Nutritional and Biological Basics for The Budding or Blooming Athlete

Interest in physical fitness is extremely high among the United States population. Whether the individual concern is with respect to general health and the overall quality of life or with the participation in athletics and possibly competition, the routes to achievement of fitness differ only in degree. Both nutrition and exercise are closely involved with the important factors of body composition, muscular competence and cardiovascular capabilities. Diets can and will influence performance to a major extent.

The Biochemistry of Exercise

Muscle filaments consist primarily of two proteins, *myosin* and *actin*, which together effect concentration and relaxation. Bending of the muscle is stimulated by nerve impulses, which provoke complex movements of contraction and relaxation that continue until the nervous stimulus has ended.

The *sliding filament theory* proposes that muscle contraction takes place when the myosin and actin portions slide across each other, with neither changing in length but in effect shortening the muscle fiber (contraction) or restoring it to its full length (relaxation). The un-energized position of the filament is in the contracted state; return of the filament to a relaxed state requires the input of energy in the form of *adenosine triphosphate* (ATP). Enzymatic splitting of ATP to form *adenosine diphosphate* (ADP) and inorganic phosphorus releases the energy for this reaction. Oxygen is not required in this stage.

The ATP present in muscles at any one time is sufficient to power activity for several seconds, thus enabling immediate response to nervous stimuli. This response is further supported by the presence in muscle cells of *creatine phosphate* (CP), which like ATP contains a high-energy phosphate group. As ATP is split, releasing energy, the ADP thus formed is combined with high-energy phosphate to form CP to re-synthesize further ATP. There is three to five times as much CP in the cell as ATP, thus providing a few more seconds of energy, for which oxygen is not required. Further energy to sustain muscle activity must be obtained from energy-containing nutrients.

The most rapidly available mechanism for supplying ATP for more than a few seconds is the process of *Glycosis*, in which the energy in glucose is released either with or without the presence of oxygen. When the process is aerobic, *pyurvic acid* is the predominant end product; *lactic acid* is the end product of anaerobic metabolism. In either, the amount of ATP furnished is relatively small (the process is only 30 percent efficient) compared with the amount yielded by mitochondrial oxidation via the Krebs cycle, which must eventually contribute energy if activity is to continue for any period of time.

Production of ATP in amounts sufficient to support continued muscle activity requires the input of oxygen. Energy stored in nutrients is transferred to the high-energy phosphate bonds in ATP through a complex series of enzymatically-guided reactions involving separation of hydrogen compounds from parent compounds. Vital to the continuation of these reactions is the presence if coenzymes (derived from dietary sources of niacin and riboflavin), which act as hydrogen acceptors until the process of oxidative phophorylation culminates with the formation of ATP. Ultimately, hydrogen is combined with oxygen to form water and the coenzymes are thus freed to accept more hydrogen in a continuation of the process. If sufficient oxygen is not present to combine with the hydrogen,

no further ATP will be forthcoming. Therefore, the oxygen furnished through the process of respiration is vitally important.
Aerobic metabolism is limited only by the availability of substrate and by a continuous and adequate supply of oxygen. At the onset of exercise and with the increase of exercise intensity, the capability of the cardiovascular system to supply adequate oxygen becomes a limiting factor.

In the absence of sufficient oxygen, such as high intensity, short-duration events, it is possible to temporarily obtain a supply of ATP through the eventual hydrogenation of pyurvic acid, the end product of glycosis. With the transference of two hydrogen atoms to pyurvic acid, thus converting it to lactic acid, a vital coenzyme is freed to participate in further ATP synthesis. The latci acid is removed rapidly from the muscle and into the blood stream. It is eventually converted to energy, either in the muscle, liver, brain, or to glycogen. This conversion to glycogen takes place in the liver and to some extent in muscle, particularly among trained athletes. Although this process provides immediate protection from the consequences of insufficient oxygen, it can only continue temporarily. As lactic acid accumulates in the blood during exercise, it eventually lowers the pH to a level that interferes with enzymatic action, leading to fatigue. Also, the amount of ATP produced through glycosis is very small compared with that available through the Krebs cycle. Substrate for this reaction is restricted to glucose provided from blood sugar or the glycogen stores in the muscle. Liver glycogen contributes to blood sugar but is limited in amount. Muscle glycogen is not capable of transfer via the blood stream, so that the anaerobic capacity of each muscle is limited to its own glycogen content.

During the recovery period after exercise, oxygen uptake continues at a high level for a period of time. The difference between this level and the amount that would be required for the same individual at rest is called *oxygen debt*. This represents in part the oxygen required for replacement of the ATP and CP reserves used during the initial exercise phase, reoxygenation of myoglobin and hemoglobin, and conversion of lactic acid to glucose and glycogen. It also includes the oxygen participating in restoration of physiological changes created by the exercise in systems such as circulation, respiration and temperature regulation. If the previous energy expenditure was primarily aerobic, the oxygen debt is repaid within several minutes after stopping exercise. However, after high-intensity strenuous exercise with lactic acid build up and body temperature increase, it may take several hours t o1 day to recover oxygen debt. This can be a problem in sports such as basketball, hockey, soccer, or volleyball in which players are pushed to a high level of anaerobic metabolism and may not fully recover in brief rest periods between points, time outs, half-time breaks, or even rest periods between games.

Fuels of Muscle Contraction

Proteins, fats, and carbohydrates are all possible sources of fuel for muscle contraction. The glycotic pathway is restricted to glucose, which can originate in dietary carbohydrates or can be synthesized from carbon skeletons of certain amino acids through the process of gluconeogenesis. The Krebs cycle is fueled by three-carbon fragments of glucose, two-carbon fragments of fatty acids, and carbon skeletons of specific amino acids, primarily alanine. Which of these nutrient substrates is used depends on the intensity and duration of the exercise.

Although carbohydrate is the most efficient fuel with respect to oxygen consumption, available carbohydrate is limited to the blood sugar and the glycogen stores in liver and muscle, which provide approximately 600 calories. In contrast, the potential supply of fatty acids in adipose tissue stores is essentially unlimited.

In general, both glucose and fatty acids provide fuel for exercise, in proportions depending on the intensity and duration of the exercise and fitness of the athlete. Exertion of very high intensity and short duration draws primarily on the reserves of ATP and CP. High-intensity exercise that continues for more than a few seconds depends on anaerobic glycosis. During exercise of low to moderate intensity, energy is derived mainly from fatty acids. Carbohydrate becomes a larger fraction of the energy source as intensity increases until eventually carbohydrate from glucose is the principal energy source and the available carbohydrate stores limit the duration of activity.

The length of time that use of fatty acids can be sustained is related to athlete conditioning. In addition to improving cardiovascular systems involved in oxygen delivery, training increases the number of mitochondria and levels of enzymes involved in aerobic synthesis of ATP, thus increasing capacity for fatty acid metabolism.

Fluid and Electrolytes

The importance of fluid replacement during exercise is well documented. The cell conducts its activities in am aqueous medium. Water transports nutrients and waste products to and from the cells via the blood stream, and adequate blood volume is essential to the body's ability to dissipate heat through dilation of skin blood vessels and sweat during exercise.

Depletion of body water occurs through sweating and respiration. Much of the water lost through sweating comes from the blood, leading to a reduction of blood volume to a level that may threaten cardiovascular function. When fluid losses reach significant levels, sweating and blood flow to the skin are diminished and core temperatures are elevated. Even partial dehydration impairs performance. A water loss of 4 to 5% reduces work capacity by 20 to 30%, while a 10% loss threatens circulatory collapse. Sweat, which contains sodium, chloride, magnesium, and potassium, is hypotonic compared to body fluids.

The amount of fluid lost during exercise depends on the intensity and duration of the effort and especially on the atmospheric temperature and humidity. Without exercise, an individual produces 500 to 700 ml/day of sweat, whereas prolonged exercise in a humid environment may result in 8 to 12 l/day of sweat. Some marathon runners lose in excess of 5 liters during competition, which amounts to 6 to 10% of body weight.

During long strenuous exercise, particularly in hot climates, athletes should replace fluid lost in amounts sufficient to maintain their pre-exercise weight. Thirst is not always a dependable indicator of fluid requirement. In some situations of strenuous exercise, such as soldiers marching in the heat or athletes running in summer marathons, drinking water *ad lib* does not replace all fluid losses. Fluid losses should be monitored by body weight measurements. One pound of loss equals two cups of fluid that should be replaced. Continuous replacement is necessary both during and after exercise, and further rehydration is required afterwards.

Exhaustion is correlated with depletion of glycogen stores and the subsequent failure to provide enough blood glucose for the exercising muscle. After 3 hours of continuous exercise at 70 to 80% of maximal oxygen uptake, athletes tire secondary to hypoglycemia. At this stage, carbohydrate is still providing 50 to 60% of the energy being used, but it is coming from blood glucose because muscle glycogen stores are depleted. (This is the rational for sports drinks which contain carbohydrate structure.) Liver glycogen is insufficient to maintain blood glucose for prolonged periods at high work intensities. Depletion can occur during a long distance event, as seen when the athlete “hits the wall”. It can also develop after consecutive days of heavy training, when the time between work-outs is insufficient for complete glycogen resynthesis. This situation, known as “staleness”, in which even the smallest amount of exercise can cause fatigue, can be avoided by increasing dietary carbohydrate and by timing the intake to improve its availability. To allow for maximal repletion of glycogen, most athletes should consume 500 to 600 g/day of carbohydrate from both the diet and supplementary.

The requirement for fluid and nutrient supplementation during an event will depend on the intensity and duration of the event and on the ambient temperature. Humans have very poor ability to take in fluids at the same rate in which they are lost. The athlete cannot depend on thirst to dictate fluid replacement during strenuous exercise and must be told how much to drink and when. The composition of the optimal replacement drink is of utmost importance to the athlete. It appears that sodium, potassium, chloride, calcium and magnesium are necessary for functions of efficient rehydration, replacement of fluid losses and improved performance. It is important to recognize that rehydration with water alone dilutes blood rapidly, increases its volume, and stimulates urine production.

Carbohydrate taken during performance of endurance exercises ensures that availability of sufficient amount during the later stages and offers an energy and performance advantage over water alone. Compared to drinks containing water alone, sucrose, fructose alone, or corn syrup solids, a carbohydrate structure composed of a precise mixture of fructose and glucose polymers offers unique benefits. These include: 1) maintenance of a positive energy balance, 2) protein sparing muscle tissue, 3) predictable levels of blood glucose, and 4) delayed onset of fatigue. The rate of carbohydrate ingestion should be about 25 to 30 g/30 min, an amount equivalent to 1 cup of an appropriate 6% carbohydrate solution every 15 to 20 minutes.

The carbohydrate content should be between 6 and 8%. Drinks of this concentration enter the blood stream at the same rate as plain water; however, unlike water, these drinks are associated with improved performance because of the available carbohydrate. It is likely that a carbohydrate concentration of less than 5% is not enough to help performance, whereas solutions with a concentration greater than 10% are often associated with abdominal cramps, nausea, and diarrhea. Guidelines for fluid replacement are given as follows:

Guidelines for proper hydration:

1) Weigh in before and after exercise, especially during hot weather.
2) For each pound of body weight lost during exercise, drink 2 cups of fluid.
3) Do not restrict fluids before or during an event.
4) Drink 2 and 1/2 cups of fluid 2 hours before practice or competition.

5) Drink 1 and 1/2 cups of fluid 15 minutes before event.
6) Drink at least 1 cup of fluid every 15 to 20 minutes during training and competition.
7) The replacement drink should contain adequate amounts of magnesium, sodium, chloride and calcium.

After a hard work-out and glycogen depletion, it takes 12 to 24 hours to replete glycogen levels and up to 48 hours for supercompensation. Because 60% of the total glycogen stores occurs within the first 10 hours after depletion, carbohydrate intake immediately after a training session or competition is very important. Athletes should consume 100-gram feeding every 2 to 4 hours thereafter. Glycogen resynthesis is proportional to the amount of carbohydrate consumed; however, the contribution of intakes in excess of 600 g/day appears to be negligible. The ideal carbohydrate for glycogen replenishment is a mixture of glucose polymers and fructose.

Other Considerations

Alcohol consumption has a detrimental effect on athletic performance, even though by reducing feelings of insecurity, tension, and discomfort it may cause the athlete to feel that he or she is performing better. Alcohol may exhibit its adverse effects on performance by virtue of its effect on depletion of intracellular magnesium.

Caffeine has been shown to contribute to endurance performance, apparently due to its ability to enhance mobilization of fatty acids and thus conserve glycogen stores. The diuretic effect of caffeine will present a negative effect for athletes with excessive fluid needs.

In Conclusion

It is vitally important to replace what your body has lost during exercise, whether that is essential minerals and electrolytes, fluids, or energy from fatty acids and carbohydrates. Following the guidelines in this article will set you upon the right path to reaching your health and fitness goals.

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