes and intensities are high and athletes may perform multiple training sessions each day.

It is important to understand that there are no single foods, combinations of foods or special sports supplements that on their own optimise sports performance or replace the need for a balanced and nutritionally adequate diet. Athletes, like others, are advised to eat a well-balanced diet that follows the food and nutrition guidelines for New Zealanders,[1] along with the more specific nutritional strategies for sports performance enhancement.

2. Energy balance

2.1 Energy balance

Physical exercise results in an increase in energy metabolism. Therefore, meeting energy needs is the first nutrition priority for athletes. Achieving energy balance is essential for the maintenance of lean BM, immune function and good health, as well as optimum athletic performance.[2] Energy balance is a state where energy intake matches energy output (comprising resting metabolic rate + thermic effect of food + thermic effect of exercise).

2.2 Energy expenditure

Energy intake requirements are variable depending on age, gender and BM along with energy expenditure. For energy expenditure in athletes, exercise should be calculated based on its intensity, frequency and duration. This requirement should be added to the energy needed for normal daily activity. There are a number of methods used to estimate basal metabolic rate for athletes, ranging from laboratory testing to using prediction equations. Two of the most widely used equations are the Harris-Benedict and Cunningham equations.[3] The former is easier to use in a clinical setting as it does not require the estimation of fat-free mass.[4]

2.3 Energy intake

An inadequate energy intake results in low muscle energy (glycogen) levels and thus reduced ability to train and perform at desired levels. In addition, lean tissue mass will be used as an alternative fuel, resulting in decreased strength and endurance.[5] Low-energy intake over time results in poor nutrient intake and impaired mental and emotional health, and low immune function.[6] However, a negative energy balance is acceptable for a short time where a loss of fat is required. Achieving an adequate energy intake can be difficult for some female athletes, whose energy needs may be as high as male athletes, but who have lower food intake.[7]

3. Body composition

3.1 Body composition and performance

Body composition (fatness and lean BM) and weight (BM) are factors that can affect an athlete's performance. BM can affect speed, power and endurance, while composition affects strength, agility and appearance.[4]

Athletes need a high strength to weight ratio. Because body fat adds weight without strength, it is desirable to keep body fat levels reasonably low. Minimal fat levels are 12% for women and 5% for men; levels below these may be indicative of an eating disorder or other health problems due to a poor energy and nutrient intake.[4] However, fat levels vary widely depending on the sport and there are no standard percentage fat levels for athletes.[8]

Information about body composition is used to identify characteristics of elite performers, assess and monitor growth, monitor training programmes and identify optimal body composition for weight category sports. Body composition data are also used to monitor changes in weight and fat levels for athletes who need to increase muscle mass or decrease fat levels.

3.2 Assessment of body composition

There are several different ways in which body composition can be measured and the method of choice will depend on the available resources and the application of results. The most common and widely used method of estimating body composition involves measurement of height, weight, girths, bone lengths and skinfolds.

The measurement of skinfolds is a quick and easy method for estimating body fat levels and is usually adequate for most situations with athletes.[9] The values obtained are either reported as sum of seven or eight skinfolds or per cent body fat derived from prediction equations; the sum of skinfolds is preferred. Skinfold measurements are subject to error from poor technique, poorly maintained equipment and use of incorrect prediction equations. To minimise error, measurements should be done by an accredited practitioner at each assessment.

Bioelectrical impedance analysis estimates fat-free mass and is often used in community gyms.[4] Diet, hydration, ethnicity and wellness affect the results, and its validity is also dependent on both client and operator following the correct procedure. Other methods for measuring body composition include dual absorption X-ray absorptiometry, plethysmography (BODPOD), doubly labelled water and hydrostatic (underwater) weighing. These methods are more accurate but not widely used as they are costly and not easily available.[4,10]

3.3 Weight change

Programmes designed to make changes to body composition should be undertaken outside the competition season.

Athletes looking to increase muscle bulk should undertake resistance exercise and increase their energy intake to meet training needs. While adequate protein intake is necessary to achieve an increase in muscle mass, energy is the most important factor: an increase in energy intake, especially carbohydrate so that protein is not oxidised. Protein is typically recommended at no more than 2 g/kg BM/day.[11] According to Tipton and Wolfe, there is no evidence that higher-protein intakes are advantageous, but best muscle gains may be from timing of food intake and the protein composition.[12]

For weight/fat loss, it is important to reduce the total energy intake while maintaining a balanced diet. To lose fat, the energy intake needs to be below the energy expenditure; however, there must be sufficient energy to enable the athlete to train. A weight loss of 0.5–1.0 kg/week is usually possible and safe and is achieved by an energy deficit of 2100–4200 kJ/day.[13]

4. Nutrient needs of athletes and active people

4.1 Carbohydrate

Carbohydrate is the preferred fuel for active muscles and its contribution to the energy pool increases as the intensity of exercise increases. Carbohydrate is stored in the form of glycogen in liver and muscle, which ranges between 300 and 400 g in muscles and 80–100 g in liver.[2] Therefore, maintenance of glycogen stores and blood glucose levels are important in endurance exercise and is achieved by consuming a diet rich in carbohydrates. Foods, such as wholegrain breads and cereals, rice, pasta, noodles, pulses, couscous, polenta, fruits and vegetables are the most suitable carbohydrate-rich choices.

The recommended level of carbohydrate in the diet varies according to BM and level of activity, but for most athletes 7–8 g carbohydrate/kg BM/day is sufficient.[14] Timing of carbohydrate intake is important for optimum glycogen repletion (see Section 6).

Ranges of recommended carbohydrate intakes.[8] 5–7 g/kg BM/day for moderate intensity training; 7–10 g/kg BM/day for increased training; 10–13 g/kg BM/day for extreme endurance training.

Glycaemic index. The GI is a ranking of carbohydrate foods according to the increase in blood glucose and insulin

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response to a standard amount of food, using glucose (GI = 100) as the reference food. Low-GI foods have a GI of 55 or less, moderate GI food 56–70 and high-GI foods have a GI of over 70. High-GI carbohydrate foods provide a quickly assimilated source of glucose to support rapid glycogen restoration.[15]

4.2 Protein

Protein is important for athletes, and most athletes consume sufficient protein in their regular diet.[12] Lean BM will be maintained within a wide range of protein intakes provided energy intake is adequate. The timing of protein intake can enhance the use of protein. Inclusion of 6–10 g essential amino-acids in the recovery snack immediately after resistance exercise will enhance the anabolic process. However, this effect has not been shown conclusively for endurance training.[16]

Foods, such as fish, lean red meat, chicken, eggs, low-fat milk and dairy products, tofu, pulses, nuts and seeds provide protein as well as a range of vitamins and minerals.

Ranges of recommended protein intakes for athletes:[11]
1.2–1.4 g/kg BM/day for endurance athletes; 1.6–1.7 g/kg BM/day for resistance training athletes; up to 2 g/kg BM/day for adolescent athletes and those undertaking strength and endurance training.

4.3 Lipids or fats

Lipids/fats should provide approximately 25–30% of energy. A fat intake of less than 15% of energy is not recommended for the maintenance of good health.[4]

During exercise, the use of fat as a fuel decreases as intensity increases. There have been some studies showing fat usage adaptation for endurance athletes on high-fat and reduced-carbohydrate diets, but there is a need to carbohydrate load prior to competition with very little or no improvement in performance shown to date.[17]

In line with the general food and nutrition guidelines, athletes and physically active individuals should keep saturated fats low and use mainly mono- and polyunsaturated fats.

Therefore, using lean meats, removing skin from chicken and using reduced fat dairy products will reduce the amount of saturated fats in the diet. Monounsaturated fats are found in a variety of plant foods, such as olive oil, canola oil and avocados, whereas polyunsaturated fats are found in some vegetable oils and in oily fish.

4.4 Vitamins and minerals

Micronutrients assist the body by taking part in energy production, nerve function, haemoglobin synthesis, maintenance of bone health, immune function and the protection of body tissues from oxidative stress. They also help muscle building and tissue repair following exercise.[18]

Exercise increases the requirement for vitamins and minerals by altering the metabolic pathways through which these nutrients are used, increasing the turnover and losses of these nutrients from the body, and increasing the need for tissue maintenance and repair.[19] However, the majority of micronutrients are consumed in sufficient amounts in the daily diet, provided the athlete's energy intake is adequate.

Athletes most at risk of micronutrient deficiencies are those who adopt fad diets or unnecessarily restrict energy or avoid one or more of the main food groups in their diet. While these athletes may benefit from a short-term course of a multivitamin or mineral supplement, the long-term solution rests with improved dietary intake. Supplementation of single nutrients is discouraged, with exceptions such as the use of iron for the treatment of iron deficiency or folic acid in women of childbearing age for the prevention of neural tube defects.

The main mineral deficiencies seen in athletes, particularly women, are calcium, iron and zinc.[20,21] Low intakes of these nutrients may occur when women avoid animal products, or limit energy in order to control bodyweight.

As calcium is essential for maintaining blood calcium levels and the building and repair of bone tissue, an inadequate dietary calcium intake can contribute to low bone density and stress fractures in athletes.[22,23]

Iron depletion is one of the most prevalent nutrient deficiencies affecting athletes. Iron is required for the formation of haemoglobin and myoglobin, which bind oxygen in the body. Iron deficiency anaemia results in fatigue, reduced concentration, increased risk of infection and reduced physical performance.[24]

Iron deficiency is usually associated with low-energy intakes; avoidance of meat, fish and poultry that contain readily available haem iron; vegetarian diets that have reduced iron bioavailability; or increased losses through sweat, urine or menstrual losses. There is also evidence to suggest that athletes may have increased rates of red cell iron and whole-body iron turnover.[25]

The initial changes to iron status occur in iron storage and can be recognised through low serum ferritin concentrations. This is followed by changes in iron transport with a decline in transferrin saturation. Eventually, iron deficiency anaemia is evident when the above are present together with low haemoglobin and haematocrit concentrations. As it may take between three and six months to reverse iron deficiency anaemia, it is wise to begin nutrition interventions before iron deficiency develops.[21]

5. Fluids and electrolytes

5.1 Fluid losses

Sweat losses associated with exercise frequently result in hypohydration (state of fluid deficit). Athletes need to know how to measure their fluid losses and replace them adequately. There is also a need for sports participants, support staff and organisers to appreciate the importance of replacing fluid losses and the effect this can have on health and performance. A sweat loss of approximately 1 L/hour of exercise is commonly observed with various types of intensive sporting activities, but can range from less than 0.5 to more than 2 L/hour in hot and humid conditions.[26] Exercise intensity and mode, temperature, humidity, radiant heat, wind, clothing and individual variation can influence the sweat rate. To determine how much fluid is required for a given exercise bout, under particular environmental conditions, it is recommended that athletes weigh themselves before and after exercise. Losing 1 kg bodyweight during exercise is equivalent to a sweat loss of slightly less than 1 L, as part of this weight loss is due to substrate metabolism. In a long-lasting event like a 42-km marathon run or an ultra-endurance event, a weight loss of 1–2% bodyweight loss can reflect euhydration. Weight gain during an event indicates overhydration and can result in hyponatraemia, which can be life-threatening.

5.2 *Consequences of dehydration and supplementation*

For those athletes engaging in long and intensive training sessions, particularly in warm weather, consuming fluids during training is necessary to prevent hypohydration. Although some degree of hypohydration is common and may actually aid in the adaptation process, it can decrease performance and, especially in warm conditions, reduce thermoregulatory capacity.[27] The percentage dehydration affects performance differentially dependent upon ambient temperature and exercise duration.[28] Water as well as carbohydrate beverages can prevent or reduce hypohydration. There are several advantages to adding carbohydrate and electrolytes to fluid replacement beverages, especially when the intensity and duration of exercise are such that glycogen depletion and reduced glucose availability occur.[29] Adding glucose or glucose-containing carbohydrates (e.g. sucrose, maltodextrins) to a sports drink can also increase the net rate of fluid absorption. However, adding too much carbohydrate can reverse this effect and can decrease the net rate of fluid absorption, relative to plain water.[30,31]

5.3 *Electrolytes and carbohydrate composition*

Electrolytes are added to replace sweat losses and, in particular, sodium facilitates intestinal absorption as the absorption of water follows the coupled absorption of glucose and sodium.[32,33] There is, however, evidence that the presence of sodium in the beverage is not necessary to enhance water absorption, because intestinal secretion of sodium can provide sufficient sodium to maintain high rates of fluid absorption.[34] Nevertheless, it is particularly beneficial to include sodium in a sports drink to facilitate retention of that fluid, resulting from a decreased urinary output. This is particularly important to restore blood volume to normal more quickly after hypohydration.[35]

For these reasons, The American College of Sports Medicine accepts the Institute of Medicines' general guidelines that sports drinks in general should contain sodium (20–30 mmol/L = 1.2–1.7 g NaCl) and 5–10% carbohydrates.[36] The college does make clear, however, that needs for carbohydrate and electrolytes vary depending on the exercise task specifics (duration and intensity) and the environmental conditions. Coyle recommends a sodium concentration of 20–40 mmol/L.[28] This is still below or on the lower end of sweat sodium concentration. Coyle also notes that the advised 30–60 g carbohydrate/hour can be met by consuming 600–1200 mL/hour of a 4–8% carbohydrate containing beverage. Consuming sufficient amounts of beverages to compensate sweat losses (e.g. 1 L/hour) can provide enough carbohydrate to improve performance and at the same time facilitate water absorption. Carbohydrate concentrations up to 10% and sometimes greater can be tolerated and can improve performance by increasing carbohydrate availability, but as carbohydrate concentration increases the rate of fluid provision decreases.[31] With the more carbohydrate-concentrated solutions it is important that the solution still has a low osmolarity, to avoid net movement of fluid into the intestinal lumen. This can be achieved by using glucose polymers (maltodextrins) rather than mono- or di-saccharides. Pure fructose beverages are not recommended because of a passive and slower absorption across the intestine than glucose, and a greater risk of gastrointestinal distress, particularly when highly concentrated. Fructose is also less available to the muscle as the enzyme in the liver responsible for fructose metabolism has a greater affinity for fructose than that of the muscle (refer to sections 6.3 and 6.4 for recommended CHO concentrations to cover needs in training and competition of different lengths and intensities).[37]

5.4 *Common diuretics*

Alcohol, caffeine and guarana in energy drinks act as diuretics, increasing urinary output, which can contribute to hypohydration. However, it has been shown that if already hypohydrated (e.g. after exercise in which fluid losses are not compensated by fluid intakes), the diuretic effect of alcohol is overridden by the hypohydration, although as alcohol concentration increases, recovery of plasma volume tends to slow down.[38] Recent research has also shown that chronic caffeine consumption (3–6 mg/kg BM/day), particularly in those accustomed to it, has little if any effect on fluid and electrolyte balance in general, and during exercise[39,40] (for review see Armstrong[41]).

5.5 *Special considerations for ultra-endurance sports*

Overhydration is uncommon in competitive athletes, but in ultra-endurance athletes, particularly in women and in the less well-trained, it does occasionally occur and can contribute to the development of hyponatraemia, particularly when pure water or hypotonic fluids are ingested.[42] Additionally, by ingesting sports beverages which are low in sodium, sodium secretion into the gut can be increased to facilitate glucose transport. This can lead to a decrease in circulating sodium, which could further contribute to the development

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of hyponatraemia. For these reasons, during ultra-endurance exercise in which a majority of nutrition is provided by sports drinks, and sweat losses are substantial, a higher sodium concentration (approximately 30–50 mmol/L) in sports beverages may be more appropriate, if tolerated. However, even with sports drinks, drinking far in excess of losses (i.e. when weight gain occurs during exercise) may still result in dilutional hyponatraemia.

5.6 Alcohol

Alcohol tolerance levels vary widely between individuals, especially between men and women.[43] This makes recommendations for appropriate alcohol intakes for athletes difficult to set. Regardless, alcohol does not improve metabolic or physiological functions essential to physical performance.[44]

Alcohol is metabolised in various systems of the body, such as the skin, liver, kidneys, muscles and brain.[38,45] Excessive alcohol intake leads to impaired decision-making and risk perception. This in turn may lead to high-risk behaviour and greater risk of accidents, for example, in sports such as diving and driving.[46,47] Taken after exercise, alcohol intake may prevent athletes from following guidelines for optimal recovery. Reaction times may be slowed and the perception of time extended for up to 24 hours, affecting sports where the game extends over several days.[45,48] Alcohol can also lead to reduced glycogen resynthesis, longer healing time from injury and decreased immunity.[38,49,50]

Inappropriate drinking behaviour is frequently associated with team sports, such as rugby and football.[51] The challenge for team management, coaches and sports dietitians is to set standards of conduct regarding alcohol and team drinking, and to educate players as to the long-term ill effects of excessive alcohol consumption on health and performance.[52]

6. Nutrition for training and competition

6.1 General considerations

There are a number of nutritional considerations for the regularly training athlete besides meeting total daily energy and nutrient needs. These include optimising energy stores and hydration status prior to exercise, preventing gastrointestinal distress and muscle glycogen depletion, and minimising dehydration during exercise, and optimising recovery post exercise. The recommended strategies for pre-, during- and post-exercise nutrition outlined below are intended as a framework for developing individual nutrition plans. Athletes are advised to trial nutrition strategies in training sessions that simulate race situations in order to determine what works best for them. In doing so, they must consider required amount and type of food and drink and frequency of consumption. Competition nutrition is further determined by environmental conditions, the time of competition, the number of events and food and drink availability at competition venues.

6.2 Carbohydrate loading

In endurance competition of more than 90-minute duration, increased dietary carbohydrate intake one to seven days before exercise (carbohydrate loading) is generally associated with enhanced performance.[53] Early carbohydrate loading protocols resulted from studies undertaken by Scandinavian researchers in the late 1960s. They found that several days of low-carbohydrate intake combined with intensive exercise depleted muscle glycogen stores, and that subsequent high-carbohydrate intake combined with exercise taper caused a super-compensation of muscle glycogen stores above normal levels. Subsequent research showed that 'modified' carbohydrate loading without a depletion phase has a similar effect. As a result, carbohydrate loading regimens usually consist of gradual tapering of activity over the week prior to competition combined with a high-carbohydrate intake (8–10 g/kg BM/day or 500–600 g/day) in the last three days to achieve supranormal muscle glycogen levels. Recently, a one-day high-carbohydrate diet of 10 g carbohydrate/kg BM has been found equally effective in elevating muscle glycogen.[54,55] However, it appears that carbohydrate loading may only be effective in subjects who do not eat a pre-event meal.[56,57] Therefore, carbohydrate loading may particularly benefit those who cannot eat a substantial meal before competition, and recommendations are best made on an individual basis. To avoid an increase in energy intake, fat intake should be restricted when carbohydrate loading. Further, because glycogen binds water, fluid intake should be increased. It should be noted that carbohydrate loading often leads to temporary (water) weight gain, and may not be appropriate in sports with strict weight criteria.

The majority of studies on carbohydrate loading have used male participants and results may not apply to female athletes. There appears to be a menstrual cycle effect on muscle glycogen synthesis, and it has also been shown that women may not be able to load carbohydrate by simply increasing percent carbohydrate.[58,59] For a female athlete to consume adequate amounts of carbohydrate, a considerable increase in energy intake may be required.

6.3 Pre-exercise meal

It has been established that carbohydrate ingestion three to four hours prior to exercise increases muscle glycogen and enhances exercise performance. A general recommendation is to consume 200–300 g carbohydrate at this time. However, individual needs, the time of day, exercise intensity and duration, the number of exercise sessions, previous food consumption and anticipated carbohydrate intake during the exercise session all need to be considered when making recommendations.

Carbohydrate ingestion 30–60 minutes before exercise results in increased plasma insulin, which can lead to a transient hypoglycaemia.[53] Generally, there are no adverse performance effects and there may be benefits. Athletes who train or compete early morning should be advised to consume carbohydrate before starting to prevent glycogen depletion. There is currently no agreement on the performance effects of low-GI carbohydrate when consumed in the pre-exercise meal.[15,60, 61] A practical approach is for athletes to experiment with such foods.

6.4 During exercise

For exercise lasting 90 minutes and longer, performance can be extended by consuming carbohydrate during the session. A general recommendation is to ingest 30–60 g of carbohydrate during each hour of exercise.[62] However, a recent review shows that optimal carbohydrate delivery is seen at ingestion rates of 1.0–1.2 g/minute, which implies a carbohydrate intake of about 60–70 g/hour.[28,63] Consuming carbohydrate during prolonged exercise is particularly important when athletes have not consumed sufficient carbohydrate in their pre-exercise meal.

Timing of consumption is important: carbohydrate should be taken at regular intervals starting shortly after exercise has commenced. Indeed, consuming a given amount of carbohydrate in a single portion after two hours of exercise is not as effective as consuming the same amount in portions at 20-minute intervals during the first two hours of exercise.[64]

The form of carbohydrate does not seem to affect the ergogenic potential.[63] Many athletes prefer sports drinks and carbohydrate gels while others prefer solid food. Generally popular and suitable food choices include ripe bananas, white bread honey or jam sandwiches and sports bars.[7]

Ingestion of carbohydrate is unlikely to enhance performance in exercise lasting less than one hour when exercising in a fed state; however, there may be benefits for athletes who exercise in the early morning after an overnight fast.[53]

6.5 Post-exercise recovery

The extent of glycogen depletion and the length of the recovery period will determine the optimum timing and composition of the post-exercise meal. By consuming carbohydrate immediately after exercise, glycogen levels six hours later will be higher than if ingestion is delayed for two hours.[65] While there is some variance in the literature regarding the optimum amount of carbohydrate, the recent International Olympic Committee consensus statement suggests an intake of 1.2 g/kg BM.[17] Consumption of 7–10 g/kg BM over 24 hours (minimally 25 g/hour) is sufficient carbohydrate to replace muscle and liver glycogen after total depletion.[30]

This practice is important for athletes who have multiple daily training sessions or competitive events/stages and thus rely on maximal recovery between sessions. However, strict timing of carbohydrate ingestion is less important for athletes who have 24 hours or longer between training sessions.[66]

The type of carbohydrate ingested after exercise is less important than the amount and timing of ingestion. However, high-GI foods result in higher muscle glycogen levels compared with low-GI foods.[15] As many high-GI foods have lower nutrient density, there is some merit in limiting consumption of these foods to occasions when time to achieve maximum glycogen storage is limited, or to consume them in conjunction with moderate-GI foods.

There has recently been interest in the role of protein in the recovery meal. The effect of protein plus carbohydrate on muscle glycogen resynthesis remains equivocal, in part because of methodological differences in study design.[67–71] As the rate of muscle glycogen resynthesis is influenced by frequency of post-exercise feeding and changes over time,[69] the benefit of adding protein to carbohydrate is best determined on an individual basis. However, inclusion of protein in the meal is likely to be beneficial for protein synthesis, the promotion of a more anabolic hormonal profile and for enhanced immune function.[71,72]

7. Special populations and issues

7.1 Child athletes

Certain key differences between children and adults affect recommendations regarding the nutritional needs of young athletes. First, children need more energy per kg BM. Second, young people have a greater need for protein to satisfy requirements for growth: children aged 5–11 years require 1 g/kg BM/day, which increases to 1.2–2 g/kg BM/day during exercise.[73] Third, during submaximal exercise, children use more fat and less carbohydrate. Fourth, children require more calcium than most adults to support bone growth.[74]

Hypohydration is more detrimental to children than adults, and children must be educated to drink enough to replenish fluid losses. Sports Medicine Australia recommends that active children drink 150–200 mL of fluid 45 minutes prior to exercise, plus an additional 75–100 mL every 20 minutes during exercise.[75] Children also need to consume more snacks compared with adults, and these become particularly important during periods of increased activity.

7.2 Older adult athletes

Nutrient needs change with age and important nutrients for exercise that may be lacking in the diets of older adults are energy, vitamin B_6, vitamin B_{12}, calcium, vitamin D, magnesium and zinc.[76] It is also important to recognise that nutrient absorption can be affected by chronic illness or disease, or by interactions with medication. For example, older adults taking diuretics are more likely to become hypohydrated.[77]

Ageing is associated with a progressive decline in muscle mass (sarcopenia) that can result in a decline in muscle strength and function. However, an intake of 1 g/kg BM/day of protein combined with weight-bearing exercise can help to reverse sarcopenia and improve the regeneration potential of muscle fibres.[78]

7.3 Pregnant and lactating female athletes

Inadequate dietary intakes of energy, iron, zinc, vitamin E and magnesium have been observed in pregnant women.[79]

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In addition, pregnant women who exercise have an even greater need for energy, carbohydrate and fluids.[80,81] Moderate exercise does not adversely affect the quantity and composition of breast milk, or infant growth.[82] However, immunoglobulin A levels in breast milk are lower after exercise in women who have exercised to exhaustion.[83]

7.4 Vegetarian athletes

Vegetarianism is not associated with improved endurance performance over that of meat eaters; however, evidence suggests that performance is not worse.[84] It is noteworthy, however, that a combination of regular exercise with a vegetarian diet results in a lower mortality than either alone;[85,86] cited in Nieman.[84]

Vegetarians can typically meet their energy and carbohydrate needs. However, because of the high fibre content and bulk of a typical, purely vegetarian diet, some athletes with a high energy need may find that they need to supplement with lower-fibre, energy-dense foodstuffs (e.g. milkshakes/smoothies/sport supplements) to meet their energy needs and avoid gastrointestinal overload.

Main areas of concern for vegetarian athletes are getting a sufficient mix of essential amino acids to meet needs for protein synthesis, as well as meeting certain micronutrient requirements. The Institute of Medicine concluded that the evidence for protein intakes above the Recommended Dietary Allowance of 0.8 g/kg bodyweight for active individuals was not compelling.[87] However, the issue of 'protein quality' could be an issue for those on vegan diets (see vegetarian definitions[88]). All essential amino acids can be obtained from non-meat sources, but this requires judicious choosing of protein sources and complementary mixtures of high-quality plant proteins. This may not always occur and, thus, to meet essential amino acid requirements, vegan athletes may need a total protein intake well in excess of recommendations. Vegetarians who eat dairy products and/or eggs have less trouble meeting their essential amino acid needs and those who occasionally eat chicken and/or fish have the least problem balancing their protein needs.

Vegetarian athletes may be at risk of low-iron status (see section 4.4 on iron status.). Although vegetarians typically have iron intakes equal to or greater than meat eaters, the majority of it is non-haem. Haem iron (from meat, fish, poultry) has a greater bio-availability. Non-haem sources are subject to binding with chemicals in the digestive tract and a greater proportion is excreted. To enhance absorption from non-haem sources, consuming those foods with a source of vitamin C is beneficial. Conversely, avoiding consumption of tea, coffee and phytic acid from many fibre-rich foods (e.g. wholegrains), when iron-rich foods or supplements are taken, enhances the absorption and bioavailability (for a complete review of factors that influence iron absorption, see Hallberg and Hulthen[89]). Iron supplementation may be beneficial for some (in particular female) athletes, but should not be taken indiscriminately as it can interfere with other micronutrient absorption and high free iron in the blood can increase free radical production. A vitamin B_{12} deficiency can occur in vegans or strict vegetarians, as vitamin B_{12} comes only from animal products. Individuals on these diets are advised to take a vitamin B_{12} supplement.

Vegetarians will, on average, have lower muscle creatine concentrations and therefore will typically respond better to creatine loading.[88]

More specific information on recommended food patterns and nutrients of concern for vegetarians can be found in publications from the American Dietetic Association and Dietitians of Canada and in Messina *et al*.[90,91]

7.5 Eating disorders

Competitive athletes may be more driven than non-athletes to push themselves physically to their limits in order to improve performance. Attributes, such as being perfectionist, competitive, self-motivated and compulsive, are also traits that can predispose individuals to eating disorders.[92,93] Adding to this pressure to perform, some sports also have categories that define levels of leanness and weight for entry and competition.[94,95]

While women are more likely than men to develop eating disorders that reduce body fat and mass, such as anorexia nervosa, anorexia athletica and bulimia nervosa, male athletes are more likely than women to develop muscular dysmorphism (bigorexia) that is often associated with body builders.[94] Between seasons, compulsive eating (bingeing) may affect both male and female athletes, resulting in yo-yo dieting practices.

The effects of these eating disorders may not only affect short-term performance but also long-term health.[96] When food choice and energy are limited, women become vulnerable to the female athlete triad of disordered eating, menstrual dysfunction and osteopenia that can also impact on immunity.[97–99] Intakes of protein, fat, carbohydrate and essential fatty acids can be poor along with low intakes of bone-building nutrients, especially calcium, the B group vitamins, iron and zinc.[100]

On the other hand, athletes affected by muscular dysmorphism often follow high-protein, very low- or no-fat diets that may rely heavily on supplements and dehydration practices before events. These athletes are more susceptible to kidney failure, bone loss, depression and low self-esteem.[101]

Athletes who suffer from compulsive eating disorders of bingeing followed by rigid dieting often rely on purging, fasting or laxative abuse to control bodyweight and are more susceptible to developing depression and obesity, hypertension, heart disease and certain types of cancers.[102]

Ultimately, treatment of athletes with disordered eating demands a team approach involving medical staff (physician, dietitian, psychologist), coaches and parents. A focus on early detection, improving physical strength (muscular and skeletal) and reducing risk of injury or illness improve ability to train and perform.[98,103]

7.6 Sports foods and dietary supplements

The use of sports supplements is widespread in the athletic community.[104] Common reasons for athletes to use supplements include: to compensate for poor dietary habits, to meet the extreme demands of training and competition, to directly enhance performance and because of recommendations by influential people. Some supplements have a beneficial effect. For instance, sports foods, such as sports drinks, carbohydrate gels, energy bars and meal supplements, can make a useful contribution towards achieving a specific nutritional goal in a particular setting.[105] Creatine monohydrate, caffeine and sodium bicarbonate have been shown to enhance exercise performance of a specific nature.[104,106] However, for the vast majority of supplements, evidence for performance enhancement or other benefits is lacking.

The dietary supplement market is a-billion-dollar industry. The large number and variety of sports supplements available, combined with the often emotive and anecdotal claims and testimonials about their efficacy, make it increasingly important for athletes to seek objective expert advice before embarking on a supplementation regimen. It is of concern that some supplements can cause adverse health effects and that a number of supplements have been found to contain prohibited substances, with the potential to lead to anti-doping violations.[104,107] Sports dietitians have the necessary expertise to advise athletes on useful as well as on unproven and possibly harmful supplements.

8. Conclusion

Diet plays a key role in exercise performance, by contributing the required nutrients in appropriate amounts, at the required time. Besides meeting total daily energy and nutrient needs, athletes will benefit from using specific pre-, during- and post-exercise nutritional strategies. Diet is also an important component of any programme intended to increase lean BM or reduce body fat. It is important to understand that there are no single foods, combinations of foods or special sports supplements that on their own optimise sports performance or replace the need for a balanced and nutritionally adequate diet.

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