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SOME NUTRITIONAL CONSIDERATIONS IN THE CONDITIONING OF ATHLETES

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INTRODUCTION

There are a variety of well-intentioned nutritional practices among athletes and those who service them. Although a greater awareness of sound nutritional practices is changing the situation, improvement in the advice offered is needed. This review covers some recent developments emanating from nutritional research related to the regular performance of rigorous physical activity. Athletes vary in age, nutritional status, state of training, etc, yet all are given the common label "athlete." The needs of the many types of athletes of both sexes who participate in different competitive contests should be recognized.

Studies of the effects of various nutrients on athletic performance or related activities underway for many years provide some theoretical basis for relating dietary modification to improvement in physical performance, but there is need for further research. A variety of reviews that have appeared through the years are listed in the appendix that precedes the bibliography of this review and may not be cited in the text. These provide basic considerations in regard to nutrition and exercise. This review is complementary information, in some instances speculative, with respect to interpretation of relatively recent research. No attempt has been made to make the review comprehensive in any given area or to provide complete coverage of the topic.

Diets that facilitate the best performances by athletes must contain adequate quantities of energy, protein, fat, carbohydrate, vitamins, minerals, and water. Present evidence provides little reason for the athlete's diet to deviate in major ways from the *Recommended Dietary Allowances* (26). For athletes in training, particularly for those who require more than 3000 kcal day^{-1}, somewhat greater emphasis may well be given carbohydrates, i.e. a shift from the normal 15% protein, 40% fat, and 45% carbohydrate, to 15% protein, 30% fat, and 55% carbohydrate (17). One recognizable exception among athletes who expend 3500 kcal day^{-1} or more is the problem of nutrient bulk and caloric density. Increasing fat intake moderately reduces bulk and enables the athlete to obtain sufficient calories in palatable forms and in food quantities that are reasonable and tolerable. The ultimate danger may well be in becoming adapted to a relatively high fat diet when no longer in competitive sport, which may carry the later risk of atherogenesis (77).

ENERGY TURNOVER

General

The quantity of calories consumed must be increased according to energy expenditure during the regimen of physical conditioning, training, or competition. The goal is to achieve and maintain optimal body weight and composition for the particular type of competition. In general, excess body weight reduces mechanical efficiency and adds to the workload. Factors that influence the energy expenditure associated with physical exercise include age, sex, body weight and size, body composition, and body configuration, plus the type, intensity, frequency, and duration of the activity or sport. The stage of growth and development in children is important, as are changes that normally occur with advanced age. All types of people with various structural and other problems are currently engaged in athletic competition. Persons with disabilities are competing (e.g. wheelchair road races), as are pregnant or lactating women. Athletes compete in all types of climates, including adverse environments. Therefore, energy requirements of athletes cannot be generalized. For more complete information the reader is referred elsewhere (10, 15, 21, 40, 42, 73, 93).

Physical activity is the major variable that affects energy expenditure and hence caloric requirements. Under normal circumstances, the responsiveness of the appetite and satiety mechanisms are sufficiently precise to compensate for changes in physical conditioning and training regimens, so body weight and composition remain near optimal levels. Although information about specific caloric requirements for regular participation in various sports is limited, an attempt has been made to present an appropriate perspective of energy turnover (Table 1) (16). It is quite probable that physical conditioning and training take at least 90% of the time an athlete devotes to his/her sport. Thus, the frequency, intensity, and duration of these preparatory activities are largely responsible for the rate of energy turnover for the athlete. The classifications in Table 1 are imprecise, but the range in caloric requirements of from 3000 to 6000 kcal day^{-1} probably includes 75% of all athletes. Very large athletes training intensively for several hours each day have the highest caloric requirements. Smaller athletes who transport their body mass over long distances on a regular basis (e.g. cross-country running or skiing) also have high requirements. Caloric intakes required to maintain body weight among middle distance runners at Penn State during training and competition averaged 3600 kcal day^{-1}. They practiced twice a day and ran 7 or more miles per day (15). Table 1 was prepared largely on the basis of data available for men. Women athletes would have requirements that average about 10% less than those for men, assuming physical conditioning and training regimens are comparable.

Table 1 Classification of activities by type of effort and range of probable daily caloric requirements in relation to the demands of the activity: effect of length of practice on the daily caloric requirements[a]

Duration of activity: Intensity of activity:	Short burst Maximum effort	Less than 1 min Strenuous effort	Sustained Low intensity	1 to 10 min Sustained effort	10 min or more Intense repeated effort	Endurance High intensity
Event:	Discus Hammer throw Shot-put Javelin High jump Diving Ski jumping	Dashes 440 yd Hurdles Long jump Hop, step, jump Pole vault Long horse vault 50 & 100 yd swimming events	Baseball Golf	880 yd run 1- & 2-mile runs Swimming events over 100 yd Wrestling Most gymnastic events Downhill, slalom skiing	Football Basketball Ice hockey Lacrosse Tennis Gymnastic all-round Fencing 3-mile run	Cross-country running 6-mile run Marathon running Soccer Cross-country skiing
Kcal per day:	3000–4000	3000–4000	3000–4000	3000–5000	3000–6000	4000–6000
Training: Percent increase in daily caloric requirement in relation to length of practice						
≤1 h	5	5	8	10	10	13
1–2 h	10	10	17	20	20	25
≥2 h	15	15	25	30	30	38

Remarks: It is assumed that body weight and size were approximately equal at each end of the kilocalorie per day range for the participants in the events referred to in the above categories. Such an assumption is an oversimplification, e.g. shot-putters are usually very large men and divers are usually small men. Note that an athlete in training requires at least 3000 kcal per day and that additional training can markedly increase daily caloric requirement.

[a] Adapted from Ref. 16.

Complex Regimens—Weight Training

It is common practice currently for athletes to train in complex regimens that include strength, power, and muscular endurance development. These programs are based on weight lifting, manipulation of resistive machinery, running, and skill development. The energy expenditure of a circuit weight training program was determined in a group of 20 men and 20 women (123). During performance of the 10-station circuit the average gross expenditure was 202 kcal for men and 138 kcal for women. The average net expenditures were 130 and 95 kcal, respectively. The circuit required 22.5 min to perform. When calculated on per kilogram of body weight basis, the energy expenditure was 7.0 kcal kg^{-1} min^{-1} for men and 6.0 kcal kg^{-1} min^{-1} for women. Thus, the sequence of resistive exercises performed at 40% of the individual's one repetition maximal value was calorically expensive and amounted to hard work.

Walking and Running

Running a given distance requires more energy than walking the same distance, particularly when walking at the most efficient speed (61). Above the most efficient walking speed, energy expenditure per unit distance increases with speed, whereas running energy expenditure per unit distance is relatively independent of speed until very fast speeds are achieved (83). For determination of energy expenditure during running, knowledge of body weight and distance run permits a reasonable approximation of energy expenditure (46). Extensive training tends to reduce energy expenditure among both men and women. A comparison of trained to untrained subjects revealed about a 7% lesser energy expenditure in the trained subjects when running at a speed of 200 m min^{-1} (11).

Intense Endurance Exercise

In a comparison of the aerobic performance of men and women marathon and ultramarathon athletes, Davies & Thompson (34) found that the energy expenditure (from $\dot{V}_{O_2}$ assessment) during treadmill running per kilogram of body weight was the same for both groups. The regression equation was

$$\dot{V}_{O_2}\text{ (mile kg}^{-1}\text{ min}^{-1}) = -7.736 + 3.966\,v; \qquad (r = 0.94)\ (n = 77),$$

where v (velocity) is in kilometers per hour, r is the correlation coefficient, and n is the number of subjects. They also found that the aerobic capacity or maximal oxygen intake ($\dot{V}_{O_2}$ max) of the athletes could be predicted with a standard deviation of ± 2 ml kg^{-1} min^{-1} from the time it took them to run either 5 or 42.2 km (marathon distance). The regression equation was

$$\% \dot{V}_{O_2} \max = 100.11 - 7.046 \bullet (42.2 \text{ km time in h}); \qquad (r = -0.52).$$

On the average men used oxygen at 82% of their $\dot{V}_{O_2}$ max and women used 79% in covering the marathon distance. Beyond the marathon distance, i.e. at 84.64 km, the sustainable relative workload for men had decreased to 75% of $\dot{V}_{O_2}$ max. Thus, when body weight is considered, energy expenditure for running appears to be relatively comparable among well-trained men and women. This observation differs from that of Bransford & Howley (11), but the difference in running efficiency of the runners who participated in the two studies provides a probable explanation: the runners they studied were less fit (11). It is important to note that very high energy expenditures can be sustained by well-trained runners. The average energy cost was 0.95 kcal kg^{-1} km^{-1} (34). Thus, a 60-kg man running 42.2 and 100 km would utilize 2405 and 5700 kcal, respectively. Energy expenditure when running outdoors against the wind increases as the square of the wind velocity (97) and could add up to 5% of the energy expenditure (34).

Cross-country skiing is a demanding and calorically expensive sport. Work is done in overcoming both the friction of the skis on the snow and the air resistance (90). Values for the maintenance of relative workloads have been found that are comparable to those of runners; for example, Jette et al (66) found that a skier could maintain 90% of his $\dot{V}_{O_2}$ max for 20 min and Niinimaa et al (90) found that skiers could maintain speeds of 15 km h^{-1} for 1 h that required utilization of 85% of their $\dot{V}_{O_2}$ max. At this level, the skiers utilized 18 kcal min^{-1} or 1080 kcal h^{-1}. The skiers' average weight with equipment was 72 kg. Thus, they utilized about 1.0 kcal kg^{-1} km^{-1}, a value only slightly higher than the 0.95 found for distance running.

From a nutritional standpoint, it is apparent that the sports discussed above fit the endurance high intensity category identified in Table 1. According to Table 1, athletes in such sports can require up to 6000 kcal day^{-1}. Such large caloric turnovers occur largely because of prolonged practice sessions. For example, in preseason football, two practices a day are routine. Although the players engage in activity on an intermittent basis, they do so intensively. Many of them are men who weigh 100 kg or more. They practice 4 h day^{-1}, engage in some additional running, and participate in a separate weight lifting or resistive exercise program.

Classification of Effort

No systematic attempt has been made to classify physical effort associated with athletics in terms of energetics or physiological responses closely related to daily energy turnover. Development of a reasonable scheme would be useful to the dieticians, physicians, trainers, and coaches responsible for the nutritional management of athletes. A rough classification scheme for physical effort has been suggested (see Table 2) (14, 21), but it was not structured for athletes. For example, body size and state of training were not taken into account. Fortunately, the resting metabolic rate (RMR) or Met [1.1 X basal metabolic rate (BMR)] can serve as a base, and the number of Mets or multiples of the RMR furnishes a convenient reference for energy turnover in relation to exercise intensity. Mets approximately equal the mean energy expenditure ($\dot{M}$) expressed as kilocalories per minute in Table 2. A Met is roughly equivalent to 3.5 ml of O_2 kg^{-1} min^{-1}. The Met approach assumes that one has measured body height and weight and can establish BMR from the calculated body surface area, or that one is willing to utilize 3.5 ml of O_2 kg^{-1} as a constant. A useful extension of such a scheme of classification would involve utilizing body weight and distance traveled as factors in preparing tables for different sports based on kilocalories per kilogram per kilometer or kilocalories per kilogram per minute. Indirect assessments of energy expenditure from physiological variables such as pulmonary ventilation volume and heart rate, although useful, tend to be inaccurate, as do the results of dietary surveys (20, 21). Thus, a need remains for useful classification of sport activities in terms of energy requirements.

Recommended Allowances

The latest edition of the *Recommended Dietary Allowances* (26) focuses on the maintenance of a desirable body weight—an aspect of considerable importance to the athlete. The desirable body weight table provides three percentiles for children (5th, 50th, and 95th) and average values plus range limits for adults. The recommended energy intake table is based on sex and

Table 2 Classification of physical effort[a]

Classification	$\dot{V}_E$	$\dot{V}_{O_2}$	$\dot{M}$	f
Very light	< 10	< 0.5	< 2.5	< 80
Light	10–25	0.5–1.0	2.5–5.0	80–100
Moderate	20–35	1.0–1.5	5.0–7.5	100–120
Heavy	35–50	1.5–2.0	7.5–10.0	120–140
Very heavy	50–65	2.0–2.5	10.0–12.5	140–160
Unduly heavy	60–85	2.5–3.0	12.5–15.0	160–180
Exhausting	⩾ 85	⩾ 3.0	⩾ 15.0	⩾ 180

[a] $\dot{V}_E$, Ventilation volume (liter min^{-1}); $\dot{V}_{O_2}$, oxygen consumption (liter min^{-1}); $\dot{M}$, energy expenditure (kcal min^{-1}); f, heart rate (beats min^{-1}). The values listed apply to steady-state exercise and also to peak effort. Adapted from Ref. 14 and 21.

age, as well as on mean height and weight. The energy allowances for young adults are based on regular involvement with light exercise. A downward adjustment with age is made for BMR and physical activity. Examples are provided in another table for participation in regular, relatively light activity, including some sports. The upper range limit for adults of any age is 3900 kcal day^{-1} for men and 3000 kcal day^{-1} for women. The comment is made that "for very active persons, such as athletes . . . in heavy training . . . the allowance may be considerably increased according to the degree of exertion. In general, the adult energy requirement for maintenance with moderate activity is 1.7 times the basal energy expenditure for men and about 1.6 times basal for young women." That athletes frequently require greater energy intakes than those covered in the *Recommendations* is evident, yet they do provide useful reference information to those who advise athletes about nutrition.

Caloric Equivalent of Loss and Gain of Weight

When body weight is lost, the caloric equivalent of the loss is dependent on initial body composition as well as on the magnitude of the loss and its duration. Other factors are composition of the diet, including sodium chloride, environmental conditions, drug therapy and status, and neurogenic and hormonal control mechanisms (21). The caloric equivalent is always less than that for stored triglyceride (9.3–9.5 kcal g^{-1}), or less than the commonly used nutritional value of 9.0 kcal g^{-1}. Data from the literature are reported in Table 3. These data were not obtained from athletes, although some active young men participated in the semistarvation experiments. During the course of weight reduction, caloric equivalent tends to gradually increase. Early weight loss involves a greater fraction of water and less of fat, and later weight loss involves more fat and less water. It is unlikely that the caloric equivalent of weight loss among athletes would exceed about 6 kcal g^{-1}.

A recent illustration of dramatic weight loss occurred when Muhammed Ali reduced about 18 kg in approximately 60 days. If the weight loss was 6.0 kcal g^{-1}, about 108,000 kcal were made available from his body tissues and stored lipid. Thus, his daily negative caloric balance averaged about 1800 kcal day^{-1}, a reasonable value for a large man. The diet restriction plus heavy exercise regimen he was on, supplemented by thyroid and diuretic treatment, proved to be debilitating. He was decisively defeated in a boxing match for the heavyweight championship of the world (October 1980).

Gaining weight for wrestling and boxing to compete in stipulated weight divisions is a long-standing practice. The advice provided scholastic, col-

Table 3 Mean calorie equivalents of body weight loss in humans[a]

Study	n	Days	kcal kg^{-1}
Undernutrition	5	4	2730
Starvation	1	4	2840
Starvation with work	6	5	2840
Semistarvation with work	6	12	4300
Semistarvation with work	13	24	5320
Reducing	12	63	6170
Prolonged semistarvation	32	168	7510
Obesity, reducing		14 or more	6000–8200

[a] n, number of subjects; days, days on experimental regimen; kcal kg^{-1}, kilocalorie deficit/kilogram of weight loss. Adapted from Ref. 21.

lege, and other competitors is frequently ill-advised. Problems arise when weight reduction is undertaken when the athlete has little stored lipid to lose (18). Abuses regarding weight reduction in wrestlers caused sufficient concern that the American College of Sports Medicine published a position stand to alert the wrestling community of the potential health hazards created by the procedures commonly employed to "make weight" (3). Among other suggestions, the need to refer to the *Recommended Dietary Allowances* was cited (26).

Energy Turnover and Longevity

The mean metabolic rate of rats allowed voluntary wheel exercise was significantly higher than that of control rats over the ages 12–21 months (56). Rats allowed voluntary exercise showed no reduction in metabolic rate per unit body weight with age, whereas the control rats did. Growth duration and longevity was significantly increased in the animals that exercised. Presumably, the exercised rats retained more muscle mass and accumulated less fat as they aged and therefore showed a lesser decrement in BMR than did the control animals. Sacher (102) pointed out that caloric restriction in rats prolongs life and this relative restriction can be brought about through either diet or regular exercise. Results of animal experiments, although revealing, cannot be directly extrapolated to man. The limited information available about the effects of regular exercise and longevity on man is inconclusive (88, 96). Nevertheless, the animal data are sufficiently suggestive to warrant additional studies of the effect of regular exercise, diet, and athletic participation on the longevity of man.

PROTEIN UTILIZATION

General

There is scant evidence that muscular activity from extensive training and physical conditioning dramatically increases the protein required for growth and the development of muscle and other tissues. Perhaps the small increase is best seen at energy intakes not adjusted for the work done so that either positive or negative nitrogen balances can be evaluated (26, 116). Another circumstance may well involve an increase in protein intake, for tissue repair is necessary following the tissue bruising that normally occurs in contact sports. During exercise in the heat, sweat losses of nitrogen are modest until acclimatization to both exercise and environmental heat is established and losses are reduced (22, 27). Because of the margin of safety in the recommended daily allowance (RDA) for protein, little adjustment in protein intake due to performance of work in a hot environment is necessary.

Protein Degradation

Nevertheless, additional research on protein requirements among sportsmen is warranted because of intriguing questions raised by recent research. Dohm et al (39) cited the following observations: a decreased nitrogen balance because of increased nitrogen excretion in exercising men on a diet adequate in energy; an increase in plasma urea following a 100-km run; a trained rat's greater capacity to oxidize leucine; and an exercised rat's greater elimination of $^{14}CO_2$ from infused [^{14}C]leucine. These latter observations suggest increased amino acid oxidation with exercise. They (39) suggested that more gluconeogensis from amino acids may be occurring during exercise, since alanine, the amino groups of which are supplied by transamination from branched chain amino acids, is released by exercising muscle, taken up by the liver, and converted to glucose. The question arises as to whether or not other gluconeogenic amino acids are also involved. Haralambie & Berg (58) observed an increase in plasma tyrosine during exercise and suggested that protein breakdown had increased.

By using a perfused rat hemicorpus preparation, Dohn et al (39) concluded that protein synthesis was decreased and degradation was increased in rats that had been swimming for 1 h compared to controls. They observed an increase in the proportion of free cathepsin-D activity and suggested that lysosomal enzymes were involved in the protein degradation. Vihko et al (118) concluded that both exercise and temporary ischemia cause cell injury, possibly involving protein catabolism, and that the lysosomes are involved in cellular repair. The increased lysosomal activity has been suggested by Dohm et al (39) to represent an adaptation of the muscle to utilize partially degraded proteins in the recovery process. If such results are representative and degradation proceeds during both exercise and recovery, the rather extraordinary net loss of protein of 15% from a single bout of exercise appears excessive. Without comparable resynthesis the animal would waste away with continued exercise. Thus, further study appears warranted.

Athletes and their advisors often hold that consumption of additional protein is necessary for the reconstitution of muscle tissue disrupted during exercise. Such destruction provides a stimulus for not only repair but hypertrophy of muscle. Goldberg (52) tested this concept in rats by sectioning tendons of the gastrocnemius muscle of one limb. The soleus muscle hypertrophied with evidence from radioactive labeling that protein synthesis in the soleus had increased and degradation had decreased.

Mole & Johnson (87) concluded that feeding of extra calories (46 kcal kg^{-1} day $^{-1}$) is anabolic at rest and catabolic with exercise for subjects consuming 2 g kg^{-1} of protein per day. Urinary nitrogen excretion increased with the amount of dietary protein and with exercise. Consolazio et al (27) reported no significant change in urinary nitrogen in exercising subjects who consumed 1.4 g of protein kg^{-1} day^{-1}. They found increased urinary nitrogen excretion when protein intake was increased to 2.8 g kg^{-1} day^{-1}. Daily caloric intakes for the subjects were about 3450 kcal day^{-1}. Yoshimura (125, 126) reported decreased urinary nitrogen excretion in exercising subjects, one of whom consumed 1.1 g of protein kg^{-1} and 3400 kcal day^{-1} (61 kcal kg^{-1} day^{-1}).

Resistance Exercise

In a progressive resistance exercise program designed to increase strength and induce muscle hypertrophy, Marable et al (82) found that urinary nitrogen excretion expressed as a percentage of nitrogen intake was reduced (Δ = 7–22%) in subjects who trained for 28 days compared to those who did not. Four groups of subjects were studied, i.e. exercisers and nonexercisers, who consumed either 0.8 or 2.4 g kg^{-1} of protein per day. Caloric intakes ranged from 50–68 kcal kg^{-1} day^{-1}. Sweat nitrogen losses were not measured. The average weight gain for the exercising subjects was 3.2 kg, which the authors interpreted as a gain of about 1.9 kg in lean body mass, although body composition was not determined. It is interesting that those who receive 0.8 g of protein kg^{-1} day^{-1} gained as much weight as those who received 2.4 g kg^{-1} day^{-1}. Marable et al (82) concluded that when caloric intakes are high enough to produce modest weight gains over several days of regular exercise, urinary nitrogen excretion decreased and/or nitrogen retention increased.

Short Studies

In shorter term exercise studies that involved periods of rest, e.g. Johnson et al (27, 87), urinary nitrogen excretion increased and/or nitrogen retention decreased. In such studies, there is the possibility of a transient response involving early nitrogen loss with the onset of a physical conditioning program in sedentary subjects and the development of muscular hypertrophy and nitrogen retention as the program continues. It is also likely that such results are highly dependent on the type of activity engaged in, as well as its intensity and duration. The time of eating in relation to exercise may also be important. By using [1-^{14}C]leucine infusion, Garlick et al (51) have shown that the rate of protein synthesis during the night was about two thirds of that during the day, whereas protein breakdown remained relatively constant. Thus, there appeared to be a need for storing protein in tissues during periods of feeding for use during subsequent periods of fasting.

Prolonged Exercise

Strenuous exercise that involves more or less continuous activity for 2 h or more promotes increased protein catabolism (35, 58, 100). Refsum et al (99) concluded that prolonged heavy exercise is accompanied by increased protein catabolism and changes in amino acid concentrations similar to those that occur with prolonged starvation, but which differ from those observed during heavy exercise of shorter duration or prolonged exercise of moderate intensity (2). They studied 10 trained skiers who participated in a 70-km ski race that lasted 4 h or more. A decrease occurred in plasma amino acid concentrations, particularly the branched chain amino acids: valine, isoleucine, and leucine. Alanine concentration also decreased. In contrast, the concentration of sulfur-containing amino acids such as taurine and cystine increased. Measurements of serum protein, blood hemoglobin concentration, and hemotocrit indicated a slight reduction in extracellular fluid volume and expansion of plasma volume. The calculated urea excretion (from urine and sweat losses) during the race ranged from 80 to 260 mmol or 4 to 11 μmol kg^{-1} min^{-1}, or about twice the average rate of loss that occurred during normal daily activity when eating a usual amount of protein. Protein intake before the race was low and no protein was consumed during the race. Refsum et al (99) speculated that prolonged heavy exercise leads to exhaustion of the muscle glycogen stores with a reduction in pyruvate production and restriction of alanine release. The relatively increased concentration of glutamate/glutamine in the total amino acid pool suggested the possibility that during heavy exercise glutamine becomes more important in the removal of amino groups from working muscle. It should be emphasized that speculation based on plasma concentrations and excretion pattern tells little about turnover or the situation within muscle. Nevertheless, the results are provocative.

Sweat Losses of Amino Acids

Sweat losses of amino acids have been studied, and in general the essential amino acids were excreted in relatively small quantities. Untrained men had significantly higher concentrations in sweat of the following amino acids: alanine, arginine, glycine, histidine, isoleucine, leucine, lysine, ornithine, phenylalanine, serine, taurine, tyrosine, and valine. There were no differences for citrulline, threonine, ethanolamine, and methionine (79). The sweat excretions during exercise were obtained by using a plastic blanket that increased the environmental temperature and humidity beneath the blanket and then washing the subject's arms with distilled water to obtain the amino acids excreted onto the skin surface. The quantity of amino acids in sweat were comparable to those in the urine. Exercise consisted of riding a cycle ergometer for 15 min at a workload of 150 W. In previous work Liappis & Hungerland (78) had found that the amino acid content of sweat varied among individuals and at different sites on the same individual. They cited the observation that exercise-induced sweat contains a greater quantity of amino acids than sweat thermally or pharmacologically induced.

There appears to be some adaptation in that regularity of sweating associated with heat acclimatization and training promotes a reduction in amino acid excretion, particularly of the essential amino acids. The ratios of sweat amino acid to urine amino acid excretion was 3.0 in trained men and 5.8 in untrained men (79). Appreciably different ratios were found for the various amino acids. The conclusion was drawn that sweat nitrogen should be taken into account in any nitrogen balance studies involving exercise particularly among untrained and unacclimatized participants.

Protein Utilization and Glycogen Depletion

The most prevalent theory to explain the observed increased protein utilization during heavy exercise has come from the work on the branched-chain amino-acid/glucose-alanine cycle (45, 53). Amino acids are transaminated within skeletal muscle to alanine from glucose-derived pyruvate carbon. Another possibility involves intramuscular enzyme efflux following heavy exercise when muscle glycogen is depleted and the ability to synthesize ATP decreases. Cellular membrane structure may be compromised because ATP is necessary for synthesis of the membrane phospholipids. The result may be intramuscular enzyme efflux, degradation, and deamination with the carbon skeletons oxidized (76). Such a mechanism is probably of minor importance. Serum urea concentration increases with duration of exercise, and serum amino acid concentration decreases after about 70 min of heavy work that severely depletes liver and muscle glycogen. This lends credence to the concept that protein metabolism is linked to glycogen depletion and compromised ATP synthesis (76).

Investigating the role of glycogen depletion in protein catabolism, Lemon & Mullin (76) exercised subjects for 1 h at 61% of aerobic capacity and found that serum urea nitrogen increased during exercise in the glycogen-depleted subjects and the increase continued into recovery. Sweat urea nitrogen increased many fold, calculated as equivalent to a protein breakdown of about 14 g kg^{-1} or about 10% of the total kilocalorie expenditure of cycling on the ergometer. It was concluded that protein was catabolized to a greater extent than was normally assumed.

Exercise Compared to Starvation

The possible effect of prolonged hard exercise and starvation on protein catabolism was previously mentioned. Gontzea et al (55) reported that nitrogen balance in young men placed on a diet that provided 1 g of protein kg^{-1} day^{-1} was positive during a 2-week period of no exercise. During the next 3 weeks they cycled on an ergometer for 120 min daily. Energy expenditure for the cycling averaged 1192 kcal day^{-1}. Their caloric intake was 10% greater than their expenditure. Nitrogen balance became negative on the first day of exercise (largely because of increased sweat nitrogen losses) and continued to become more negative until days 3 and 4. Thereafter, nitrogen balance returned toward zero with the near achievement of nitrogen balance by 11 to 12 days. This pattern resembled that found during starvation by Saudek & Felig (105). The restoration of nitrogen balance under these stressful conditions lends confidence to the view that ample protein can easily be supplied in the diet of most athletes and that protein intake, other than for careless vegetarians, need not be higher than about 1 g kg^{-1} of body weight per day, or perhaps 1.1 g kg^{-1} of fat-free weight per day in a 70-kg athlete with about 10% body fat.

LIPID UTILIZATION: FREE FATTY ACIDS

Free fatty acids (FFA) are an important fuel source during exercise with the FFA coming from intramuscular, plasma, and adipose tissue sources. It has been calculated that 30% of the intramuscular lipid was oxidized as a result of running a 30-km race and 50% was oxidized during a 100-km race (30, 44). Skeletal muscle exhibits an enhanced capacity for FFA oxidation following extensive physical conditioning and endurance training. Lipoprotein lipase activity in both adipose tissue and skeletal muscle is elevated in long-distance runners (91). If the hydrolysis of triglyceride to FFA and glycerol is enhanced, the increased concentration of FFA in the plasma apparently drives FFA oxidation within working muscle, and the quantity oxidized is proportional to the plasma concentration. If FFA mobilization and oxidation are enhanced, then some glycogen or glucose is spared (33). For lower intensity exercise, i.e. intensities less than 70% of aerobic capacity, FFA comprises the dominant fuel source.

Activated FFA (CoA derivatives) presumably cross the mitochondrial membrane only as esters of carnitine. Carnitine palmityl transferase is essential for utilization of FFA via the Krebs cycle. Bank et al (5 & 6) have suspected that after intense prolonged exercise and some fasting, resulting in glycogen depletion, entry of FFA into the mitochondria would be compromised, resulting in inefficiency of energy conversion, sarcolemma damage, myoglobinuria, and a marked performance decrement. Whether or not such is the case remains to be proven.

CARBOHYDRATE UTILIZATION: GLYCOGEN AND GLUCOSE

General

The amount and relative proportion of energy derived from carbohydrate for the support of muscular work is dependent upon a number of factors, including diet; body composition; physical condition; type, intensity, and duration of exercise; and environmental conditions (19). It has been suggested (33) that the mobilization and utilization of FFA may be partially suppressed if the diet is high in carbohydrates and that more carbohydrate is utilized. Paradoxically, such utilization should accelerate depletion of liver and skeletal muscle glycogen stores. A larger residual deposit, although facilitating more rapid utilization, may well extend the period of glycogen degradation, thereby compensating for rapid usage.

At low intensity workloads little glycogen is oxidized. Utilization increases exponentially with increased exercise intensity (62, 103). Hultman (62) has reported a maximum rate of glycogen utilization during maximal isometric exercise of 40 mmol kg^{-1} min^{-1}. Some glycogen is utilized during the early or oxygen-deficit phase of exercise; the greater and more prolonged the oxygen deficit the more rapid the rate of glycogen utilization. Presumably the delivery of other fuels to working muscle via the circulation is inadequate. With exercise in a hot environment and the resulting competition between the skin and skeletal muscle for circulatory perfusion, utilization of glycogen by skeletal muscle may increase relative to the quantity of glycogen used when exercising in a cool environment (47).

Glycogen Storage

The capacity for prolonged (30 min to 3 h) severe exertion can be altered by dietary manipulation that increases liver and skeletal muscle glycogen stores. The dietary regimen that results in supranormal storage of glycogen usually involves a depletion phase, a high fat and protein intake phase, and a high carbohydrate intake phase. The respective dietary phases concomitantly involve performance of exhausting work for depletion, regular training during the high fat and protein intake, as well as during the high carbohydrate intake. During a day of rest preceding competition, the athlete remains on the high carbohydrate intake. Such dietary manipulation has resulted in increases in glycogen stores in skeletal muscle from a normal concentration of about 1.6 g per 100 g of wet muscle to 4.0 g per 100 g (7,103). Presumably glycogen synthetase is increased in the glycogen-depleted muscle, and glycogen repletion proceeds at an accelerated rate when extra carbohydrate is available in the diet (95). Increased training may also increase glycogen synthetase activity and hence glycogen storage capacity. The fast-twitch white skeletal muscle fibers appear to store more glycogen than the slow-twitch red fibers (95). During prolonged exercise at less than 70–80% of aerobic capacity, glycogen depletion is greatest in the slow-twitch red fibers—in this instance oxidative metabolism presumably plays a major role and glycogen is depleted because the slow-twitch fibers are preferentially recruited (32, 33).

Athletes who trained hard for 2 h each day showed a pattern of skeletal muscle glycogen depletion and repletion that was diet dependent. If less than 40% of caloric intake was derived from carbohydrate, a steady decrease in glycogen stores with days of training was evident. When more than 70% of an equal caloric intake was from carbohydrate, near restoration of glycogen stores took place within each 24-h period and glycogen stores were retained near normal with 3 days of training (33). Subjects who ate more carbohydrate perceived successive days of effort as less stressful than those who received less carbohydrate. It was concluded that athletes who train hard daily (i.e. to relative exhaustion) should consume ample carbohydrate to lessen the possibility of progressive glycogen depletion and reduced performance.

The review by Costill & Miller (33) indicated that muscle glycogen repletes within 24 h (see also 81), but others have shown that complete repletion takes longer, perhaps as long as 48 h (94). Costill & Miller (33) suggest that more hours are required for repletion if the subjects eat a mixed diet ad libitum—their appetite is reduced and they may remain in negative caloric balance for a period even though ample carbohydrate is available.

Carbohydrate Feeding

Athletes trained for endurance competition demonstrated lesser serum insulin response and less hyperglycemia than control subjects following an oral glucose load (80). Presumably much of the glucose load was diverted to glycogen storage. Serum lipid values of endurance athletes tend to be low with only the high density lipoprotein cholesterol relatively elevated (124). Thus, the finding that high carbohydrate intake results in the elevation of plasma triglycerides (9, 89) probably does not apply to endurance athletes if the fate of dietary carbohydrate results in relatively more liver and skeletal muscle glycogen storage and less lipid storage than in nonathletes. Since most athletes are not endurance athletes but have caloric turnovers closer to the normal range, a high carbohydrate diet may result in a small elevation of their plasma triglycerides.

Hodges & Krehl (60) showed that the metabolic events induced by glucose and starch were somewhat different. Starch feeding resulted in a lower serum insulin and glucose concentration than did glucose feeding. Serum cholesterol and triglyceride showed the same pattern. The resulting glucose and insulin curves with starch feeding resembled those for endurance athletes given glucose (80). Costill & Miller (33) reported a trend toward greater glycogen storage in the muscles of men who consumed starch as compared to glucose, which must be regarded as equivocal because no significant difference was found between the diet groups in the rate of glycogen synthesis. The effect of types of dietary carbohydrate on glycogen storage deserves additional clarification. In attempting to explain their results, Hodges & Krehl (60) implicated a heavier load on the hexosemonophosphate shunt with glucose feeding that favored production of more NADH and the synthesis of FFA. Starch feeding presumably involves the shunt to a lesser extent.

Liver Glycogen

Liver glycogen, the source of much blood-borne glucose, is markedly depleted with deprivation of carbohydrate for only 24 h (63, 92). Values of 10 g kg^{-1} of liver tissue were found, whereas normal values were above 40 g kg^{-1} (see Table 4). As a result of strenuous exercise lasting 60 min, liver glycogen decreased from 44 to 20 g kg^{-1}. Thus, exhausting exercise plus a carbohydrate-free diet will appreciably lower liver glycogen content (see Table 5). A single, relatively large, high carbohydrate meal increased liver glycogen above the control level. Thus, Costill & Miller (33) suggest that ample carbohydrate in the diet together with rest at least for a day preceding competition may be sufficient to insure liver glycogen reserves and minimize the possibility of hypoglycemia during competition. The availability of ample liver glycogen is important to all athletes, not only endurance athletes.

During low to moderate intensity exercise, glucose release from the liver is increased in proportion to the exercise intensity and can attain four to six times the resting value. At low intensity workloads much of the glucose is presumably produced by gluconeogenesis, as it is with low liver glycogen stores. At higher intensities glycogen is degraded. Hultman (62) has calculated that with glycogenolysis of 2.5 mmol min^{-1} and a liver store of 500 mmol glucosyl units, the glucose needs for about 200 min of low intensity work could be supplied. At high intensity workloads other performance-limiting factors enter the picture, but the glucose supply may still be helpful in sustaining performance as long as possible, i.e. with a relatively stable blood sugar concentration. The liver changes metabolism when its glycogen content is low and glucose production continues via gluconeogenesis from lactate-pyruvate, glycerol, α-amino acids, and particularly alanine. The gluconeogenic process requires more oxygen and is too slow to provide all of the glucose needed at high workloads. Hultman (62) reports that blood glucose concentrations as low as 2 mmol per liter have been observed after sustained hard exercise that followed the eating of a low carbohydrate diet.

Glycolysis and Muscular Contraction

During skeletal muscle contraction, glycogenolysis and glycolysis are apparently initiated by calcium release with the rate determined by the increased amount of ADP and AMP. A high ATP content inhibits glycolysis. If oxidative capacity is insufficient, glycolysis is stimulated but lactate accumulates and pH decreases. At greater hydrogen ion concentrations the glycolytic enzymes are inhibited and glycolysis is reduced, and release of FFA from adipose tissue is reduced. Thus, continuation of contraction may be curtailed. The intramuscular use of glycogen appears to be limited to a major extent to workloads in which excessive lactate does not accumulate. If the glycogen can be converted to glucose and oxidized to CO_2 and H_2O, there appears to be no problem; or if rest periods are provided so that the lactate and hydrogen ion concentration in muscle decrease, or the muscle mass used is sufficiently small so that the produced lactate can be metabolized elsewhere, contractions can continue (62).

Table 4 Liver glycogen content and glucose release in relation to preceding diet[a]

Diet	Glycogen content (mmol/1.8 kg) Mean	Range	Glucose release (mol min^{-1}) (mean ± SE)
CHO poor 1–10 days	60	20–130	0.30 ± 0.03
Mixed	500	160–830	0.87 ± 0.06
CHO rich 1–5 days	900	480–1120	0.95 ± 0.06

[a] Adapted from Hultman (62). CHO, Carbohydrate.

Table 5 Liver carbohydrate metabolism at rest and during 25 min of exercise following a carbohydrate-rich or a carbohydrate-free diet[a]

Diet condition	CHO-rich exercise	CHO-free exercise
Liver $\dot{V}_{O_2}$ (mmol min^{-1})	2.70	4.46
Total glucose production (mmol)	57.55	49.50
Total metabolite uptake (mmol)	9.0	72.2
Glucoeneogenesis (mmol)	4.5	36.1
Glycogenolysis (mmol)	53.0	13.4
(g)	8.6	2.2

[a] Liver vein catheterization studies in two subjects. Gluconeogenesis was calculated from substrate uptake. The difference between gluconeogenesis and hepatic glucose production = glycogenolysis. CHO, Carbohydrates. Adapted from Hultman (62).

Time of Feeding

The use of carbohydrate feeding during exercise is limited by gastrointestinal absorption and reduced splanchnic blood flow. Since gastric emptying is slow during hard exercise, the rate of glucose transfer to the small intestine or subsequent absorption is reduced. The glucose that is absorbed is metabolized, but the quantity of energy supplied in relation to energy demands is small and therefore of limited benefit. During exercise of several hours duration, such as cross-country ski racing or prolonged events that require lesser energy expenditure, carbohydrate intake may play a significant role (1, 8, 30, 119).

Foster et al (49) and Costill & Miller (33) emphasize that no carbohydrate should be ingested during the 2 h just prior to competition. Because carbohydrate digestion and absorption temporarily elevate blood glucose and insulin concentration, there is suppression of the liver's output of glucose. The rate of glucose removal from the circulation is increased with the onset of hard exercise with a failure of glucagon concentration to rise, and blood glucose may fall precipitously. Under these circumstances more liver and muscle glycogen are utilized with the potential for earlier depletion of glycogen stores. Glucose ingestion has been found to result in diminished splanchnic uptake of glucogenic precursors such as lactate, pyruvate, glycerol, and alanine with decreased hepatic gluconeogenesis. Perhaps exercise fails to overcome the inhibitory influence of carbohydrate intake on hepatic gluconeogenesis (45, 119). If the precompetition meal (largely carbohydrate) is scheduled about 4 h prior to competition, blood glucose and insulin concentrations will have returned to normal and the potential exercise-induced hypoglycemia and muscle glycogen depletion is avoided (31).

Problems

Glycogen loading increases the water and electrolyte content of muscle. Hultman (62) calculated that if the active muscle mass was 20 kg and the glycogen store in these muscles was normally about 1650 mmol glucosyl units, tripling the glycogen store would add 3300 glucosyl units or about 0.6 kg of glycogen. About 3.4 liters of water are stored per kg of glycogen so about 2 liters of water would be stored in association with the 0.6 kg of glycogen—an increase in body weight of approximately 2.6 kg. It is conceivable that such an increase in glycogen and H_2O storage would not only increase body weight but would stiffen the muscles and perhaps adversely affect contractile properties and thereby compromise performance. Such potential consequences await either confirmation or rejection.

It has been suggested that nutritional state can be altered by carbohydrate loading with partial depletion of niacin, modification of oxidative pathways, and greater anaerobiasis with accumulation of lactate (65). Blair et al (9) have also suggested that serum triglycerides may increase with carbohydrate loading. Mirkin (86) reported electrocardiographic S-T depression in a runner who followed a carbohydrate loading regimen. Bank (5) cited two cases of myoglobinuria, possible sarcolemma disruption, and renal failure in two marathon runners who had carbohydrate loaded. Exercise intolerance with muscle damage has been seen in relatively sedentary individuals following extreme exertion (36), particularly with exercise conducted in a hot environment (106). Knochel & Schlein (71) have related rhabdomyolysis to potassium depletion. Thus, the problem of rhabdomyolysis following carbohydrate loading and severe exercise should be explored further. Leg cramps and excessive fatigue during runs complained of by some local runners following carbohydrate loading may be a related phenomenon.

Advice

Based on current evidence it appears wise to advise most athletes against carbohydrate loading and for athletes who compete in endurance events to test their tolerance of the procedure and then use it sparingly, i.e. reserve it for important competition. It is most important for the endurance athlete to ingest ample carbohydrate on the day prior to competition, i.e. large feedings that end 10–12 h before competition plus a small amount of carbohydrate (400–600 kcal equivalent) about 4 h before competition. A modified loading program that eliminates the glycogen depletion phase may be well advised for more common use. The issue of complex versus simple sources of carbohydrate regarding the effectiveness of the loading process has not been resolved satisfactorily. Tanaka (115) found that Kalahari Bushmen, who largely live off the land with hunter-gatherer subsistence that involves small amounts of meat at infrequent intervals and foods largely of roots, nuts, beans, and other vegetable types, were capable of sustained hard physical work. During a hunt they walk and run down a selected animal quarry, a process that may take several days. One wonders about the glycogen storage status in such hunters and the intensity of physical activity they can sustain.

Complex carbohydrates are normally associated with other nutrients in the food in which they are contained. Thus, breads, cereals, vegetables, and fruits are also good sources of vitamins and minerals. Thus, there is ancillary nutritional merit in using sources of complex carbohydrates rather than simple sugars in the athlete's diet.

SPECIAL DIETARY CONSIDERATIONS

B-Vitamin Supplementation

Available evidence indicates that vitamin B supplementation to those athletes on balanced diets will not change performance. There are, however, suggestive studies in the literature, such as the one conducted by Early & Carlson (41) on experimental and control subjects (not double blind), that the amout of fatigue was reduced during hard exercise in a warm environment that induced considerable sweating when a B supplement was given for 6 days. The supplement consisted of 100 mg of thiamine, 8 mg of riboflavin, 5 mg of pyridoxine, 25 mg of cobalamin, 100 mg of niacin, and 30 mg of pantothenic acid. The authors speculated that thiamine and pantothenic acid accounted for the lessened fatigue, because normally large amounts of both vitamins may be lost in sweat. With reduction in available thiamine and pantothenic acid, for example, their important roles in oxidative decarboxylation as a component of acetyl-CoA may shift substrate utilization to greater glycolysis and perhaps reduce oxidative efficiency with greater accumulation of lactate. Lactate accumulation was not measured.

Thiamine is essential in key reactions in energy metabolism, principally carbohydrate metabolism, and the requirement for thiamine has been related to total energy intake or non-fat calories. Sauberlich et al (104) confirmed this concept in a study on men in whom calories were derived mainly from carbohydrate. The RDA for riboflavin and niacin have also been related to caloric turnover, although White et al (121) concluded that the niacin requirement is difficult to assess because niacin may be synthesized from tryptophan. There is no evidence that riboflavin or niacin supplements above the RDA are of value in improving athlete performance.

Lawrence (75) investigated the effects of vitamin B_6 (51 mg of pyridoxine HCl) on the capacity to perform 10 intermittent 100-yard swims. The subjects were matched by age, sex, and swimming ability and were assigned to a supplemented or placebo group for a period of 6 months. No effects of the supplementation on performance were observed although blood from those supplemented contained more B_6.

Despite the fact that B_{12} supplementation is common among athletes, and some athletes have received injections prior to competition, there is no evidence to recommend B_{12} supplementation for healthy athletes (122).

Vitamin E

A survey by Kavanagh & Shephard (69) revealed that more than 50% of those involved in International Master's Competition were taking vitamin E. Cooper (29) observed that high intakes of vitamin E were routinely used by athletes in the 1968 Olympics held in Mexico City and use of vitamin E occurred in Munich (110).

Studies of the effects of vitamin E among those engaged in strenuous training are essentially negative. Sharman et al (108) carried out a double blind study using two groups of teenage boys in training for competitive swimming. The swimmers were tested for motor fitness and cardiovascular efficiency. Improvements in performance and function were noted with continued training, but the daily administration of 400 mg of α-tocopherol acetate produced no supplementary effects. Subsequently, Sharman et al (107) studied more highly trained swimmers with comparable results. About the same time Shephard et al (111,112) studied intercollegiate swimmers who were in training and half of whom received 1200 IU of D-α-tocopherol succinate in three 400-IU doses. No changes attributable to vitamin E were observed. In reviewing these experiments Shephard (110) emphasized the need for "double blind" design, careful group matching, appropriate coding, and debriefing.

An unpublished PhD thesis has reopened the issue of improved physical performance under conditions of hypoxia. The subjects were given either a placebo or 1200 IU of D-α-tocopherol succinate for 6 weeks. A crossover design was utilized. Aerobic capacity with acute exposure increased about 9% at 1524 m (5000 ft) and 14% at 4572 m (15,000 ft) with respective reductions in O_2 debt of 16 and 20% (72). These changes are rather marked and indicate return of aerobic capacity to virtually sea level values (72, 113). Despite these surprising results, such acute hypoxic exposure experiments in man plus hypoxia survival experiments in animals indicate the need for further research regarding hypoxia, performance, and the effect of vitamin E.

Iron and Sports Anemia

Iron deficiency anemia is generally associated with a reduction in physical performance capacity (50), but iron status is also of consequence in relation to physical activity. Strenuous physical conditioning and training appear to be associated with transient reduced blood hemoglobin concentrations, and these low concentrations in turn may be associated with a reduced aerobic capacity (59, 126, 127). "Sports anemia," as described by Yoshimura (126), is normocytic and normochromic. The cause is unknown, but it has been postulated that there is mechanical destruction of fragile older red blood cells within the circulation with the onset of a strenuous exercise program and the released iron is utilized in the formation of myoglobin and new red blood cells (126). Evidence of increased uptake of radioactively labeled iron occurred in skeletal muscle, heart muscle, bone marrow, liver, and spleen after only 1 week of training. Fragility of the red blood cell apparently increases during the first week of training in man (126), whereas in the rat the red blood cells were found to be more fragile after 6 weeks of training compared to untrained animals (54). Kilbom (70) found a 25% decrease in serum iron values in women who engaged in a 2-month exercise program. In addition, iron is lost in sweat; Vellar (117) found that 0.5 mg h^{-1} was lost by young men who sweated profusely; Consolazio et al (28) reported sweat iron losses among young men working under hot conditions were about 1 mg day^{-1}, but then remained in iron balance at an intake of 23.4 mg day^{-1}.

Cerruloplasmin [a copper-containing plasmaprotein necessary for oxidation of ferrous (Fe^{2+}) to ferric iron (Fe^{3+}) and its binding to transferrin] concentration is increased during exercise, as are plasma iron and transferrin concentrations (57, 59). Why this should occur is unknown, but the increases are greater than hemoconcentration.

Haymes (59) concluded that 22–25% of women athletes and less than 10% of men athletes have low plasma iron concentrations even though many had hemoglobin concentrations above 10 g per dliter. About 3% evidenced iron deficiency anemia (37, 38, 114). A survey of the Canadian Olympic team in 1976 revealed lower blood hemoglobin concentrations as compared to the general population (25). Not all observations agree; e.g. Brotherhood et al (12) reported that blood hemoglobin concentration, packed cell volume, and total iron binding capacity were not significantly different between men runners and non-runners.

In a study of eight long-distance runners (men aged 24-37 years) Ehn et al (43) found that hemoglobin and serum iron concentrations were comparable with those for non-runners, whereas there was either an absence or only traces of iron in the runner's bone marrow. ^{59}Fe studies of heme and non-heme iron absorption and incorporation showed low values. The rate of elimination of iron was calculated as 2 mg day^{-1}. ^{59}Fe was detected in urine following a 30-km run. Absorption was found to be 3.45 mg of Fe^{2+} or 16.4% and for hemoglobin iron 3.5 mg or 13.5%—relatively low rates when compared to control subjects who absorbed 30% of the non-heme iron. (All of these values appear to be somewhat high when compared with the widely held belief of normal iron consumption, which is 5–10%.) They concluded that the "low" iron absorption and increased elimination probably explained the low iron stores. In healthy persons with low iron stores, higher rates of absorption are usually seen, but this contrasts with what was found for the runners. Daily iron intake was calculated as 14 mg of non-heme and 6 mg of heme iron, but because food inhibits absorption of ferrous iron the dietary absorption percentages were estimated as 8 and 13%, respectively. Thus, the diet supplied 1.1 mg of iron from the non-heme and 0.8 mg from the heme pool. Thus, the runners were conceivably near balance at a turnover rate of 2 mg day^{-1}. The obvious suggestion for achievement of iron balance would be to increase the intake of heme iron for such runners.

The situation regarding iron deficiency has generally been assumed to be worse among menstruating women and growing children. In both groups the recommended allowances have been set intentionally high. However, athletes are found among both groups and their special requirements have not been considered in the RDAs.

A recent summary from the Health and Nutrition Examination Survey on hemoglobin and selected iron-related findings of persons 1–74 years of age in the US (67) confirms that the mean values for blood hemoglobin and serum iron concentration, as well as mean percent transferrin saturation, were higher for males than for females and for whites compared to blacks. The results suggest that different standards for iron deficiency anemia should be developed that take both sex and race into account. In other words, black women athletes may deserve special consideration.

Yoshimura et al (127) reported experiments designed to clarify whether or not sports anemia is related to iron deficiency. University students were given 1000 mg of $FeSO_4$ per day for 13 days. A control group was also utilized. After remaining sedentary for 1 week, the experimental subjects ran for 4 h each day the second week. Despite the iron supplement, blood hemoglobin concentrations decreased with exercise. The supplement may not have been given for a long enough period of time and blood hemoglobin concentrations did not fall below 13 g per dliter. In related studies (see 127), 2 g of protein kg^{-1} were provided an exercising group. The protein was of high quality with 50% from animal sources. Another exercising group received 1.25 g kg^{-1} and the low protein group received 0.5 g kg^{-1} of vegetable protein. Red blood cell counts gradually decreased for 2 weeks in the low protein group, decreased about 15% in the 1.25-g group in week 1 and returned toward normal in week 2, and decreased only slightly in week 1 and increased above the initial value in week 2 in the 2.0-g group.

The results were interpreted as establishing the importance of protein nutritional status in avoiding sports anemia during exercise. In any event, sports anemia appears to be a problem of relatively small magnitude and may only reflect transient adjustment to the changed metabolic activity, including fluid shifts that occur with the onset of a physical conditioning or training regimen. If iron stores are not depleted, the ultimate effects on oxygen transport may be minimal. Provision of adequate amounts of protein and iron as set by RDAs should suffice.

Yoshimura et al (127) have raised the possibility that a spleen secretion, lysolecithin, or some other hemolyzing factor released during strenuous exercise may initiate sports anemia. This possibility deserves investigation.

Gastric Emptying and Nutrient Absorption

A factor that limits performance at high work intensities is the relative depletion of available carbohydrate (63, 68). Lack of carbohydrate-derived substrate plus the partial dehydration that normally accompanies vigorous prolonged exercise in a hot environment has led to investigations of appropriate replacement. Many of these studies have been summarized by Foster et al (49).

A variety of materials may slow gastric emptying. Burn-Murdoch et al (13) have found that gelatin hydrolysate was equivalent to glucose in slowing gastric emptying; casein but not native egg albumin produced greater slowing than did glucose. Foster et al (49) found that glucose produced greater slowing than did a glucose polymer. Apparently two sets of osmoreceptors are stimulated in the walls of the duodenum to produce the slowing of gastric emptying (13, 64, 85). One set is stimulated by the osmotic properties of the digestion products of protein and carbohydrate and the other is stimulated by similar products from fat; all three products apparently slow gastric emptying equally when expressed as kilocalories per liter (64, 98). Despite the greater slowing of gastric emptying by more nutrient/energy dense meals (i.e. volume transfer), the quantity of nutrient or the rate of transfer of calories from stomach to duodenum is greater for the energy richer foods of comparable nutrient mixture (64).

Most of the available studies of gastric empyting that involve nutrients other than glucose or saline solution have been conducted with the subjects at rest. There is evidence, however, that gastric emptying is not greatly affected by exercise unless exercise intensity exceeds 70% of aerobic capacity or the exercise is conducted in a hot environment (49).

It has been postulated that the net gain from consumption of a carbohydrate-containing beverage is likely to be small during the running of a marathon that takes 2–3 h with the ingestion of 500–1000 ml of fluid and the absorption and utilization of about 50 g of glucose equivalent (49, 84).

Nevertheless, this small amount of glucose may play a role in helping maintain circulating blood glucose (48). Of more serious consequence is the inhibition of water absorption by more concentrated solutions. Water is undoubtedly of greater value to the perspiring athlete engaged in endurance types of competition than is glucose (48, 49). In addition, with concentrated solutions the fluid may be retained in the stomach, producing abdominal discomfort or fullness that could reduce performance.

During a 50-km cross-country ski race, which requires about 3 h for the top racers, skiers may drink about a liter of thick blueberry solution that contains about 300 to 400 g of glucose (4,48). The racers believe that this "soup" is helpful and drinking it has become a tradition. That such ski racing is performed in a cold environment may be significant.

During relatively intense but submaximal exercise in the heat, 600 to 800 ml of blood can be redistributed to the skin to support heat loss and thermoregulation (101). This volume of blood becomes available largely because of a reduction in splanchnic blood flow, for splanchnic flow is reduced in proportion to the relative exercise intensity expressed as a percentage of aerobic capacity. Such a reduction in blood flow may well play a role in reduced intestinal absorption. Despite the demonstrated reduction in splanchnic blood flow, intestinal blood flow autoregulation may play a partially compensatory role. Shephard (109) has found that flow regulatory mechanisms compensated for nearly 50% of imposed pressure reduction. When metabolic rates of the perfused gut sections were increased via greater substrate availability, myogenic vasoconstriction followed venous pressure elevations with better pressure-flow autoregulation. In other words, intestinal blood flow may be somewhat substrate dependent, at least at tolerable workloads and in thermally neutral, cool, or cold environments.

Nutritional Knowledge

Misconceptions about nutrition and dependence upon "fad diets" are prevalent among athletes. Cho & Fryer (23) found that the general nutritional knowledge of women athletes was considerably less than that of students enrolled in a basic nutrition class and that food recommendations made by the athletes were poorly conceived from a nutritional point of view. Nutrition education in either high school or college significantly improved both nutritional knowledge among women college athletes and their attitude toward good food selection (120). It appears that women athletes involve themselves with weight control both for purposes of achieving a competitive advantage and for aesthetic reasons. It was concluded that appropriate sound weight control information should be provided in any nutrition course taken by women athletes. As an aside it was found that only 1% of the women athletes had tried carbohydrate loading.

When college physical education majors and nutrition students were compared with respect to nutrition knowledge, the physical education majors were significantly less well informed and evidenced more incorrect nutritional concepts (23). Physical education students considered high school and college courses, parents, and coaches as their primary sources of nutritional knowledge. The nutrition students rated their college courses as their most important source. Few students in either group stated that they obtained significant amounts of information from physicians, nurses, news media, or popular books and magazines. In a related study Cho & Fryer (24) found that physical education students were more prone to recommend consumption of such things as honey, wheat germ, gelatin, Gatorade, etc, than were the nutrition students.

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APPENDIX:

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