Nutrition, Metabolism and Exercise

Mark L. Wahlqvist and Richard S. D. Read
Section of Human Nutrition, Deakin University

ABSTRACT

Adequate nutrition is essential for maximum performance and for athletes in most sports the consumption of a variety of foods will ensure an adequate intake of all essential nutrients. For endurance events, dietary manipulation can be used to increase muscle glycogen reserve and performance may thereby be extended. Additional protein in the diet is not generally warranted except where a rapid build-up of body protein is required. Vitamins and minerals, with the possible exception of iron are generally adequate. Meals taken before heavy physical activity should be high in carbohydrate and readily assimilable. Alcohol should be avoided. During endurance events sweat loss of water should be replaced and salt may also be required, but excessive intake should be avoided. Aust. J. Sports Med. Vol. 12(3): 54-57, 1980.

NUTRITION, METABOLISM AND EXERCISE

Nutritional advice is often sought by athletes and the present review summarizes the possibilities and limitations of diet in physical performance as well as the more general implications for health. Prerequisites for optimal physical work performance include:

a. adequate cardio-respiratory reserve (5)
b. relevant muscle type and mass (5,25)
c. optimal fuel supply (3,4)
d. other nutrients (amino acids, minerals, vitamins and water) (2,29)
e. minimal adiposity (26)
f. aptitude (5).

In its broadest sense, nutrition touches on each of these considerations. For example, the heart, free of coronary disease, with its dietary determinants, will have a better reserve. Even aptitude may benefit from a sense of well-being that good nutritional status confers.

ENERGY SUPPLY

The ultimate substrates for skeletal and cardiac muscle (1,25,44) are either endogenous stores of glycogen and triglyceride or carbohydrates and lipids derived from the blood. Carbohydrate substrates are glucose, lactate and pyruvate, while lipid substrates include free fatty acids, triglycerides, ketone bodies and acetate (15,34). The relative importance of these substrates depends on the nutritional state of the individual and the level and duration of physical activity. In a healthy individual, the total energy requirement can be met from a range of substrates; thus, a variety of food intake patterns can meet energy needs. Alcohol may affect performance by altering the blood substrate profile in the direction of lactate, ketones, acetate and acetaldehyde, and by depression of cardiac function (24).

There is good experimental evidence that increased glycogen stores in skeletal muscle can improve performance in endurance events exceeding about 60 minutes. These stores can be favourably influenced by:

1. The Astrand regime of low carbohydrate intake followed by high carbohydrate intake on the days immediately before an event (5,11);
2. Supplementary carbohydrate during an event (14).

To some extent glucose is replenished during exercise by gluconeogenesis (the formation of new glucose) in the liver. It is worth noting that glucose, whether derived from glycogen stores or the blood, is the only fuel which can be used anaerobically (without oxygen) to generate high energy phosphate stores as ATP and creatine phosphate. The substrate interrelationships of exercise are interwoven in many ways. For example, lactate generated in skeletal muscle can be used as a fuel directly by the healthy heart and also for gluconeogenesis by the liver. Gluconeogenesis in the liver also occurs by the use of amino acids derived from the turnover of body protein, particularly alanine released from skeletal muscle (35).

In the training athlete, energy intake is regulated by appetite and, except at extremely high energy expenditure, individuals are protected from a deficiency of energy. Thus the athlete need not worry about providing additional energy except to satisfy appetite. An athlete following a heavy training schedule may have a surprisingly high energy utilisation. Energy intakes are frequently 15,000 to 25,000 kilojoules per day but may be higher and intakes as high as 35,000 kJ/day are not uncommon (40). The best objective guide to satisfaction of energy demand is maintenance of body weight.

To meet energy requirements energy may be consumed as carbohydrate, protein or fat. These three food molecules are all well utilised. However, the athlete with a high energy demand is advised to increase particularly the consumption of starchy foods such as bread and potatoes to meet his demand. One of the reasons for this has already been alluded to in that carbohydrate is particularly efficient as a source of muscle glycogen. There are additional reasons, however, in that these foods contribute useful amounts of protein as well as vitamins (particularly thiamin) necessary for the energy-yielding metabolic conversions that occur in all cells. There is the likelihood of encouraging the development of atheroma if the consumption of saturated fats and cholesterol principally from meat, dairy products and egg yolk, is excessive (6). Although fatty acids may contribute to the additional oxidative metabolism of exercise, cholesterol will not.

An increased consumption of sucrose may also be used to increase energy intake. However sucrose is devoid of protein, minerals and vitamins, it is thus preferable to increase the consumption of other constituents of the diet.

FOOD INTAKE DURING THE EVENT

In an event of long duration (more than 30 minutes), there is a shift in the major sources of muscular energy. Initially, the major part of the energy is supplied from carbohydrate (muscle glycogen and blood glucose) and as body glycogen reserves are reduced, an increasing proportion of energy is derived from fatty acids and ketones. Fatigue and a reduction in energy output are associated with a reduction in carbohydrate fuels, although lipid fuels may still be present in abundance. The period of high energy output can be considerably extended by taking in a readily assimilable carbohydrate food source during the event (5,11). Glucose, sucrose and Caloreen (a commercial preparation of short chain polysaccharides) are all suitable, and starch also appears to be well utilised (45). The carbohydrate supplement may be taken as a solution or suspension and will of course provide water as well. It is advisable to keep the concentration of sugar low initially since excessive ingestion of carbohydrate may produce nausea. A cupful (200-250 ml) of a 5% solution of glucose (isosmotic with body fluids) would be a useful starting point. Some experiments have shown that very large amounts of sugar in solution can be ingested during exercise without apparent ill effect. In a series of four-hour cycling trials at 50 kJ/min, glucose supplements of 250 ml of a 40% solution every 20 minutes were tolerated and were shown to significantly improve work performance (14). The rate of energy input here (80 kJ/min) was approximately 1.5 times the rate of energy output in the exercise.

PROTEIN

Protein is essential in the diet; the question for the athlete is how much and of what type. Traditionally, it has been held that a large amount of protein, often consumed as near-raw steaks, is a desirable part of the training diet. Endogenous muscle protein, however, is not used up to any significant extent during physical exertion and it is generally held that it is not necessary to provide additional dietary protein for the individual who eats a variety of foods and who is participating in strenous physical exercise. (29,39). Recent work suggests that for the athlete in training, a high input of protein in the diet will increase body protein, but that increased body protein will not necessarily be correlated with the improved physical performance (16). However, in situations where the athlete is required to build up muscle rapidly, for example, at the beginning of a training season, a high intake of dietary protein may be beneficial in increasing the rate of accumulation of body protein. Similarly, there may be advantages from high intakes of protein in sports where muscle mass is a key determinant of performance as, for example, in weight lifting. Increased sweat production may also increase nitrogen loss and hence protein requirement (16).

The recommended quantity of good quality protein for the normal individual, an allowance which incorporates a generous margin of safety, is about 1.0 g/kg or 70 g for a 70 kg man (33). Good quality protein or protein mixtures have an essential amino acid composition which will support anabolism. The average protein consumption by Australians is probably near 90 g/day (7), while many are consuming 120 or more grams per day, thus protein consumption is usually 1.3 g/kg or greater and is substantially higher than the recommended daily allowance. Additionally, it might be expected that the athlete in training will have an increased protein intake as a consequence of increased energy intake. Thus, if an individual weighing 70 kg has an energy intake of 20,000 kJ/day and protein accounts for 12% of energy intake (an average value), the protein intake will be 2.1 g/kg; an amount which is more than twice the recommended allowance. Hence a relatively high intake of protein can be obtained from a normal mixed diet and there is no need for high protein supplements.

In protein feeding trials on athletes in training, 1 g/kg per day was found to be inadquate to maintain nitrogen balance while 1.4 to 1.5 g/kg was adequate. Higher intakes (2.76 g/kg) resulted in increased protein retention though there was no measurable increase in physical performance (16,21). The interpretation of such trials is complicated by two factors. Firstly, the initiation of heavy physical training may lead to a negative nitrogen balance which becomes positive after a few days, due apparently to an adaptive mechanism (22). Thus, a protein intake which initially appears to be inadequate, may be observed to be adequate some days later. Secondly, it has been observed that, at constant protein input, protein retention is improved with increasing energy intake (36). Thus, the adequacy of protein intake cannot be considered in isolation from energy intake.

Diets high in protein and energy also appear to be advantageous in minimizing the loss of body protein which may occur as the result of the stress of injury or surgery (28). Protein in the diet is obtained from cereals, legumes and dairy products as well as from meat. Although meat may contribute substantial amounts of vitamins and minerals, as well as protein, there is no specific need for it and it is a relatively expensive form of protein. A vegetarian diet which includes dairy products or complementary proteins from cereals and legumes can be entirely adequate.

VITAMINS

A number of the vitamins act as co-enzymes in body reactions; some B-group vitamins (thiamin, riboflavine and niacin) are involved in energy metabolism. It has long been known that vitamin supplements to the diet will improve physical performance if the subject is in a deficient state (17,20); however, if vitamin status is satisfactory, additional supplements do not appear to give any further improvement in physical capacity (29). Chief sources of B-group vitamins in the Australian diet are cereals for thiamin, milk for riboflavin and meat and fish for niacin; liver is a good source and vegetables a fair source for all three vitamins.

A number of studies (13,42) have shown an apparent deficiency of certain vitamins as determined by biochemical measurements or in terms of apparent intake in relation to recommended dietary allowances. However, it has been much more difficult to show any significant improvement in performance when diets have been supplemented with additional vitamins. Thus, the results of a dietary questionnaire sent to pre-games Olympic athletes, suggested that some athletes were low or marginal in their intake of thiamin in relation to recommended daily allowances (42), but the significance of this with regard to performance could not be assessed. Refined carbohydrates such as sucrose contain no thiamin, yet thiamin is a key vitamin in the metabolism of carbohydrate; thus, any diet which relies substantially on sucrose for energy may be suspect with regard to adequacy of thiamin supply.

A possible increased requirement for niacin in athletes had been indicated on the basis of the rate of excretion of niacin metabolites (13) yet pharmacological niacin supplements decrease fatty acid mobilisation and could decrease endurance performance. Such supplements do not appear to affect short term performance (12).

Vitamin B_{12} is supplied almost entirely from animal products (meats and dairy foods). The amounts required are extremely small and even the pure vegetarian who eats none of these foods rarely shows deficiency symptoms. Supplementary vitamin B_{12} has not been found to improve physical performance (43).

A so-called vitamin B_{15} (d-gluconodimethylaminoacetic acid) has become available in health food shops. However, it has not been shown that this substance is required by man. The compound has no known biochemical significance although a considerable amount of work has been done with it in Russia where it has been claimed that there are beneficial effects on exercise tolerance (41). Further evidence is required to substantiate these claims.

Vitamin C is fashionable as a dietary supplement. The amount required to prevent scurvy is 5 to 10 mg/day and the recommended daily allowance is set at 30 to 50 mg/day (a 6 to 10-fold safety margin). This is approximately the amount obtained from a single orange. With an intake of approximately 100 mg/day, the body tissues become saturated, and the excess is excreted in the urine. Vitamin C in excess is fairly safe, however, caution is urged since there appears to be some possibility of detrimental effects such as the development of high dose dependency or kidney stones (9). A number of trials have failed to show any beneficial effect of supplements on athletic performance (10,23).

Vitamin E has frequently been claimed to be beneficial to the athlete. Vitamin E protects against oxidative damage to tissue lipids and against a muscular dystrophy in certain animals. Yet vitamin E deficiency is exceedingly rare in humans. Cereals and vegetable oils in the Australian diet provide more vitamin E than is required. Trials of vitamin E supplementation to athletes in training have failed to show any beneficial effect (27,28).

MINERALS

Minerals are generally adequate in the diet with possible exception of iron. The haem iron of meats provides the most readily available source. However, non-haem iron in, for example, legumes and green vegetables, is also important and its availability is enhanced by adequate dietary vitamin C. A small proportion of athletes have been found to have an anaemia which responds to iron supplementation (46). Females may require additional iron because of the iron loss associated with menstruation (2,47). Deficiencies of numerous other minerals such as potassium, magnesium or calcium, could theoretically reduce performance. However, such deficiencies are not thought to occur when a variety of foods is consumed.

SALT AND WATER BALANCE

Salt and water balance are important to the athlete and may pose problems when substantial sweat loss occurs (8). In the long term, it is desirable to keep salt (sodium) as low as is practicable, since, in susceptible individuals, the consumption of excess salt is associated with the development of hypertension (31). The minimum requirement for salt in the diet is approximately 1 g/day (31). The normal intake for most Australians is in the range 4 to 12 g/day though some individuals consume considerably more (18). The general recommendation is that salt consumption should not exceed 5 g/day (37). However, under conditions of athletic activity, particularly in hot conditions, salt and water losses through sweat may make it necessary to take both water and salt supplements. Excessive sweating produces dehydration and reduces physical performance. Water losses may be in the region of 1 to 2 litres per hour during heavy exercise and, for best performance, water should be taken in repeated small amounts to maintain body water constant. Sweat contains salt (0.1 to 0.2%) as well as water, but at a lower concentration than blood plasma. If excessive losses of sweat (3-51) are placed with water, a relative deficiency of sodium chloride develops. Water intake may quench thirst, but the blood will become hypotonic (diluted). If dehydration is not corrected, heat stroke may supervene. This is characterised by lethargy, nausea, vomiting and eventually coma. Heat stroke requires prompt medical attention and intravenous fluids (8).

Because of the dilution effect, it is wise to include a little salt (1-2 g/l) in drinking water in situations where protracted exercise is carried out under hot conditions. Various proprietary formulations of drinks containing both salts and glucose are now marketed and their use may be appropriate. Excessive consumption of these drinks however, should be discouraged because of the likelihood of consuming an excessive amount of salt. Salt tablets may be used to replace lost salt. However, because it is difficult to regulate the dose and because they may cause gastric discomfort, they are not recommended. Excessive salt intake will produce excessive thirst and consequent excessive water intake which will reduce performance.

MAINTAINING BODY TEMPERATURE IN COLD ENVIRONMENTS

Adequate nutrition is important in the maintenance of normal body temperature under cold conditions. Ambient temperature and humidity, clothing, food energy input, rate of energy output and sweat production all interact in the maintenance of body temperature. For the skier, special problems arise because of the low ambient temperature and alternating periods of high and low energy expenditure. Thus the tired cross-country skier or bushwalker whose clothes are damp with sweat may be in danger of hypothermia if return to normal conditions is delayed by darkness or injury (19). Clothing should be of the type that can be conveniently opened for ventilation during heavy exercise as this will avoid moisture build up and loss of insulating properties later in the day. It is also advisable to carry an emergency supply of readily assimilable carbohydrate such as glucose or sucrose sweets for use when tired and cold. Metabolic rate and consequent body heat production are reduced by fasting and are increased by 10 to 20% following the ingestion of food. Alcohol should not be used under cold and difficult conditions because it impairs judgement and though it may produce a subjective feeling of warmth, the peripheral vasodilation produced will increase the rate of heat loss from the body (32). The skier or walker is unwise to set out under cold conditions without first having an adequate meal.

FIBRE

Fibre in the diet, derived from whole grain cereals, fruit and vegetables, provides non-nutritive bulk. The term refers to complex molecules which are not digested (non-absorbable carbohydrate) and therefore do not provide energy. One important function of dietary fibre is to maintain normal intestinal function (30).

In the athlete's diet, fibre is as desirable as in any other diet, however, gas production in the bowel may be a problem. It is probably desirable to avoid high fibre foods within 48 hours of a competitive event. Fibres such as cellulose and pectins are, to a certain extent, digested by gut bacteria with the production of organic acids and gas. Gas may give rise to considerable pain and discomfort during heavy physical activity.

MEALS BEFORE COMPETITION

Meals before competition should be mainly carbohydrate. Carbohydrate boosts the glycogen reserve, as already discussed, and absorbable carbohydrate alone will be rapidly assimilated. A gastro-intestinal tract loaded with food is likely to decrease performance because of discomfort and, in any case, digestion will be slowed when exercise begins because of reduction of blood flow to the splanchnic area. Thus the meal should be almost completely digested before competition. A pre-competition meal of white toast and honey, two or three hours before competition would be more appropriate than a meal of protein and fat.

Man requires nearly fifty specific nutrients to maintain health. In order to ensure an adequate supply of all of these, sound advice would be to consume a variety of foods. Adequate nutrition is an essential adjunct although not a substitute for genetic potential and training in the development of superior athletic performance.

REFERENCES

1. Ahlborg, G. and P. Felig. Substrate utilisation during prolonged exercise preceded by ingestion of glucose. *Amer. J. Physiol.* 233 (3) E188-E194, 1977.
2. Andersen, H. T. and H. Barkve. Iron deficiency and muscular work performance. *Scand. J. Clin. Lab. Invest.* 25 Suppl. 114, 1970.
3. Anonymous. Energy production during exercise. *Nutrition Reviews* 31 (1): 11-12, 1973.
4. Astrand, P. O. Diet and athletic performance. *Federation Proceedings* 26 (6): 1772-1777, 1967.
5. Astrand, P. O., and K. Rodahl. Text book of work physiology. 2nd edition. McGraw-Hill, New York. 455-488, 1977.
6. Australian Academy of Science. Report of a Working Group on Diet and Coronary Heart Disease. *Report No. 18*, 1975. Australian Academy of Science. Canberra.
7. Australian Bureau of Statistics. *Year Book*, No. 62. 295, 1977-78. Australian Govt. Publ. Service, Canberra, ACT.
8. Bailey, R. Water, electroytes, heat and the athlete. *Scholastic Coach*, May/June. 90-92 and 122, 1978.
9. Barness, L. A. Safety Considertions with high ascorbic acid dosage. *Ann. N. Y. Acad. Sci.* 258: 523-527, 1975.
10. Bender, A. E. and A. H. Nash. Vitamin C and physical performance. *Plant Foods for Man.* 1 (3/4): 217-231, 1975.
11. Bergstrom, J. and E. Hultman. Nutrition for maximal sports performance. *J. Amer. Med. Assoc.* 221 (9): 999-1006, 1972.
12. Bergstrom, J., E. Hultman, B. Pernow, L. Jorfeldt and J. Wahren. Effect of nicotinic acid on physical working capacity and on metabolism of muscle glycogen in man. *J. Appl. Physiol.* 26: 170, 1969.
13. Borisov, I. M. Obespechennost niatsinom studentov sportivnogo ouza. *Voprosy Pitaniya* No. 6, 43, 1977.
14. Brooke, J. D., G. J. Davies and L. F. Green. The effect of normal and glucose syrup diets on the performance of racing cyclists. *J. Sports Med.* 15: 257-265, 1975.
15. Carlson, L. A., L. Kaijser, S. Rossner and M. L. Wahlqvist. Myocardial metabolism of exogenous plasma triglycerides in resting man. *Acta. Med. Scand.* 193: 233-245, 1973.
16. Consolazio, C. F., H. L. Johnson, R. A. Nelson, J. G. Dramise and J. H. Skala. Protein metabolism during intensive physical training in the young adult. *Amer. J. Clin. Nutr.* 28: 29-35, 1975.
17. Crandon, J. H., C. C. Lund and D. B. Dill. Experimental Human Scurvy. *New Engl. J. Med.* 223: 353-369, 1940.
18. Doyle, A. E., K. G. Chua and S. Duffy. Urinary sodium, potassium and creatinine excretion in hypertensive and normotensive Australians. *Med. J. Aust.* 1: 898-900, 1976.
19. Figueras, J. M. Skiing Safety 11. *International Series on Sports Sciences* 5, 1978. University Park Press, Baltimore, Md.
20. Foly, E. E., C. J. Barborka and A. C. Ivy. The level of Vitamin B-Complex in the diet at which detectable symptoms of deficiency occur in man. *Gaestroenterology* 2: 323-344, 1944.
21. Gontzea, I., R. Sutzescu and S. Dumitrache. The influence of muscular activity on nitrogen balance and on the need of man for protein. *Nutrition Reports International 10* (1): 35-43, 1974.
22. Gontzea, I., R. Sutzescu and S. Dumitrache. The influence of adaption to physical effort on nitrogen balance in man. *Nutrition Reports International 11* (3): 231-236, 1975.
23. Howald, H. B., Segesser and W. F. Korner. Ascorbic acid and athletic performance. *Annals N.Y. Acad. Sci.* 258: 458-463, 1975.
24. Jorfeldt, L. and A. Juhlin-Dannfelt. The influence of ethanol on human splanchnic and skeletal muscle metabolism during exercise. *Scand. J. Clin. Lab. Invest.* 37 (7): 609-618, 1977.
25. Kaijser, L., B. W. Lassers, M. L. Wahlqvist and L. A. Carlson. Myocardial lipid and carbohydrate metabolism in fasting man during prolonged exercise. *J. Appl. Physiology* 32: 847-852, 1972.
26. Katch, F. I. and W. D. McArdle. Nutrition, weight control and exercise. Houghton Mifflin Co., Boston, 1977.
27. Lawrence, J. D., R. C. Bower, W. P. Riehl, and J. L. Smith. Effects of -tocopherol acetate on the swimming endurance of trained swimmers. *Amer. J. Clin. Nutr.* 28 (3): 205-208, 1975.
28. Long, C. L. Energy balance and carbohydrate metabolism in infection and sepsis. *Amer. J. Clin. Nutr.* 30: 1301-1310, 1977.
29. Mayer, J. and B. Bullen. Nutrition and athletic performance. *Physiological Reviews* 40 (3): 369-397, 1960.
30. Mendelhoff, A. R. Dietary fibre and human health. *New England J. Med.* 297 (15): 811-814, 1977.
31. Meneely, G. R. and H. D. Battarbee. Sodium and potassium. Ch. 26 in Present Knowledge in Nutrition, 4th edition, 1976. The Nutrition Foundation Inc., New York.
32. Meyers, F. H., E. Jawetz and A. Goldfien. *Review of Medical Pharmacology.* Sixth Edit. Lange Medical Publishers, Calif., 1978. p. 246.
33. National Health and Medical Research Council. Dietary Allowances for use in Australia. Australian Govt. Publ. Service, Canberra, 1971.
34. Paul, P. and W. L. Holmes. Free fatty acids and glucose metabolism during increased energy expenditure and after training. *Med. Sci. Sports* 7: 176-184, 1975.
35. Poortmans, J. R. and L. Delisse. The effect of graduated exercise on venous pyruvate and alanine in humans. *J. Sports Med.* 17: 123-130, 1977.
36. Rao, C. N., A. N. Naidu and B. S. N. Rao. Influence of varying energy intake on nitrogen balance in men on two levels of protein intake. *Amer. J. Clin. Nutr.* 28: 116-1121, 1975.
37. Senate Select Committee on Nutrition and Human Needs. Dietary Goals for the United States. *2nd Edit. Nov.* 1977. Government Printing Office Washington, D.C.
38. Sharman, I. M., M. G. Down and R. N. Sen. The effects of vitamin E and training on physiological function and athletic performance in adolescent swimmers. *Br. J. Nutr.* 26: 265-276, 1971.
39. Shepard, R. J. Endurance Fitness, 2nd Ed., 236, 1977. University of Toronto Press, Toronto.
40. Spence, H. A. Dietary requirements of ultra-long distance runners. Seventh International Congress of Dietetics, Sydney, Abstracts 113, 1977.
41. Stackpoole, P. W. Pangamic acid (Vitamin B_{15}). World Review of Nutrition and Dietetics 27, 145-163, 1977.
42. Steel, J. E. A nutrition study of Australian olympic athletes. *Med. J. Aust.* II: 119-123, 1970.
43. Tin-May-Than, Ma-Win-May, Khin-Sann-Aung and M. Mya-Tu. The effect of vitamin B_{12} on physical performance capacity. *Brit. J. Nutr.* 40: 269-273, 1978.
44. Wahlqvist, M. L., L. Kaijser, W. Lassers and L. A. Carlson. Fatty acid as a determinent of myocardial substrate and oxygen metabolism in man at rest and during prolonged exercise. *Acta. Med. Scand.* 193: 89-96, 1973.
45. Wahlqvist, M. L., E. G. Wilmshurst, C. R. Murton and E. N. Richardson. The effect of chain length on glucose absorption and the related metabolic response. *Amer. J. Clin. Nutr.* 31: 1998-2001, 1978.
46. Wijn, J. F. de. Haemoglobin, packed cell volume, serum iron and iron binding capacity of selected athletes during training. Proceedings Nutricia Symposium, Nutritional Aspects of Physical Performance, Zeist, Netherlands, 1972.
47. Wirth, J. C., T. G. Lohman, J. P. Avallone, Jr., T. Shire and R. A. Boileau. The effect of physical training on the serum iron levels of college-age women. *Med. Sci. Sports* 10 (3): 223-226, 1978.