EUROPEAN COMMISSION
HEALTH & CONSUMER PROTECTION DIRECTORATE-GENERAL

Directorate C - Scientific Opinions
C2 - Management of scientific committees; scientific co-operation and networks

SCIENTIFIC COMMITTEE ON FOOD

SCF/CS/NUT/SPORT/5 Final (corrected)
28 February 2001

Report
of the Scientific Committee on Food
on
composition and specification of food intended to meet the expenditure of intense muscular effort, especially for sportsmen

(Adopted by the SCF on 22/6/2000,
corrected by the SCF on 28/2/2001)

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Athletes	Generic term used for sportsmen and sportswomen
CES	Carbohydrate-electrolyte solution
CHO	Carbohydrate
Ergogenic	Tendency to increase physical work or mental work performance.
FIFA	Fédération Internationale de Football Association
Glycemic Index	Blood glucose response to a 50 g portion of the food as area under the curve over 3 hours, expressed as percentage of the response to the same amount of ingested glucose over the same period of time
IAAF	International Federation of Athletic Associations
Isotonic	Refers to osmolality of body fluids (297 mOsm/kg water)
NPU	Net Protein Utilisation
Osmolality	The number of particles (molecules or ions) per unit of molecular weight of undissociated solute. For example: 180 g of glucose in 1-kg water is 1 osmol with an osmolality of 1 Osm/kg.
PRI	Population Reference Intake

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1. Executive summary

Council Directive 89/398/EEC on foodstuffs intended for particular nutritional uses, as amended by Council Directive 1999/41/EC, foresees the adoption, by the Commission, of a specific directive on foodstuffs for particular nutritional uses intended to meet the expenditure of intense muscular effort and especially for sportsmen. In order to prepare this specific directive the Commission asked the Scientific Committee for Food (SCF) for advice on the nature, the essential composition where necessary, and any other specific requirements concerning the labelling and the appropriate use of such foodstuffs.

The Committee reviewed the scientific literature in the area of sport nutrition as well as a number of consensus reports that were prepared by various sport organisations and came to the conclusion that the concept of a well-balanced diet is the basic nutritional requirement for athletes. Nevertheless, taking the aspects of intense muscular exercise in consideration such as intensity, duration and frequency as well as specific constraints like time and convenience, individuals can benefit from particular foods or food ingredients beyond the recommended dietary guidelines for the general population.

As the increased energy need of these individuals is the most apparent difference, the food intake is higher. This can lead to differences in food choice and eating pattern as well as gastro-intestinal distress. Specially adapted nutritious foods or fluids may help to solve specific problems so that an optimal nutritional balance can be reached. These beneficial effects are not only limited to athletes who are taking regular intense prolonged muscular exercise, but are also intended for other target groups, for example for occupational jobs with hard physical work or with extreme environmental conditions, as well as for individuals with irregular physical high intensity or fatiguing leisure time activities.

In relation to these general considerations, four food categories have been identified, reviewed and where applicable, essential requirements were formulated.

- Carbohydrate-rich energy food products

Consensus has been reached about the essential role of carbohydrate intake in relation to physical performance during all types of exercise, generally lasting longer than one hour. This knowledge is based on the importance of increased body glycogen stores in liver and muscle for sustaining prolonged heavy exercise, as well as the direct relationship between the level of carbohydrate intake and the resynthesis of muscle glycogen after exhausting exercise.
Ad libitum eating during 24 h after prolonged heavy exercise may lead to an inadequate intake of energy, especially carbohydrates and consequently, a sub-optimum recovery. Therefore when athletes have only 24 h to recover from prolonged heavy exercise, optimal carbohydrate intake should be guaranteed by specific instructions regarding the timing and choice of carbohydrate intake by food and/or carbohydrate rich food products. High glycaemic index carbohydrate foods are recommended and they should provide 10g per kgbw during the 24-h recovery. The refuelling should begin immediately after the exercise bout when athletes should consume up to 1 g/kgbw of carbohydrate and then about 0,5 g/kgbw at hourly intervals until the next meal, which should be made up of high glycaemic index carbohydrate foods.
In this respect all types of bio-available carbohydrates that increase blood glucose concentration effectively are suitable. Besides the high carbohydrate/low fat dietary guidelines, especially developed carbohydrate-rich energy food products can be of benefit in reaching an adequate carbohydrate intake

- Carbohydrate-electrolyte solutions (C.E.S.)

The two factors that have been considered to contribute most to the onset of fatigue in exercise are the depletion of the body's carbohydrate reserve and the onset of dehydration, as a consequence of the loss of water and electrolytes in sweat.
Compared to water as a control drink, a substantial body of scientific evidence supports the suggestion that during prolonged exercise drinks containing carbohydrates and electrolytes, in particular sodium, improve the performance.
The optimum carbohydrate concentration in the drink depends on a number of factors, among others the need for water (hot/cold conditions) and the intensity and type of exercise (gastro-intestinal absorptive capacity, osmolality (rate of gastric emptying as well as water absorption in the small intestine), type of carbohydrate simple vs. polymers). Therefore a range from 80-350 kcal (335 - 1470 kJ) CHO/1000 ml CES drink is advised. The only electrolyte added to drinks consumed during exercise that is known to confer physiological benefit is sodium. A sodium concentration of 20-50 mmol/l (460 - 1150 mg/l) will stimulate carbohydrate and water uptake maximally in the small intestine and will help to maintain extracellular fluid volume. The

evidence to support the inclusion of other components as essential ingredients, is not at present convincing.

- Protein and protein component

Athletes continue to believe, as did the Olympians of antiquity, that extra protein intake is essential for maximal performance. There is not much scientific evidence available to support this.

Endurance athletes have a modest increase in protein requirements and, therefore, the recommended daily intake is increased to 1.2 - 1.4 g per kgbw per day. A diet containing 10-11 % En protein meets this modest increase, as the daily energy needs may be two to three-fold higher than those of non-athletic subjects. The use of protein-carbohydrate solutions or protein-carbohydrate rich solid food products in the post-exercise period may help to rapidly re-synthesis glycogen stores that were lost during the exercise.

The protein requirement for strength athletes, who have trained for years, is not higher than 1.0 to 1.2 g per kgbw per day. Novice athletes involved in strength training programs have a marginally higher protein requirement and their recommended intake is therefore increased to 1.3 to 1.5 g per kgbw per day. A diet containing 10-12 % En protein of mixed quality may not contain enough protein to meet this temporary need if the total energy intake is relatively low. In addition there is no scientific evidence at all for further increases in protein intake with protein supplements to levels of 3-6 g per kg bw per day, as frequently occurs in practice. Also the use of supplements of free amino acids has not beneficial effects on the whole body and protein synthesis when compared to the use of a balanced protein in a mixed meal.

- Supplements

For micronutrients there is a scientific consensus that with an adequate dietary intake, there is no further need for additional supplementation for essential micronutrients such as minerals, trace elements and vitamins. In the case of restricted food intake, as is frequently observed in weight related sports, micronutrient intake could become marginal or deficient, which would justify supplementation. Intake of a number of minerals and vitamins such as magnesium, calcium, zinc and the anti-oxidants vitamins C, E as well as carotenoids, have been suggested to be critical in relation to physical performance. So far, scientific evidence is lacking or inconsistent in supporting recommendations for nutritional intakes beyond the accepted dietary guidelines. The upper safe levels of vitamin- and mineral intake are at present under consideration of the SCF and have not been reviewed in this report.

Finally, a number of food components have been reviewed since they are often related to physical performance. So far, only for caffeine and creatine is there scientific data to show that they have an ergogenic effect. For caffeine levels of 3 to 8 mg/kgbw improve short-term high intensity exercise as well as endurance performance. Creatine intake levels of 2 – 3 g per day have been shown to be effective in increasing total muscle creatine and in improving performance of a short term high intensity exercise.

The Committee wishes to stress that this report is dealing with the physiological needs and appropriate uses of food and food ingredients to meet the expenditure of intense muscular effort. The safety aspects of high level of intake of certain compounds such as free aminoacids are not taken into consideration. Upper safe levels of vitamin and nutrient intakes are at present under consideration of the SCF. The Committee has adopted opinions on the safety of caffeine in the past (Opinion on caffeine, taurine and D-glucurono- gamma -lactone as constituents of so-called "energy" drinks, expressed on 21 January 19991). The Committee considers the safety aspects of creatine supplementation in a separate report.

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[1] available on the internet at the SCF pages

2. Terms of reference

To advise on the nature, the essential composition, and, where necessary, any specific requirements concerning the labelling and appropriate uses of foods intended to meet the expenditures of intense muscular effort, especially for sportsmen.

The Commission intends to use this advice to prepare a specific directive on these foods as foreseen in the framework Council Directive 89/398/EEC of 3 May 1989 as amended by Council Directive 1999/41/EC on the approximation of the laws of Member States relating to particular nutritional uses.

3. Consulted experts and documents

In drafting the opinion, the Working Group on Nutrition of the SCF was enlarged with four experts:

- Dr. A. Berg, Dept. of Sport Medicine, University Freiburg, Freiburg, Germany
- Prof. Dr. R.J.M. Maughan, Environmental and OccupationalMedicine University of Aberdeen, Aberdeen, United Kingdom
- Dr. A.J.M. Wagenmakers, Nutrition and Toxicology Research Institute NUTRIM, University of Maastricht, Maastricht, The Netherlands
- Prof. Dr. C. Williams, Dept. of Physical Education and Sports Sciences, Loughborough University, Loughborough, United Kingdom.

The Committee examined many published papers in the area of sports nutrition, including the proceedings of an IOC (International Olympic Committee) International Scientific Consensus "Food Nutrition and Sport Performance" in 1991 [49] the FIFA Consensus "Food, Nutrition and Soccer Performance" in 1994 [50] and the IAAF Consensus "Current Issues in Nutrition and Athletes" in 1995 [104] and had a meeting with some experts from the IDACE.

The Committee also took notice of the report "Sports food" from the Association of Dietetic Food Industry of the EC [73].

4. General considerations

Nutrition significantly influences physical performance. This relationship is even more clearly demonstrated during intense muscular exercise. As a consequence in competitive sports disciplines, nutrition has become important for performance, now those athletes have reached the limits of training volume and training intensity. Among athletes and exercise physiologists this has led to a renewed interest in the role of nutrition and the influence of gastrointestinal problems on physical performance and well being.

A realistic conclusion in the literature, is the concept that a well-balanced diet is the basic nutritional requirement for athletes. In addition to this, specific nutritional requirement may arise depending on particular physiological conditions, which are the consequence of the athletic training and performance. The question remains to what extent these specific nutritional needs differ from the dietary guidelines for the general population.

This question should not be limited to athletes taking regularly intense prolonged muscular exercise, but also to other target groups involved in regular or irregular intense muscular exercise in a number of occupational jobs, such as rescue services, military services and industrial sites with extreme environmental conditions (high/low temperature). There are also large numbers of individuals who are physically active on a recreational basis, sometimes in irregular high intensity or fatiguing exercise. In a recent pan – EU survey [52] 30 to 40 % of the adult EU population spent more than 8 h per week being physically active. A proportion of this group, including those involved in sport should be regarded as a potential target group that can benefit from specific sports food to support health and performance and to minimise the risk of unwanted outcomes such as injury.

In the past three decades the question about extra nutritional needs beyond a well-balanced diet has been extensively addressed within the nutritional and exercise sciences. This research was also stimulated by the rapidly increasing market for sports foods, in particular the carbohydrate-electrolyte solutions (CES). At the same time, an increasing interest in functional food ingredients, which may affect body functions in a positive way, has arisen. In this respect sport nutrition is the good example of scientifically developed concepts in the area of foods or food ingredients intended to influence particular physiological functions.

For the evaluation of the scientific background to the use of particular foods for intense muscular exercise, one should address in the first place the issue of beneficial effects of food or food ingredients beyond the normal recommended nutritional intake on physical performance, taking specific constraints like time and convenience into consideration.

Several aspects of intense muscular exercise are relevant, including duration, intensity and frequency. Based on these factors, specific food categories can be defined, including food products, which give an increase of fluid/energy/nutrient availability per unit of time in order to optimise physical performance directly or indirectly by an improved rate of recovery from exercise.

The first and clearest difference in nutritional needs between individuals who are engaged in intense muscular exercise and the general population is related to energy expenditure.

The energy expenditure of a sedentary adult female/male amounts to approximately 8.5-12.0 MJ (1825 - 2580 kcal) per day. Physical activity by means of training or competition will increase the daily energy expenditure by 2 to 4 MJ (430 - 860 kcal) per hour of exercise, depending on physical fitness and on duration, type and intensity of sport. For this reason, individuals with a substantial increase in their daily physical activity must adapt the energy intake by an increased food consumption to meet the energy needs according to the level of daily energy expenditure. This increased energy demand could be achieved by an increased intake of selected normal foods. Many athletic events are characterized by high exercise intensities. As a result, energy expenditure over a short period of time may be extremely high. For example, to run a marathon will take about 10-12 MJ (2150 - 2580 kcal). Depending on the time to finish, this may induce an energy expenditure of approximately 3.2 MJ (688 kcal)/h in a recreational athlete and 6.3 MJ (1355 kcal)/h in an elite athlete. A professional cycling race like the Tour de France, will cost an athlete about 27 MJ (5800 kcal)/day with extremes up to 40 MJ (8600 kcal)/day [136].

Compensating for such high energy expenditure by ingesting normal solid meals will pose a problem for any athlete involved in such competitions, since the digestion and absorption processes will be impaired during intensive physical activity. These problems are not restricted to competition days. During intensive training days, energy expenditure is also high. In such circumstances, athletes tend to ingest a large number of ‘in between meals’ up to 40% of the total energy compared to about 25% in the general population [159]. These 'in between meals' are often composed of energy rich snacks, but are often high in fat and low in protein and micronutrients. Such a diet would lead to a deficient nutrient intake if energy intake becomes low as is sometime observed in athletes such as gymnasts.

Specially adapted nutritious foods/fluids which are easily digestible and rapidly absorbable, may solve this problem.

In addition to the energy needs and the limited capacity and time to digest and metabolise foods, is the importance of the selection of fuels in the muscle. Metabolic capacity and power output depend on this selection. For maximal muscle performance the muscle cell depends almost entirely on carbohydrate (CHO) as a substrate. Therefore, the diet selection is not only a matter of energy but also a selection of the substrate sources, especially carbohydrate and fat.

At the other end of the energy expenditure scale it is seen that energy intake, especially in females athletes such as gymnasts and ballet dancers is often extremely low [159]. This can partly be explained by the urge to limit energy intake and to reduce body mass and particular fat mass. In addition eating disorders are frequently observed in these groups [135].

The low energy intakes in these circumstances may lead to a low intake of essential nutrients such as protein, iron, calcium, zinc, magnesium and vitamins. The CHO intake may not be sufficient to balance the CHO used in training. This aspect should receive special attention since many of these athletes are young and still in a period of growth and development.

Another essential difference between sedentary and very active individuals is the high rate of heat production and consequent sweat loss. It is therefore essential that, besides restoration of energy and nutrient loss, fluid and electrolyte replacement is secured. In terms of homeostasis and optimum performance, fluid (and electrolyte) replacement during exercise has the highest priority.

Finally, over the years a number of natural food ingredients have been identified and scientifically proven to be ergogenic. For example, supplementation of comparable modest levels of caffeine or high levels of creatine compared to the normal dietary intake, can benefit endurance and high intensity performance. At the same time it is not surprising that many faddish diets and exotic ingredients have come and gone.

It is against this background that the SCF examined the requirements of foods for particular nutritional uses to meet the demands of intense muscular effort, especially for sportspeople. The Committee has attempted to define a number of food categories and to evaluate the scientific evidence for the need and/or benefit of such food category for particular nutritional uses beyond the general accepted food habits and dietary guidelines. If possible, "composition and specifications" have been formulated.

The safety aspects of high level of intake of specific foods or food compounds are not taken into consideration in this report.

5. Categories of food products intended to meet the expenditure of intense muscular effort, especially for sportsmen.

Food products can be broadly classified on their intended functionality in relation to the physical exercise:

A Carbohydrate-rich energy food products
B Carbohydrate-electrolyte solutions
C Protein and protein components
D Supplements
D1 Essential nutrients:
  D1-1 Minerals
  D1-2 Trace elements
  D1-3 Vitamins
  D1-4 Essential fatty acids.
D2 Other food components
  D2-1 Caffeine
  D2-2 Creatine
  D2-3 Carnitine
  D2-4 Medium Chain Triglycerides (MCT)
  D2-5 Branched Chain Amino Acids (BCAA)

Each of these four categories are reviewed in greater detail below.

6. Category A Carbohydrate-rich energy food products

6.1. Background

The systematic study of the link between carbohydrate intake and exercise capacity began over sixty years ago. In a series of studies examining the link between diet and submaximal endurance cycling capacity Christensen and Hansen [35] showed that time to exhaustion is increased when a high carbohydrate diet is consumed for about three days before exercise. In contrast, time to exhaustion (endurance capacity) was shorter when the diet was low in carbohydrate, though adequate in fat and protein. These times to exhaustion were compared with the performance times of their subjects when they had consumed their normal mixed diets in the days before exercise.

Thirty years later the explanation for the improvement in exercise capacity was provided by several studies, which used a percutaneous, needle biopsy technique to obtain small samples of muscle before, during and after exercise [17, 16]. Bergstrom and colleagues showed that fatigue during prolonged heavy submaximal exercise was closely associated with very low muscle glycogen concentrations. Those subjects who began submaximal exercise with the largest muscle glycogen stores tended to cycle longer than those with smaller stores. Therefore, dietary and exercise manipulations were designed to increase muscle glycogen stores before prolonged exercise in order to improve endurance capacity [2, 140]. Most studies using dietary carbohydrate loading in the days before prolonged submaximal exercise report improvements in endurance capacity during subsequent exercise [4, 22, 63, 115, and 134]. However, some studies report no improvement in performance following carbohydrate loading [99, 140].

The benefits of carbohydrate loading are most clearly demonstrated during prolonged submaximal exercise where the endpoint is fatigue. However, when the exercise demands that the participants complete a fixed distance in the shortest possible time (e.g. endurance races) then there are factors, other than muscle glycogen stores, which dictate the performance of the athlete. For example, running speeds are largely dictated by the maximum rate of oxygen consumption and training status of participants in endurance races. During heavy exercise lasting about an hour, the normal high muscle glycogen stores of athletes are usually sufficient to cover the demands of muscle metabolism. This is illustrated in the study reported by Sherman et al [140] where well-trained runners completed 20.9-Km races after dietary carbohydrate loading and after eating their normal mixed diets. There were no differences in the times taken to complete the distance (approximately 83-min) even though there were significant differences in pre-exercise muscle glycogen stores. Furthermore, it is clear from this latter study and an earlier study [81] that high pre-exercise muscle glycogen stores do not enable athletes to run faster in the early part of a race, although, they do allow them to maintain their chosen running speed for longer. It is this capacity to maintain their race pace which leads to improved performance times. Thus, carbohydrate loading improves performance only when the duration of races is such that they make large demands on muscle glycogen stores. This is also true for prolonged heavy intermittent exercise as seen in sports as such as soccer, rugby and hockey [115, 179].

Endurance trained athletes use less muscle glycogen than less well-trained individuals during submaximal exercise of the same absolute intensity. The greater aerobic capacity of the skeletal muscles of athletes allows them to use more fat for energy metabolism and so they use less glycogen. Nevertheless athletes need a high carbohydrate diet to support their heavy daily training because muscle glycogen is the main fuel for prolonged high intensity exercise.

Health professionals recommend that we should eat a diet, which provides at least 50% of our daily energy intake in the form of carbohydrates. A daily energy intake of approximately 10.5 MJ (2500 kcal) would therefore provide about 310 g of carbohydrate or 4.5 g/kgbw for a 70-kg man. This should provide sufficient carbohydrate to cover an active lifestyle and many recreational activities which do not produce exhaustion. However, a carbohydrate intake of about 5 to 6 g/kgbw is required to support daily exercise which is of moderate to high intensity and lasts no more than an hour. This amount of carbohydrate can be achieved simply by changing the composition of the diet to include more carbohydrate containing foods. Nevertheless, during activities in which fatigue limits performance, dietary carbohydrate loading will be of benefit to recreationally active people as well as to athletes preparing for competition. During this preparation period, a daily carbohydrate-intake of approximately 70% of energy intake has been recommended [49]. Therefore, in order to achieve high muscle and liver glycogen stores before exercise, it is essential to consume foods, which can collectively provide the necessary amount of carbohydrate.

The following is a brief summary of the nutritional strategies adopted to prepare for participation in and recovery from sport and exercise.

6.2. Pre-Exercise Meals

The current method of 'carbohydrate-loading' during the week prior to competition is to gradually reduce the volume of training throughout the week and to increase the carbohydrate intake to about 600 g/day during the last four days before the event [140]. Muscle glycogen concentration is increased above normal resting values as a consequence of this dietary preparation for competition. However, the recommended amount of carbohydrate may not be appropriate for female athletes because, for many, it would be equivalent to their daily energy intake (approximately 10 MJ (2400 kcal). Therefore, it is more appropriate to prescribe daily carbohydrate intake in terms of g/kgbw. Expressed in this way the recommendation for carbohydrate loading is a daily intake of 9 to 10g/kgbw of carbohydrate during the days immediately preceding competition.

A wide range of carbohydrate-containing foods appear to be equally effective in increasing muscle glycogen concentrations following carbohydrate loading [132] and increasing endurance running capacity [4, 22, 63, 115, 134]. However, one study suggests that there are advantages to eating low glycaemic index carbohydrate foods (Table 1) before exercise because they provide a slow release of glucose for muscle metabolism [150]. Logical as this advice may sound, the performance benefits of pre-exercise meals containing low glycaemic index carbohydrates have not been confirmed in more recent cycling and running studies [55, 175].

Table 1 **EXAMPLES OF MEAN GLYCAEMIC INDICES OF COMMON FOODS**

Breads and Grains	
Rice, instant	91
Wheat bread, white	70
Bread, whole wheat	69
Cornmeal	68
Rice, white	56
Rice, brown	55
Mixed grain bread	45
Spaghetti, white	41
Spaghetti, whole wheat	37
Rye	34
Barley	25

Breakfast cereals	
Corn Flakes	84
Rice Krispies	82
Grape Nuts Flakes	80
Shredded wheat	69
Grape Nuts	67
Oatmeal	61
Porridge	61
Muesli	52
All Bran	42

Fruits	
Watermelon	72
Pineapple	66
Raisins	64
Banana	53
Grapes	52
Orange	43
Pear	36
Apple	36

Starchy Vegetables	
Potatoes, baked	83
Potatoes, instant	83
Potatoes, mashed	73
Carrots	71
Sweet potatoes	54
Green peas	48

Legumes	
Baked beans	48
Chick peas	33
Butter beans	31
Lentils	29
Kidney beans	27

Dairy	
Ice cream	61
Yoghurt, low fat sweetened	33
Milk, skim	32
Milk, full fat	27

Snacks	
Rice cakes	82
Jelly beans	80
Corn chips	73
Candy bar	68
Wheat crackers	67
Popcorn	55
Oatmeal cookies	55
Potato chips	54
Chocolate	49
Banana cake	47
Peanuts	14

Sugars	
Honey	73
Sucrose	65
Lactose	46
Fructose	23

Beverages	
Sports drinks	95
Soft drinks	68
Orange juice	57
Apple juice	41

Foods listed from highest to lowest glycaemic index within category. Glycaemic index was calculated using glucose as the reference with GI of 100. Modified from Foster-Powell and Brand Miller [59].

COMMENT:

The given glycaemic indices are not fixed values. Mostly they represent a range that is based on production process and preparation of the food. For example: wheat bread: white flour; 5 studies, mean±SE:70±0; whole meal flour 12 studies mean±SE:69±2.

The pre-exercise meal, eaten no later than 2 to 3 hours before exercise, should be easy to digest and high in carbohydrates. Adopting this dietary recommendation improves endurance capacity during cycling and running [36, 181] when compared with fasting before exercise.

6.3. Food intended to be consumed during exercise

Eating during exercise is a practical option in only a few sports. For example, long distance cyclists and canoeists, as well as triathletes, eat easy to digest carbohydrate snacks during races. High-energy bars and confectionery products tend to be the snacks of choice because they are energy dense and easy to carry. Carbohydrate-electrolyte solutions are a convenient way of obtaining fluids, to off-set dehydration, and fuels to delay the onset of fatigue [106, 153] (see section on carbohydrate-electrolyte solutions).

6.4. Food intended to be consumed after exercise

Although much attention has been paid to nutritional preparation for exercise, nutritional intervention during recovery has received much less attention. In order for athletes to train or compete daily they must recover quickly. Replacing muscle and liver glycogen stores as rapidly as possible is essential for successful recovery. Failure to restock these carbohydrate stores will prevent athletes from completing prolonged periods of heavy exercise [43]. Glycogen resynthesis is most rapid during the first few hours after exercise [125]. Therefore, consuming carbohydrates immediately after exercise results in a greater rate of glycogen resynthesis than occurs when intake of carbohydrate is delayed [74, 83]. The provision of carbohydrates, as a substrate for glycogen synthesis, also stimulates a release of insulin, which enhances the uptake of glucose by muscle. The increased permeability of muscle to glucose is a post-exercise phenomenon that is a consequence of an activation of glucose transporter proteins (GLUT 4) [76]. Therefore, it is not surprising that the most effective carbohydrate foods for rapid glycogen resynthesis are those which have a high glycaemic index because not only will they provide glucose but they will also stimulate a large increase in plasma insulin concentration [28, 85]. The post-exercise presence of insulin complements the action of exercise on GLUT 4 transporter proteins by increasing the availability of these transporter proteins during the recovery period [76].

Consuming approximately 1 g per kgbw of carbohydrate immediately after exercise and every 2 hours up to 6 hours of recovery increases the rate of muscle glycogen synthesis (50 %) above that which would be achieved without consuming carbohydrate [75]. A carbohydrate intake of very much more than 1 g per kgbw (e.g. 2 to 3 g) does not appear to produce a further increase in the rate of glycogen resynthesis in the first hours after exercise. However, there is some evidence to suggest that adding protein to the recommended amount of carbohydrate may further increase the rate of glycogen resynthesis [182]. The explanation for this increased resynthesis rate is the higher flux of carbohydrate into the muscle cell caused by the increased concentration of circulating insulin. Also single amino acids can raise the insulin concentration considerably [58]. Recent studies have shown that a combination of carbohydrate and proteins (hydrolysates and/or amino acids) maximize post-exercise muscle glycogen synthesis compared to carbohydrate supplementation alone [162].

The concentration of muscle glycogen restored during recovery after exercise is proportional to the total amount of carbohydrate consumed. Figure 1 shows the relationship between the amount of carbohydrate consumed during 24 hours recovery from exercise and the increases in muscle glycogen concentrations.

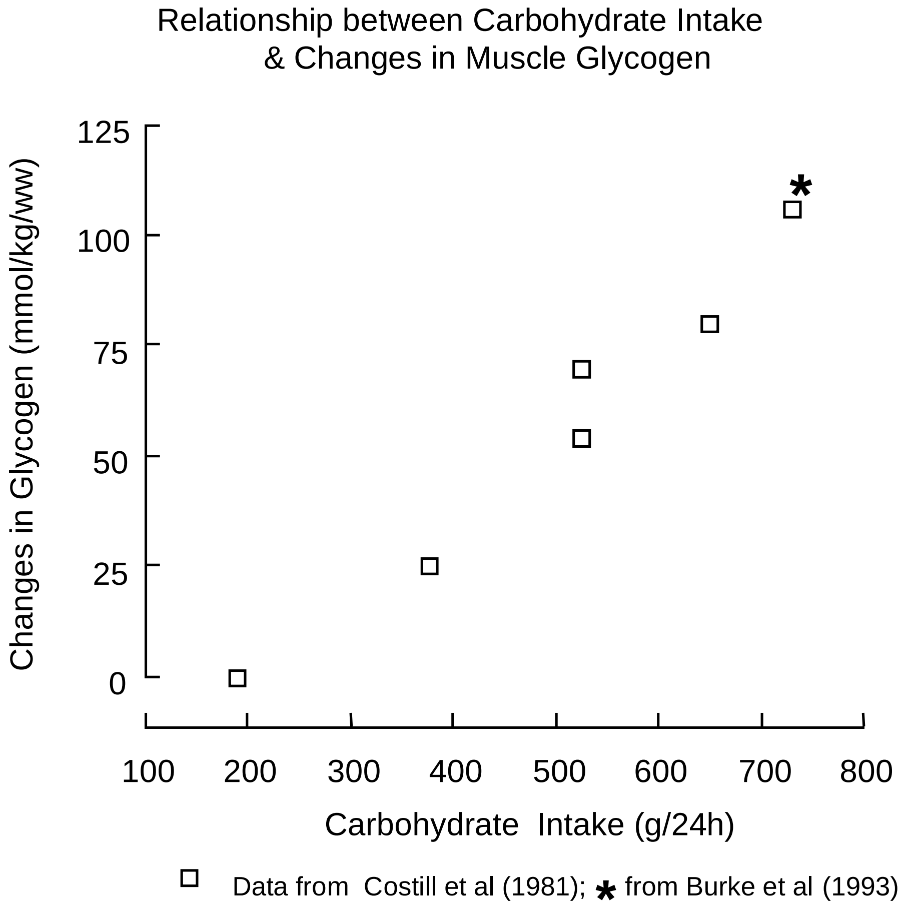

Figure 1

Result from 24-h post-exercise recovery studies in changes in muscle glycogen and carbohydrate intake.

Having followed the recommendation to restock muscle glycogen stores, the obvious question is whether or not performance will also be restored. The available research shows that a high carbohydrate diet during recovery does restore endurance performance during subsequent exercise. For example, raising the carbohydrate intake from 5 g/kgbw to 9 - 10g/kgbw during 24 hour recovery allowed endurance runners to match their 90 minute training run of the previous day. However, on another occasion, when they had their normal intake of carbohydrate, along with additional protein and fat to match their energy intake on the carbohydrate recovery diet, they were unable to complete the 90-minute run [53]. A high carbohydrate diet during recovery from prolonged intermittent exercise has also been reported to improve subsequent endurance performance [4, 115]. These studies clearly show that it is the additional carbohydrate in the recovery diet which is responsible for the restoration of performance rather than the intake of energy in the form of protein or fat.

6.5. Composition and specifications for carbohydrate- rich energy food products

The product should supply at least 75 % carbohydrate as a main source of energy (Energy %). If it is a drink, the carbohydrate concentration should exceed 10 % of weight by volume. At least 75 % of energy should be derived from metabolisable carbohydrates. Metabolisable carbohydrates such as glucose, glucose polymers, sucrose and carbohydrates with similar properties are those types of carbohydrates with a high glycaemic index.

In addition, these products may contain at least 0,05 mg vitamin B_1 (thiamine) per 100 kcal provided by carbohydrates (at least 0,2-mg vitamin B_1 (thiamine) per 100 g of carbohydrates).

7. Category B Carbohydrate-electrolyte solutions (C.E.S.)

7.1. Background

The aim of the athlete who ingests drinks before, during or after training or competition is to improve performance, and this can be achieved by minimising the impact of the factors that cause fatigue and impair the performance of skilled tasks. The two factors that have been considered to contribute most to the onset of fatigue in exercise are the depletion of the body's carbohydrate reserves and the onset of dehydration resulting from the loss of water and electrolytes in sweat [102]. There are good reasons for taking drinks containing added carbohydrates and electrolytes.

Commercially formulated sports drinks are intended to serve a variety of purposes, including supply of substrate, prevention of dehydration and promotion of post-exercise recovery.

7.2. Formulation of sports drinks

The major components of the sports drink that can be manipulated to alter its functional properties are shown in table 2.

Table 2

Variables that can be manipulated to alter the functional characteristics of a sports drink
- Carbohydrate content: concentration and type - Osmolality - Electrolyte composition and concentration - Other ingredients (such as caffeine, see category D2)

7.3. Carbohydrate content: concentration and type

Many studies have shown that the ingestion of glucose during prolonged intense exercise can prevent the development of hypoglycaemia by maintaining or raising the circulating glucose concentration. Beneficial effects of carbohydrate ingestion are seen during cycling as well as during running. This ergogenic effect may be related to a sparing of the body's limited muscle glycogen stores by the oxidation of the ingested carbohydrate, but the primary benefit of ingested carbohydrate is probably its role in supplementing the endogenous stores in the later stages of exercise [44]. It is clear from tracer studies that a substantial part of the carbohydrate ingested during exercise is available for oxidation, but there appears to be an upper limit of about 1 gram per minute to the rate at which ingested carbohydrate can be oxidised, even when much larger amounts are ingested [168].

As well as providing an energy substrate for the muscles, addition of carbohydrate to drinks can promote water absorption in the small intestine. It is sometimes difficult to separate the effects of water replacement from those of substrate and electrolyte replacement when CHO-electrolyte solutions are ingested, but Below et al [8] have shown that ingestion of carbohydrate and water had separate and additive effects on exercise performance. Most reviews of the available literature have come to the same conclusion [92, 113, 102, 106]. Most of the common types of carbohydrates such as glucose, sucrose and oligosaccharides are effective in maintaining the blood glucose concentration and in improving endurance capacity. Substitution of glucose polymers for glucose will allow an increased carbohydrate content without an increased osmolality, and may also have taste advantages, but the available evidence suggests that the use of glucose polymers rather than free glucose does not alter the blood glucose response or the effect on exercise performance, and similar effects are seen with the feeding of sucrose or mixtures of sugars. Some studies have suggested that long chain glucose polymer solutions are more readily used by the muscles during exercise than are glucose or fructose solutions, but others have found no difference in the oxidation rates of ingested glucose or glucose polymer. Massicote et al [101] also found that ingested fructose was less oxidized during exercise than glucose or glucose polymers during exercise.

Mixtures of glucose and fructose in equal amounts seem to have some advantages: when ingested in combination there is an increased total exogenous carbohydrate oxidation. Fructose in high concentrations is generally best avoided on account of the risk of gastrointestinal upset. There may be benefits in including a number of different carbohydrates, including free glucose, sucrose and maltodextrin: this has taste implications, which may influence the amount consumed, and, by limiting the osmolality and providing a number of transportable solutes, may maximize the rate of sugar and water absorption in the small intestine [141].

The optimum concentration of carbohydrate to be added to drinks will depend on individual circumstances. High carbohydrate concentrations will delay gastric emptying, thus reducing the amount of fluid that is available for absorption, but will increase the rate of carbohydrate delivery. If the concentration is high enough to result in a markedly hypertonic solution, net secretion of water into the intestine will result, and this will actually increase the danger of dehydration. High carbohydrate concentrations (>10%) may also result in gastro-intestinal disturbances. Where the primary need is to supply an energy source during exercise, increasing the carbohydrate content of drinks will increase the delivery of carbohydrate to the site of absorption in the small intestine. Beyond a certain limit, however, simply increasing carbohydrate intake will not continue to increase the rate of oxidation of exogenous carbohydrate [168]. Dilute glucose-electrolyte solutions may also be as effective, or even more effective, in improving performance as more concentrated solutions and adding as little as 90-mmol/l (16-g/l) glucose may improve endurance performance [105].

7.4. Osmolality

It has become common to refer to carbohydrate-electrolyte sports drinks as isotonic drinks, as though the tonicity was their most important characteristic. The osmolality of ingested fluids is important as this can influence both the rates of gastric emptying and of intestinal water flux: both of these processes together will determine the effectiveness of rehydration fluids at delivering water for rehydration. An increasing osmolality of the gastric contents will tend to delay emptying, and increasing the carbohydrate or electrolyte content of sports drinks will generally result in an increased osmolality. The composition of the drinks and the nature of the solutes is, however, of greater importance than the osmolality itself [102].

Although osmolality is identified as an important factor influencing the rate of gastric emptying of liquid meals, there seems to be rather little effect of variations in the concentration of sodium or potassium on the emptying rate, even when this substantially changes the test meal osmolality [130]. The effect of increasing osmolality is most consistently observed when nutrient-containing solutions are examined, and the most significant factor influencing the rate of gastric emptying is the energy density. Vist and Maughan [164] have shown that there is an acceleration of emptying when glucose polymer solutions are substituted for free glucose solutions with the same energy density: at low (about 40 g/l) concentrations, this effect is small, but it becomes appreciable at higher (180 g/l) concentrations; where the osmolality is the same (as in the 40 g/l glucose solution and 180 g/l polymer solution), the energy density is shown to be of far greater significance in determining the rate of gastric emptying. This effect may be important when large amounts of energy must be replaced after exercise, but is unlikely to be a major factor during exercise where more dilute drinks are taken. Water absorption occurs largely in the proximal segment of the small intestine, and, although water movement is itself a passive process driven by local osmotic gradients, is closely linked to the active transport of solute. Osmolality plays a key role in the flux of water across the upper part of the small intestine. Net flux is determined largely by the osmotic gradient between the luminal contents and intracellular fluid of the cells lining the intestine. Absorption of glucose is an active, energy-consuming process linked to the transport of sodium. The rate of glucose uptake is dependent on the luminal concentrations of glucose and sodium, and dilute glucose-electrolyte solutions with an osmolality, which is slightly hypotonic with respect to plasma, will maximize the rate of water uptake. Solutions with a very high glucose concentration will not necessarily promote an increased glucose uptake relative to more dilute solutions, but, because of their high osmolality, will cause a net movement of fluid into the intestinal lumen [62]. This results in an effective loss of body water and will exacerbate any pre-existing dehydration. Other sugars, such as sucrose or glucose polymers can be substituted for glucose without impairing glucose or water uptake, and may help by increasing the total transportable substrate without increasing osmolality. In contrast, iso-energetic solutions of fructose and glucose are isosmotic, and the absorption of fructose is not an active process in man: it is absorbed less rapidly than glucose and promotes less water uptake.

The use of different sugars which are absorbed by different mechanisms and which might thus promote increased water uptake is supported by recent evidence from an intestinal perfusion study [141]. Although most of the popular sports drinks are formulated to have as close to that of body fluids [102] and are promoted as isotonic drinks, there is good evidence that hypotonic solutions are more effective when rapid rehydration is desired. Although it is argued that a higher osmolality is inevitable when adequate amounts of carbohydrate are to be included in sports drinks, the optimum amount of carbohydrate necessary to improve exercise performance has not been clearly established.

7.5. Electrolyte composition and concentration

The only electrolyte added to drinks consumed during exercise that is known to confer physiological benefit is sodium. Sodium will stimulate carbohydrate and water uptake in the small intestine and will help to maintain extracellular fluid volume. Most soft drinks of the cola or lemonade variety contain virtually no sodium (1-2 mmol/l); sports drinks commonly contain about 10-30 mmol/l; oral rehydration solutions intended for use in the treatment of diarrhoea-induced dehydration, which may be fatal, have higher sodium concentrations, in the range 30-90 mmol/l. If exercise duration is likely to exceed 3-4 h, addition of sodium helps avoid the danger of hyponatraemia, which occurs when excessive volumes of low-sodium drinks are taken. Supplementation with sodium salts may be required in extremely prolonged events where large sweat losses can be expected and where it is possible to consume large volumes of fluid.

Restoration of fluid and electrolyte balance after exercise is an important part of the recovery process, especially when a second exercise session must be performed after a short time interval. Urine output in the few hours after exercise when volume replacement is undertaken is inversely proportional to the sodium content of the ingested fluid, with an almost linear relationship between net sodium balance and net water balance [103]. Only when the sodium content exceeded 50 mmol/l were the subjects in positive sodium balance, and only then did they remain in positive fluid balance throughout the recovery period. Shirreffs et al. [142] showed that even drinking large volumes (twice the sweat loss) did not allow subjects to remain in positive fluid balance for more than 2 h when the sodium content of the drinks was low (20 mmol/l): increasing the sodium content to 60 mmol/l allowed subjects to remain well hydrated when volumes equal to 1.5 times or twice the sweat loss were ingested.

It has been speculated that inclusion of potassium, the major cation in the intracellular space, would enhance the replacement of intracellular water after exercise and thus promote rehydration [114]. Potassium is normally present in commercial sports drinks in concentrations similar to those in plasma and in sweat, but there is little evidence to support its inclusion. Although there is some loss of potassium in sweat (about 3-7 mmol/l), an increase in the circulating potassium concentration is the normal response to exercise: increasing this further by ingestion of potassium does not seem useful. A similar situation applies with magnesium replacement, and in spite of the commonly held belief that exercise-induced cramp is associated with a falling plasma magnesium concentration, there is little or no experimental evidence to substantiate this belief. A slight decrease in the plasma magnesium concentration is generally observed during exercise, but this seems to be the result of a redistribution of the body magnesium stores, and there is no good scientific reason for its addition to sports drinks [106].

7.6. Composition and specification for carbohydrate-electrolyte solutions

The drink should supply carbohydrate as the major energy source and should be effective in maintaining or restoring hydration status.

To achieve this, these beverages should contain not less than 80-kcal/1000 ml and not more than 350 kcal/1000 ml. At least 75 % of the energy should be derived from metabolisable carbohydrates characterised by a high glycaemic index. Examples are glucose, glucose polymers and sucrose. In addition these beverages should contain at least 20 mmol/l (460 mg/l) of sodium (as Na^+) and not more than 50 mmol/l (1150 mg/l) of sodium (as Na^+). They may be formulated to cover a range of osmolalities between 200 and 330 mOsml/kg water. Beverages with an osmolality of 300-m Osm +/- 10 % range (270 - 330 mOsm/kg water) may be designated as isotonic.

8. Category C Protein and protein components

8.1. Background

There is a long history from Ancient Greece till modern times that athletes and their trainers believe that the daily dietary protein requirements of subjects participating in endurance or strength training programs are increased. The rationale for the increased intake differs between endurance and strength training athletes. In the case of endurance exercise it is assumed that the rate of protein oxidation increases during exercise and that this should be compensated in the recovery period following exercise. In the case of strength training it is assumed that muscle hypertrophy and increases in strength can only be maximal when the dietary protein intake is high. However, among scientists this is an issue of continued discussion, as it is not clear which underlying physiological processes lead to an increased metabolic need for protein. In this respect there is a major difference compared with the effect of an increase in carbohydrate intake, which has been shown to improve endurance performance both when taken acutely and when the carbohydrate content of the diet is increased.

Concern has been raised relative to the possible long-term health-hazards of protein intakes as high as 2 - 4 g protein/kgbw, such as an impaired kidney function and/or negative calcium balance. However, scientific evidence and consensus is lacking on these issues.

8.2. Protein metabolism in endurance athletes

In the 1840's the German physiologist Von Liebig hypothesized that muscle protein was the main fuel used to achieve muscular contraction [165]. Von Liebig's ideas have lead to the 19th and 20th century belief that industrial workers exposed daily to heavy physical labour and a high energy expenditure have an increased protein requirement and, therefore, should eat large steaks and have protein rich nutrition. In the late 19th century the hypothesis that muscle protein was the main fuel for physical exercise was shown to be false as controlled nitrogen balance studies as early as 1866 [56, 32] failed to show a substantial increase in nitrogen losses during and following exercise. Also in recent literature most of the controlled nitrogen balance studies show that trained athletes accustomed to a high energy expenditure (e.g. running = 125 km per week [144]) or several days of cycling with energy expenditures of 25 MJ per day [24] can maintain a positive or zero N-balance on diets containing 1.0-1.4 g protein per kgbw per day [65, 107, 24, 61, 144, 96]. Only when subjects are fasted overnight or for longer periods [94] may exercise lead to increased N-losses.

In summary, N-balance studies suggest that there is a modest increase and therefore the recommended daily intake has been increased from 1.2 to 1.4 g per kgbw per day in elite endurance athletes. A diet containing 10-12%En protein contains enough protein to meet this modest increase in the protein requirement as the daily energy expenditure of elite endurance athletes can be as much as two to three-fold higher than that of normal subjects.

With the introduction of stable isotope amino acids, new techniques became available to investigate protein metabolism and its components (protein oxidation, protein synthesis and protein degradation) during exercise. Early studies [180] using with a leucine tracer suggested that protein oxidation was increased and that whole body protein synthesis (indirectly calculated as protein flux minus protein oxidation) was decreased during exercise in man. However, direct estimates of muscle protein synthesis did not show a difference between rest and exercise [29]. Whole body urea production, another measure of protein oxidation, was similar at rest, during 3 h of treadmill running at 40% VO_{2max} and during 1 h of exercise at 70% VO_{2max} [30]. Recently Wagenmakers et al. [169] performed a study with 3 tracers in highly trained subjects ingesting carbohydrates (as athletes do in sports practice) during 6 h of exercise (cycling-running-cycling) at 50% VO_{2max}. In agreement with Wolfe [180] leucine as tracer suggested that protein oxidation was 2- to 3-fold higher during exercise. However, the other tracers failed to confirm this. This indicates that the metabolic needs of endurance athletes for dietary protein do not seem to be substantially increased.

Recent studies [182, 160, 162] have shown that the combined ingestion of glucose and protein increases glycogen re-synthesis and plasma insulin levels in the post-exercise period (see also section Carbohydrate-rich energy food products). Calculations based on glycogen resynthesis rates measured in the laboratory show that it takes 16-20 h before the glycogen stores are fully replenished after exercise and that co-ingestion of protein may accelerate glycogen re-synthesis by 4-8 h [170]. This effect of protein co-ingestion could explain an increased metabolic need for protein of endurance athletes and could provide a metabolic rationale for an increment of the Recommended Daily Allowances. More research is needed to investigate how much additional protein is needed to reach this effect, and whether the increased protein intake is required in all the post-exercise meals or only in a limited post-exercise time frame. In the latter case it could well be true that the metabolic need of endurance athletes for protein is only marginally increased, but that more attention should be given to the timing of the intake of the extra protein.

8.3. Protein metabolism in body builders and strength athletes

Tarnopolsky et al. [144] reduced the protein intake of 6 male elite body builders from the habitual intake of 2.77 g per kgbw per day to 1.05 g per kgbw per day (isoenergetic diets) and observed that they were able to maintain a zero or positive nitrogen balance on this low protein intake. Tarnopolsky et al. [146] investigated the effect of a low, moderate and high protein intake on N-balance in a group of young male strength athletes (training for about 2 months) and observed that they reached a zero N-balance on 1.4 g protein per kgbw per day. A similar value was observed by Lemon et al. [95] in novice bodybuilders starting an intensive body building program. A further increase of the protein intake to 2.62 g per kgbw per day in the latter study did not increase the strength and muscle mass gain during a one-month training program. Based on these studies it can be concluded that young strength athletes and novice body builders (with a rapid muscle mass gain and strength gain) reach zero N-balance on about 1.4-1.5 g per kgbw per day. In elite body builders, training for several years, the protein requirements are assumed to be only marginally higher than in sedentary subjects [147].

Acute and long-term increases in the protein content of the diet do not by definition lead to increases in muscle protein mass or whole body protein mass when the initial protein content exceeds the dietary requirement [129]. There are several physiological reasons for this. The main reason is that most of the enzymes involved in the protein synthetic machinery of the cells and organs of the body have a low K_m. They operate at maximal velocity when the intracellular amino acid concentration is between 10 and 30 µM and basal levels of amino acids generally are much higher. Therefore, an acute increase in the plasma or intracellular concentration of the amino acids following the ingestion of a meal with a high protein content does not lead to a substrate activated increase in the rate of protein synthesis [129]. An increase in the protein synthesis rate will occur after ingestion of a protein containing mixed meal as a consequence of the insulinotropic effect of protein/carbohydrate ingestion [129, 58]. The K_m for the oxidative enzymes (e.g. urea cycle enzymes, dehydrogenases) is much higher. This implies that the rate of amino acid oxidation and urea production increase rapidly following ingestion of a meal with a high protein content. The main effect of an acute increase in the protein content of the diet, therefore, is increased amino acid oxidation when the protein intake exceeds protein requirement. Tarnopolsky et al [146] observed a significant (+30%) increase in whole body protein synthesis (measured with ^{13}C-leucine as tracer) in young male strength athletes when the protein intake was increased from 0.86 to 1.40 g per kgbw per day. No further increase was observed when the protein intake was further increased to 2.4 g per kgbw per day. In a group of sedentary controls maximal whole body protein synthesis rates were observed already at the lowest protein intake. This again indicates that the protein requirement in strength athletes is slightly increased to the recommended protein intake of about 1.4-g per kgbw per day.

Protein hydrolysates and balanced mixtures of free amino acids are more rapidly absorbed than intact proteins and lead to higher increases in plasma amino acid concentration than intact proteins. Due to the difference in enzyme kinetics indicated above, the hydrolysates and free amino acids are more rapidly oxidized and less efficiently used for protein synthesis [40]. Therefore the effectiveness of protein hydrolysates as means to increase muscle protein synthesis in athletes is not supported by scientific evidence. When the increased protein content of the diet is maintained for several days, then the concentration of the enzymes involved in amino acid oxidation will start to increase too [129]. Maximal concentrations are seen only after 1 to 2 weeks. This induction of the oxidative enzymes induced by a high protein diet also leads to more protein being oxidized more rapidly on a high protein diet. This induction in part also explains the lower plasma amino acid levels and increased amino acid oxidation rates that are seen in the overnight fasting period in subjects on a high protein diet [121].

Leucine oxidation has been reported to be similar at rest and during and following resistance-type exercise [145] indicating that increased amino acid oxidation does not lead to an increased protein requirement. However, it has been shown clearly that muscle protein synthesis and protein degradation increase by 50-100% in the first hours after resistance-type exercise [34, 98, 19, 124] in previously untrained young male subjects. The increase in muscle protein synthesis persists for 24 hours and returns to baseline after 36 hours [98, 124] This increase in protein turnover most probably is essential for the increase in myofibrillar protein content and remodelling of the muscle structure that is following heavy resistance exercise [97]. The increase in muscle protein synthesis following resistance exercise is also seen in 62- to 75-yr-old men and women [176]. In these subjects an increase of the protein content of the post-exercise meal from 7 to 14 and to 21 % En did not further increase the protein synthesis rate in muscle.

8.4. Composition and specifications for protein and protein components

* General considerations

  - The Committee recommends that the protein source used for these products should have a minimal protein quality (NPU) level
  - Based on the concept that the requirement for vitamine B_6 is closely related to the protein intake the Committee recommends additional supplementation of vitamine B_6 per gram of protein [41].

* Protein concentrates

The product should supply at least 70 % of the dry matter as protein with at least a NPU quality 70 % or higher.

* Protein enriched foods

Foods presented as protein enriched should contain at least 25 % of the total energy as protein with protein quality (NPU) of 70 % or higher.

* Amino acids addition is allowed for the purpose of improving the nutritional value of the protein, in the proportion necessary of that purpose.

* In addition, these products may contain vitamin B_6. If added, it should contain at least 0.02-mg vitamin B_6 per gram of protein.

9. Category D Supplements

9.1. Category 1 Essential nutrients

9.1.1. Background

Recommended dietary allowance for essential nutrients in healthy adults are published by various national nutrition boards and are also given in the reports of the Scientific Committee for Food (nutrient and energy intakes for the European Community) [41] (Tab.1). They do not distinguish between recommended dietary allowances for normal healthy or physically active people. Nevertheless, in case of intensive physical exercise and regularly performed training there are some problems and peculiarities in practice and reactions to sports which may influence the balance and requirements for some essential nutrients [11, 26, 178].

For some vitamins and minerals there are potential hazards from the intake of high levels of these nutrients, especially among athletes where supplementation with high doses of vitamins and minerals is very popular. The upper safe levels of vitamin- and mineral intake are at present under consideration of the SCF and will not be covered in this report.

Other non-nutrients are considered on the basis of their ergogenic properties. For the evaluation of the sports-specific requirements of micronutrients some general points should be taken into account.

9.1.2. General considerations

9.1.2.1. Energy related nutrient density

It is a frequently asked but an open question whether there is a definite, linear correlation between total energy output and the requirement for nutrients. Diet balances have not supported the common assumption that there is a generally increased requirement for essential nutrients in athletes induced by their physical exercise or data from controlled studies. Even in the case of energy related micronutrients such as vitamin B_1 (thiamine) which functions as a co-enzyme in carbohydrate metabolism no conclusive data are available. The recent US RDA’s concluded that those who are engaged in physical demanding occupations or who spend much time training for active sports may require additional vitamin B_1 [60]. This conclusion reflects the uncertainty about the energy related nutrient requirements. The hypothesis of a possible exercise-induced over-proportional need for a special group of essential micronutrients is nowadays obsolete. With regard to a causative positive correlation between energy output produced by physical exercise and additional nutritional requirements for micronutrients it is accepted that these additional requirements are sufficiently covered by an energy-related, additional uptake of well-balanced food. However, under conditions of endurance exercise and training there may be an increased consumption of carbohydrate-rich diets as sports drinks or snacks showing no optimal nutritional density. To compensate this possible disadvantage in sports practice athletes often take nutrient supplements to adjust the difference between recommended and actual nutrient density [26, 178].

9.1.2.2. Sports related factors

In combination with intensive physical exercise and regular training, some sports-specific endogenous and exogenous factors can influence the balance and therefore the requirements for essential and micro-nutrients during and after exercise, e.g. increased loss of nutrients in urine and sweat, increased cellular uptake and modulated distribution of nutrients in the body compartments, loss of nutrients by haemolysis and intestinal bleeding or decreased absorption of nutrients by the circulation-deficient intestinal tract [15, 25, 112]. Without the possibility of measuring nutrient balances or even nutrient deficiencies athletes often take nutrient supplements to compensate this possible sports-related disadvantage.

In weight category sports or in sports with a competitional benefit for underweight subjects, athletes are tempted to reduce their body weight by chronic energy restrictions. In combination with energy restrictions and the sports-related factors mentioned above, female athletes represent a particularly high-risk population group for deficiencies of essential nutrients. Athletes showing a total energy intake below 10.5 MJ (2.500 kcal)/day for males and below 8.4 MJ (2.000 kcal)/day for females, respectively, may not be able to reach their daily nutrient requirements during periods of regular training [159].

9.1.2.3. Exercise related health risks

Beside those conditions which are directly related to physical exercise and training it has to be considered that under special circumstances (e.g. started training, irregular training, inadequate training) athletes may be defined as a population group at an increased health risk. Therefore, new aspects in sports nutrition are added with regard to health promotion instead of athletic performance. Food composition and essential nutrients may influence the following known sports-related negative side effects also:

** Upper respiratory tract infections (URTI)*

Athletes, in particular endurance athletes with high training volumes, show an increased risk for URTI [57, 116]. Experience suggests that athletes may benefit from a diet rich in immune-stimulating Nutrients [12, 13, 119, 139].

** Exercise-induced inflammation*

Athletes and in particular endurance athletes again, also show an increased risk for exercise-induced tissue injuries and overuse syndromes [23, 131]. Since these tissue injuries are in general accompanied not by muscle and tissue soreness alone but also by an acute inflammatory response [27, 117], it has been discussed whether the amount of this exercise-induced inflammation can be reduced by food quality or selected nutritional supplements [119].

* *Oxidative stress*

A new aspect of a health related consideration of sports is the ongoing discussion about increased oxygen uptake during physical exercise: Maximum physical work load can result in an increase of free radical production and the subsequent increase of oxidative stress [82]. Athletes may belong to the population group with an increased risk for oxidative stress and has been suggested that athletes should optimise their body pool of antioxidants by an increased intake. However, at present there is no scientific agreement on the question of whether a sufficient quantity of antioxidants, in particular of vitamin E, vitamin C and ß-carotene can be supplied by daily food intake alone [18, 91]. It is also unclear whether this increase is necessary due to an increased activity of endogenous free radical scavengers enzymes during training.

9.2. Minerals (K, Mg, Ca)

Key minerals involved in muscular functions include K, Ca and Mg, but there are no objective data which attest that dietary intake of these minerals is insufficient in athletes as compared with the recommended dietary intake. As mentioned above, it is likely that athletes consume sufficient amounts of minerals by increasing their energy intake during training periods. There may be a deficiency of minerals, however, in athletes under conditions of chronic energy restriction [11, 26, 159].

The potassium (K) content of the body is approximately 2-g/kg-body weight. K is the principal cation occurring in cell water and most of total body K mass is found in skeletal muscle, partly coupled to by glycogen storage; only 0.4% of the total body K mass is found in the plasma compartment. The working muscle loses potassium during contractions. Consequently plasma K concentration is increased during exercise; the amount of the K increase is directly correlated to the intensity of the exercise performed. In contrast to conditions during exercise, in rest plasma K concentrations of trained individuals are often lower (4.0-4.2 mmol/l) as compared to concentrations in untrained subjects [9]. This phenomenon can be explained by the training-induced adaptation of the cellular potassium uptake and a higher activity of the specific transport system, the Na-K-ATP-ase [39]. In that way moderately reduced plasma K concentrations (4.0-4.2 mmol/l) during resting conditions can not be used as indices of impaired K balance in athletes.

The magnesium (Mg) content of the body is 270-400 mg/kg body weight. About 95% of this mass is found within the cells, about 70% is in the skeleton and only a small extracellular fraction (1.3-%) is only metabolically available. Low plasma magnesium concentrations in athletes have been found at resting conditions as well as after exercise. These findings should not be interpreted as a symptom of Mg deficiency and may be explained by an exercise-induced redistribution of Mg. However, objective data about Mg deficiency in healthy athletes or about significant benefits of Mg supplementation from controlled intervention studies are not available.

The calcium (Ca) content of the body amounted to about 1200 g (16 g/kg body weight), approximately 99% is found in the skeleton, the small plasma fraction (1%) represents the metabolically active pool. Plasma Ca concentrations are particularly maintained by hormones controlling bones metabolism and do not show uniform variations after acute exercise. In regard to chronic energy restriction special attention has to be drawn to the problem of "athletic osteoporosis" [46, 177]. Under-weight athletes - particularly females - often show calcium intakes lower than recommended. In addition, urinary calcium loss rises in athletes consuming a high protein diet, which is generally accompanied by high phosphorus intake from protein sources. However, the role of an inadequate calcium intake in the pathogenesis of stress fractures and reduced bone density in athletes is not clear; on the contrary there is agreement that the aetiology of the "athletic osteoporosis" has been associated with depressed levels of plasma hormones, e.g. GnRH, sex hormones and leptin, which influence bone metabolism. No prospective studies about the benefit of calcium supplements in the prevention of stress fractures or bone density in athletes are available.

9.3. Trace elements

As an important constituent of oxygen and electron binding molecules, iron is a significant element in aerobic metabolism and energy production. As in normal populations a poor iron status can be diagnosed in athletes by routine clinical and biochemical markers without problems. However, the term "sports anaemia" is very commonly, but often not appropriate used in sports and physical performance medicine. In a representative sample the prevalence of anaemia, documented by plasma ferritin concentrations, is nearly the same in athletes as in controls [10]. Due to the harmful effects of iron overload to the organism [155] iron supplements are no longer recommended for self-medication in athletes. Iron preparations should only be prescribed to athletes with clinically diagnosed anaemia.

There are indications that Zn-intake in athletes is marginal. About 20% of the examined endurance athletes [6, 12] did not reach the 10-mg/d-zinc intake level according to their dietary records. Further research is indicated because clinical experience showed that objective symptoms of zinc deficiency occurred when the daily supply chronically fell below 10-mg/d [123]. In addition, studies have shown a positive correlation between urine Zn losses and systematic stress parameters, such as cortisol and interleukin 6 (IL-6) [12, 88]. These observations are of importance since Zn is essential for immunological functions [33, 88]. Although no clear Zn deficiency has been reported in athletes, it is suggested that the increased risk for URTI in athletes could be related to the Zn status [116]. Further studies are warranted.

The trace elements copper (Cu), selenium (Se), and manganese (Mn) are significantly involved in physical performance playing a role in energy and free radical metabolism [37, 88, 139]. Unfortunately, because of analytical difficulties and missing clinical routine, data about balances of these trace elements in athletes are not representative, and in addition, specific recommendations for trace element intake in athletes other than the usual recommended dietary allowance for healthy people [41, 48] have not been published. Trace elements, particularly Cu, are lost in significant amounts in sweat - that means at a range up to the dietary requirement. Sustained exercise-induced sweating may lead to an increased loss of trace elements in general [11].

As an essential component of the enzyme glutathione peroxidase, Se is involved in the regulation and breakdown of hydroperoxides [151]. Thus, Se may play a significant role in the prevention of free radical damage and oxidative stress, even in situations of muscular stress and exhaustive exercise [154]. Se acts similarly to vitamin E, and vitamin E deficiency synergistically augments symptoms of Se deficiency. Muscular discomfort or weakness is documented after continuous periods of selenium-free diets (e.g. parenteral nutrition) [151]. In conditions of Se deficiency significant limitations of cellular anti-oxidative properties can be observed. However, controlled studies concerning the impact of Se supplementation on lipid peroxidation in athletes are not yet available.

The trace element Mn is an essential component of the mitochondrial metallo-enzyme superoxide dismutase (SOD) and is involved in the regulation of free radical metabolism [93]. Animal studies have shown that the activity of this mitochondrial enzyme may be regulated by the dietary Mn intake. However, well-controlled experimental data in athletes are not available.

Data about the nutritional requirements and essentiality of trace elements such as cobalt, nickel, silicon, boron, lithium, tin and vanadium in athletes are weak or not available.

9.4. Vitamins

In the past decades several studies have addressed the issue whether athletes have problems related to dietary vitamin intake and tissue levels. Reviews on this topic uniformly conclude that data on plasma vitamin levels and enzymatic stimulation tests in athletes show the same incidence of marginal or deficient levels as observed in sedentary populations. It is generally accepted in the scientific community that with an adequate dietary intake, there is no further need for supplementation, since supplementation studies with vitamins do not show an improvement in performance [156].

9.4.1. Vitamins involved in energy metabolism (Vitamin B1, Vitamin B2, Vitamin B6, Vitamin B12, Niacin)

As far as their biochemical functions are concerned, these vitamins play an essential role in energy metabolism and consequently physical performance. Results from studies concerning the vitamin status of athletes as well as studies examining for the ergogenic effects of extra vitamin supplementation have not yielded any support to recommend intakes beyond an adequate balanced diet [1, 69, 84, 148, 174, 174 A, 178].

Recommended daily intake is set at 0.5 mg vitamin B1/1000 kcal, at 0.6 mg vitamin B2/1000 kcal, at 6.7 mg niacin/1000 kcal energy, and at 0.02 mg vitamin B6/g protein intake [41] in normal subjects.

9.4.2. Antioxidants (Vitamin C, Vitamin E and carotenoids)

Exercise results in an increased production of free radicals. There is growing evidence that exercise-induced free radical production could result in muscle fatigue and contribute to the late phase of exercise-induced muscle injury [128]. To defend against radical damage, two important classes of endogenous protective mechanisms work together in the muscle cell: 1) the endogenous enzymatic antioxidants such as Super Oxide Dismutase (SOD) and catalase and the non-enzymatic exogenous antioxidants including vitamin C, E, Beta-Carotene and ubiquinones. A high level of training results in a higher level of endogenous anti-oxidative capacity [138]. In this regard, high intensity exercise training is superior to low intensity exercise in upregulation of the endogenous enzymatic systems [128]. So far, limited information is available on the effects of endurance training on the exogenous antioxidants. There are some indications that regular exercise improves the antioxidant reserve such as vitamin E in skeletal muscle. However the results are not consistent [77].

Numerous studies with both antioxidant supplemented and antioxidant deficient diets have been carried out to understand the role of dietary antioxidants in oxidative stress [138]. In this context mainly vitamin E was tested. In contrast to studies of the 70’s more recently published data did not find significant effects of the antioxidative vitamins C, E and beta carotene on physical performance in well designed controlled and double-blind studies [38, 64]. Moreover, there is no agreement on the hypothesis that antioxidants, predominantly vitamin E, can prevent an increase of lipid peroxidation and prevent oxidative muscular damage following physical exercise [120]. Since vitamin E can reduce lipid peroxidation, it is assumed that this vitamin may protect against oxidative damage and exercise-induced inflammation. Recently published data in a homogenous group of athletes [14] indicate that neither the exercise-induced peroxidation rate, expressed by diene production, nor the muscular cell damage, expressed by an increase in serum creatine kinase activity, is related to the individual plasma vitamin E concentration.

9.5. Essential fatty acids

Essential fatty acids are components of cellular membranes and structures; they significantly influence the plasticity and rigidity of muscle and blood cells, both of which are stressed by exhaustive aerobic exercise [13, 86] Data about membrane fluidity and oxygen diffusion in relation to membranes PUFA distribution in athletes have been published [51, 80]. So far, results about improved aerobic capacity with PUFA supplementation are not available. The longchain PUFA's, particularly eicosapentaenoic acid (EPA, fish oil) and gamma-linolenic acid (γ-LA, evening primrose oil), can weaken the inflammatory response to physical stress by modulating the eicosanoid pathway, studies have shown that both muscular and systemic inflammatory stress can be influenced in apparently healthy individuals including endurance athletes, by modulating the composition and quality of dietary fat [87]. Within the trend for a lower fat intake of about 30% of total energy intake, athletes should pay greater attention to the intake of PUFAs and essential fatty acids. It is recommended that the omega-6 to omega-3 ratio be maintained at about 5 to 1.

9.6. Composition and specifications for supplements in particularly minerals, trace elements, vitamins and essential fatty acids

The committee is of the opinion that specific mineral and/or vitamin food supplements do not satisfy any additional particular physiological needs of individuals involved in intense muscular exercise taking an adequate dietary intake into consideration.

For essential fatty acids the scientific literature do not allow any recommendation at this moment.

10. Category D.II. Other food components

10.1. Caffeine

Caffeine is known as one of the most widely used non-nutritive components in beverages in the Western world and is therefore already present in the diet of many athletes. Already for a long time caffeine is considered as a nutritional ergogenic aid in physical performance. However, only in the last decade have a number of well-controlled studies clearly demonstrated its efficacy in relation to prolonged endurance exercise as well as short term intense exercise [143].

At present, the mechanism by which caffeine acts is not well known. Three major theories for the ergogenic effect have been suggested.

The first theory involves a direct effect on the sympathetic nervous system (SNS), leading to a stimulatory effect on the neural signals between brain and neuromuscular junction.

The second theory proposes a direct effect on the skeletal muscle metabolism by increasing, among others, cyclic AMP.

The third and most accepted theory involves an increase in fat oxidation, sparing endogenous carbohydrate stores and thus improving performance especially in exercise where CHO availability limits performance. The evidence demonstrating that caffeine is an ergogenic substance has forced the IOC to set a limit to prevent extreme use of this component. Caffeine is a restricted substance for athletes in competition that allows up to 12-ug caffeine/ml urine. This level would only be approached by an excessive intake of more than 6 regular cups of drip-percolated coffee. There is no restriction in training. In a well-controlled study, intake of 9 and 13 mg/kg body weight caffeine resulted in urine levels above the doping limit in some individuals [122].

However, caffeine ingestion even at low levels i.e. 3-8 mg/kg body weight prior to exercise, enhances performance of both prolonged endurance exercise and short-term intense exercise lasting approximately 5 minutes in the laboratory [143]. Recently it was also demonstrated that carbohydrate-electrolyte solutions with low concentrations of caffeine (2.1, 3.2 and 4.5 mg/kg BW respectively) improve endurance performance with low post-exercise urinary caffeine concentrations (1.3; 1.9 and 2.5 ug/ml respectively) [90].

10.2. Creatine

Creatine is a non-essential dietary compound found in high abundance in meat and fish. It is synthesized within the body, primarily in the liver, from the amino acids arginine and glycine. Diet and endogenous synthesis each contribute about half in subjects on a normal diet [172].

Creatine phosphate (CrP) serves as a readily available source of energy in skeletal muscle and other tissues [110, 109]. The rapid re-phosphorylation of ADP from CrP via the Creatine kinase reaction buffers changes in ATP during transitions between rest and exercise, and contributes a substantial fraction of ATP synthesis during short duration, high intensity exercise.

The relative importance of CrP during exercise is dependent on the nature of the exercise. For most exercise situations, the demand for ATP is predominantly provided through oxidative phosphorylation in the mitochondria. However, when aerobic energy production cannot meet the demand for ATP, anaerobic energy production from CrP hydrolysis and glycogenolysis/glycolysis is required to assist in the provision of ATP [143]. Such cases include the transition from rest to exercise, the transition from one power output to a higher power output, and power outputs above 90-100% maximal oxygen consumption (VO_2max). During a bout of high intensity exercise the relative importance of CrP hydrolysis to ATP synthesis falls off dramatically as the exercise duration is increased beyond a few seconds.

Research [31, 54, 70, 72, 133] has shown that creatine ingestion increases the total creatine content in human muscle by approximately 15-20% (mean value). Such increases can be achieved by ingestion of 20 gram per day for 4-5 days, but also by ingestion of 3 gram per day over a period of 1 month [72]. The increased creatine content is maintained when the ingestion is reduced to 2 gram per day after the original loading period [72]. The increase in creatine content is rather variable between subjects, ranging from zero to up to 40% [68]. Thus, there are ‘responders’ and ‘non-responders.’

Sub-maximal exercise performed prior to creatine ingestion can augment muscle creatine accumulation by approximately 10%, but again the variation in response is marked among individuals [72]. Muscle creatine accumulation can be substantially augmented by ingesting creatine in combination with large quantities of simple carbohydrates [66, 67].

Coincident with the retention of creatine, there is a substantial reduction in urine production on the first 3 days of the loading period [72]. This retention of water is thought to be related to an osmotic load caused by creatine retention and to account for the rapid-onset weight gains experienced by many individuals ingesting creatine. Many studies have reported increases in body mass of 1-3 kg following short-term (5-7 days) creatine supplementation [149].

Short-term creatine supplementation (5-7 days of ~20 g/d) can lead to an improvement in performance. Most but not all of the studies indicate that creatine supplementation significantly enhances the ability to produce higher muscular force and/or power output during short bouts of maximal exercise in healthy young adults [149]. At present, exercise performances that are improved include: various protocols of short-term, all-out cycling, sprinting, repeated jumping, swimming, kayaking/rowing, and resistance exercise performance. Interestingly, the greatest improvements in performance seem to be found during a series of repetitive high power output exercise bouts [149]. Exercise performance during the latter bouts of a series (e.g., third, fourth, fifth) can be increased by 5-20% over that measured for the placebo group. These experimental protocols employed exceptionally high power output efforts (e.g., maximal cycling and/or power jumping that can be maintained for only a short period, usually seconds) separated by fairly brief periods of rest (e.g., 20-60 seconds). These are the exercise conditions where the transitional energy contribution from CrP is likely most significant; further, the short-term rest periods between bouts are apparently sufficient to permit an enhanced recovery of the muscle CrP concentration in those individuals with a greater total creatine concentration as was shown in an in vivo magnetic resonance spectroscopy study [89]. It, therefore, is likely that creatine supplementation improves exercise performance in sport events that require explosive, high-energy output activities especially of a repeated nature.

In some [100] but not all studies, creatine supplementation increased maximal isometric muscle strength and not alter the rate of maximal force production [157, 161]. Creatine supplementation also did not appear to enhance aerobic-oriented activities [3, 158].

Few data exist on the long-term effects of creatine supplementation. A number of studies indicate that creatine supplementation in conjunction with heavy resistance exercise training (e.g., 4 to 12 weeks in duration) enhances the normal physiological adaptations to a weight training program [149]. Typical training adaptations including, increases in body mass fat-free mass, maximal strength and power, lifting volume, and muscle fiber hypertrophy, are all significantly enhanced concurrent with creatine supplementation.

The loading doses suggested by the manufacturers are 10-20 g/day for 5-7 days and then 2-5 g/day as a maintenance dose.

There are numerous anecdotal reports of creatine supplementation causing gastrointestinal, cardiovascular and muscular problems. There is no scientific evidence to support these reports. However, at this moment in time it also cannot be concluded (documentation is lacking or incomplete) that creatine supplementation is free from health risks [149]. Creatine ingestion prior to competition in the heat should be discouraged as it may interfere with water absorption and as there is no rationale for intake immediately before competition (despite such claims on some commercial preparations). Creatine supplementation increases urinary creatine and creatinine excretion [70, 72]. Thus, it would be expected that creatine supplementation will increase plasma creatinine concentrations in healthy individuals; there is no a priori reason to expect that acute and long-term creatine ingestion impairs kidney function. This has been confirmed recently in experimental studies [126, 127].

10.3. Carnitine

The main sources of L-carnitine are red meats and dairy products in the diet and endogenous biosynthesis from trimethyllysine and methionine in liver and kidney [21]. Healthy humans produce enough carnitine to maintain normal bodily functions, even when the diet contains no carnitine. About 98% of the carnitine of the human body is present in skeletal muscle and heart. In the human body carnitine functions to transport long-chain fatty acids across the mitochondrial inner membrane so that the fatty acids can be subjected to Beta-oxidation and used for ATP production in the mitochondrial matrix. Another function of the carnitine pool in the muscle is to store excess acetyl groups and keep free CoA available for muscle metabolism during high intensity exercise, when the pyruvate dehydrogenase complex is maximally activated [42]. Carnitine containing supplements are widely available in health food and sport nutrition shops and are used by athletes in an attempt to improve performance and by obese subjects to try to burn fat and lose weight. However, oral carnitine supplementation in humans for periods of 2-3 weeks in amounts of 5-6 gram per day did not increase the carnitine concentration in muscle [5, 152, 166] and carnitine supplementation, therefore, can not have an effect on muscle metabolism at rest or during exercise. In agreement with this conclusion, controlled studies [167, 171, 71] do not support the commercial claims that carnitine supplementation: 1. Helps to lose weight or reduce body fat mass; 2. Increases fat oxidation and reduces glycogen breakdown during prolonged cycling or running; 3. Increases VO_{2max} and reduces lactate accumulation during maximal and supramaximal exercise; and 4. Improves endurance performance. In conclusion, the scientific data available do not support the use of carnitine supplements in relation to physical performance.

10.4. Medium-Chain Triglycerides (MCT)

In theory addition of a fat source to a carbohydrate containing solution could increase plasma FFA availability and oxidation in muscle and thus spare muscle glycogen breakdown and improve performance. This effect, for various reasons (slow gastric emptying, slow absorption, inhibition of long-chain fatty acid oxidation by glucose ingestion), cannot be reached by co-ingestion of carbohydrate (CHO) and long-chain triglycerides (LCT) immediately before or during exercise. Several studies, therefore, investigated whether co-ingestion of CHO and medium-chain triglycerides (MCT) could have a performance effect via this mechanism. MCT ingested orally immediately before and during exercise, in contrast to LCT, did not reduce gastric emptying [7] and, therefore, did not reduce the availability of the co-ingested glucose. MCT are rapidly absorbed by the intestine, directly into the portal vein as medium-chain FFA [171] and are rapidly oxidized after absorption [47, 137, 108, 78]. Probably part of the MCT oxidation occurs in the liver and part in the exercising muscles after conversion to ketone bodies. Only one study [163] observed muscle glycogen sparing and a positive effect on time trial performance when 86 g of MCT was added to a CHO drink and ingested in small repeated boil during 2 h of endurance exercise. Several other studies [78, 79] failed to find endogenous glycogen sparing and a performance effect when 30 to 86 g of MCT was added to CHO containing solutions ingested during exercise. In several of these studies MCT ingestion alone and in combination with CHO caused severe gastrointestinal problems and interfered with the outcome of the performance tests. In all studies ingestion of MCT alone had no or a negative effect on performance, often as a consequence of gastrointestinal cramping.

10.5. Branched Chain Amino Acids (BCAA)

Although the subjective sensations of fatigue that accompany prolonged exercise are generally considered to be the result of events occurring in the muscles or the cardiovascular system, there is growing evidence that the signals that arise in the periphery are modulated by events occurring within the central nervous system [45]. Newsholme and colleagues [20] proposed that an increase in brain serotoninergic activity was a cause of central fatigue during endurance exercise. Increases in brain 5-hydroxytryptamine (5HT) could result from an increase in the transport of the precursor tryptophan (Trp) from the plasma across the blood-brain barrier. Increasing the plasma concentration of the branched chain amino acids (BCAA), which are competitive inhibitors of Trp uptake, could reduce brain 5HT accumulation, and these observations have led to suggestions that BCAA should be added to drinks intended for consumption during prolonged exercise.

Controlled studies to improve performance by the administration of BCAA during exercise at ambient temperature all failed to demonstrate the claimed effect [172]. Mittleman et al., [111] observed an ergogenic effect during exercise in the heat, but this isolated finding in a special condition does not prove that BCAA supplementation could improve endurance performance in other situations.

10.6. Composition and specifications for supplements in particular caffeine, creatine, carnitine, MCT and BCAA

Controlled scientific studies investigating claimed mechanisms and performance do not provide a basis for the use of carnitine, MCT and BCAA intended as nutritional ergogenic aids, to meet expenditures of intense muscular efforts and especially for sportsmen.

Caffeine ingestion at levels of 2-8 mg per kg body weight prior to and during exercise enhances performance during prolonged endurance exercise as well as during short-term (approximately 5 minutes) intense exercise.

Creatine ingestion leads to a small improvement in exercise performance in sport events that require explosive, high-energy output activities especially of a repeated nature. The general recommended advised ingestion protocol is 5 days of creatine loading (10-20 gram per day in 2-4 equal portions) followed by a maintenance dose of 2-3 gram per day. Ingestion of larger amounts for more prolonged periods may not be safe [149].

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