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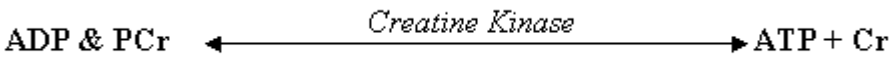
Introduction

Energy Systems and Metabolic Pathways

As previously stated ATP is not stored in high concentrations in the cell, but is the immediate source of energy for muscular activity. Thus, ATP must be rapidly resynthesized during exercise. There are multiple pathways involved in the production of ATP. The simplest and fastest mechanism of ATP production is the ATP-PC system (also called the phosphagen or phospho-creatine system). Phospho-creatine (usually abbreviated PC or PCr) is a high energy compound that can readily "donate" its phosphate group to ADP in order to rapidly produce ATP. This reaction, which is catalyzed by the enzyme creatine kinase, is summarized below.



Glycolysis is the breakdown of six-carbon glucose molecules into two three-carbon pyruvate molecules in the cytoplasm of the cell. Pyruvate produced during glycolysis has two possible fates. One fate of pyruvate, which requires oxygen (aerobic), which can then enter the citric acid cycle. The other major fate of pyruvate in exercising skeletal muscle, which does not require oxygen (anaerobic), is the formation of lactate.

The "training effects" discussed in the next unit involve among many other effects, the physiologic adaptations enabling the trainee to achieve a greater capacity for sustaining aerobic activity.

In addition to the problem of lactic acid release, anaerobic glycolysis results in an energy release approximately 20 times less than that produced by aerobic glycolysis. Therefore, it is obvious that anaerobic metabolism is not the most efficient method of releasing energy for muscle function, since it leads to fatigue and does not make the most efficient use of nutrients. The key to continue exercise over a long period lies in the capacity of the trainee to effectively utilize oxygen through the aerobic processes.

The desirable "training effects," particularly the "chronic effects," will not occur under anaerobic processes." Therefore, aerobics is not only more efficient than anaerobics at the time because it is more effective in releasing energy, but the training effects through physiologic adaptation to aerobic stress provides the trainee with a greater capacity for sustaining aerobic activities. The lasting benefits derived from an exercise or a training program must come from sustained aerobic activity.

However, in spite of the apparent inefficiency of the anaerobic system when compared to the aerobic system, it still has some important advantages. It is through anaerobics that one has the capacity for extra effort or an all-out performance for short periods of time. Such requirements are necessary during times of emergency or when the challenge of the exertion is too great to be supported through aerobics. Because of this built-in capacity to function through an oxygen debt, one is able to enjoy or tolerate maximal effort now and pay the oxygen debt later.

In summarizing the energy pathway processes, it might be pointed out first that energy derived from phospho-creatine is broken down to phosphate and creatine as it is used to develop new ATP for continued cellular activity. Hence PC (phosphate and creatine) helps to keep the ATP concentration at the desired level during intense energy utilization, but it is in short supply. When immediate energy is needed to ensure continuation of action, PC provides that quick energy without oxygen or lactic acid involvement. This breakdown without oxygen of the ATP-PC system is needed for strenuous activities that last less than 30 seconds, such as the 100-meter dash or a vault on the horse in gymnastics.

When strenuous activities last between 30 seconds and one-half minutes, the main energy systems are both the ATP-PC and the lactic acid systems; for example, the 400-meter run or the 100-meter swim.

When strenuous activities require performance times between one and one-half to three minutes, both the lactic acid system and the aerobic system involving oxygen are used; for example, the 800-meter run.

After appropriate rest periods, as in interval training, the replenished ATP-PC becomes available once again as an energy source. If, however, the work load is too heavy or the relief interval is too short, the greater will be the influence of the lactic acid system and its consequences of fatigue on muscle function.

When activities last for time periods greater than five minutes, the cardio-respiratory or oxygen system supplies the energy to regenerate ATP; examples are jogging, soccer, and cycling. This is the aerobic process with minimal involvement of the lactic acid system. In this case, the advantage gained is twofold: (1) the aerobic process produces a far greater number of ATP molecules than anaerobic processes, and (2) the aerobic breakdown of glycogen does not result in the accumulation of lactic acid; as a consequence, a steady state of exercise can be maintained and carried on almost indefinitely without an oxygon debt. One of the best examples of this state is the marathon run.

Training Effects or Benefits of Exercise

Perhaps the body changes which Cooper calls "training effects" or which physical educators consider fundamental and beneficial as a result of exercise or training can be categorized by body systems to facilitate understanding. However, students should recognize once again that these benefits are related to the holistic concept. Therefore, they will imply interrelationships and synthesis as opposed to self containment and analysis.

In discussing these benefits, it is assumed that exercise means regular, vigorous, and planned activity that places demands on the heart and circulatory system. No claim is made that such exercise can provide immunity from communicable or infectious diseases nor can exercise alone offset the effects of other disintegrating forces of the environment.

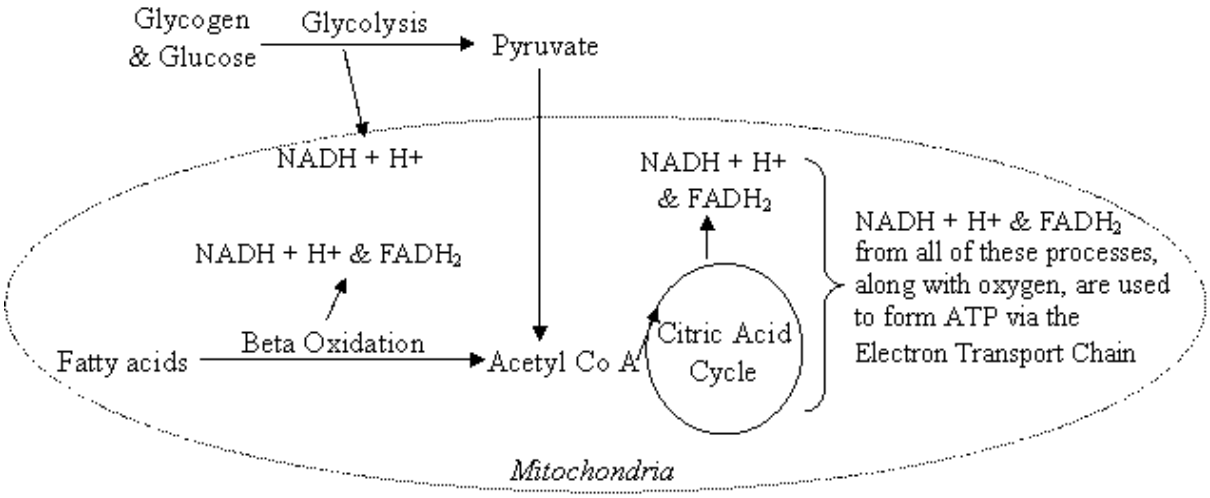


Figure 3. Highly simplified figure depicting the aerobic production of ATP from fats and carbohydrates.

Benefits of Exercise to the Heart and Circulatory System

In keeping with the law of use and disuse, the heart and circulatory system become stronger and more efficient after a prolonged period of regular vigorous exercise. The normal heart through this training has an increased volume per stroke. It contracts more forcefully and relaxes more completely, thereby pumping more blood per stroke. The systolic pressure increases more rapidly in order to force the blood through the circulatory system at a faster rate to meet the stepped-up need of the cells. The heart of the conditioned individual can do more work in fewer beats. Also, the heart rate goes up less during work than in untrained persons and returns to normal more quickly. The resting rate of the heart in trained persons is lower. All of these benefits add up to a more efficient heart and a great saving in energy at rest and in work along with providing more blood to the body tissues. The average well trained distance or cross-country runner generally has a heart rate between 50 and 60 beats per minute, whereas the average untrained person will generally have a rate of 70 to 90. An "athlete's heart" was once thought to be a weakened heart that was injured through too strenuous exercise. There is no scientific basis for this belief, because the normal heart cannot be injured through exercise. Thus, an "athlete's' heart" is a strong and efficient heart.

Another benefit to the circulatory system is an improved venous circulation, particularly in the extremities. The muscular contractions brought on by strenuous exercise force the blood back into the heart by increasing the venous pressure and the higher the venous pressure, the better the circulation. The capillary circulation in the muscle tissues is increased by almost half because latent capillaries are opened and new ones are formed. More efficiency is obtained in temperature regulation through more effective dilation of the peripheral blood vessels. With training there is a lower blood lactate concentration for the performance of a given amount of work and an ability to achieve a higher blood lactate concentration before exhaustion sets in.

There is also an increased storage of glycogen in the muscle fibres and a greater utilization of anaerobic energy reserves. Also, the amount of haemoglobin per unit volume of blood is increased since strenuous prolonged exercise can increase the number of red corpuscles. Thus, the amount of blood and Its payload of oxygen made available to the cells is conditioned by a stronger and more efficient heart with its increased stroke volume, arteries that can adapt readily to the increased needs of the cells by adjustment in size to speed the flow of blood, increase in the number of functioning capillaries, enrichment in the composition of the blood, and improved venous circulation and ventilation in the lungs for removing waste products.

Benefits of Exercise to the Respiratory System

Paralleling the more efficient heart and circulatory system through training and exercise there is a corresponding increase in the efficiency of the

respiratory functions in order to obtain the vital oxygen so necessary for body processes.

Due to training there is a slight decline in the rate and depth of respiration during rest. This is accompanied, however, by a slower, more even, and deeper respiration during exercise and a return to normal more quickly following it. There is an actual increase in the pulmonary ventilation as the lungs can take in more air with each inspiration; there is an increased efficiency in external respiration where oxygen and carbon dioxide are interchanged more effectively between the lungs and the capillaries within the alveoli. There is an increased efficiency in absorption of oxygen per litter of ventilation during exhausting work along with the more efficient elimination of carbon dioxide. This is accompanied by an increased ability to attain a greater minute volume of ventilation partly due to the increase in the surface of alveoli, thereby increasing the area from which oxygen can be absorbed.

A greater mechanical efficiency of the system is effected due to the increased flexibility of the chest and a strengthening of the respiratory muscles. The lungs do their work as a result of the action of the diaphragm. Like other muscles, the more they are exercised, the stronger and more efficient they become. At the same time the volume of the blood is reduced by as much as one-fourth with some of the fluid being forced out of the blood vessels into spaces in the tissues. This process permits a higher concentration of blood and enhances its oxygen-carrying capacity.

The efficiency of internal respiration also increases. The amount of oxygen and carbon dioxide per unit of blood exchanged between the blood in the capillary system and the muscle cells is enhanced through a more efficient rate of oxygen utilization by the tissues.

Benefits of Exercise to the Muscular System

The muscles themselves develop in strength, power, and endurance, which thereby results in improved muscular performance. First, an increase occurs in the size of the muscle, which is known as hypertrophy. This increase is due in part to the smaller and unused fibres becoming functional. The elastic walls of the muscle fibres, called sarcolemma, grow thicker and correspondingly tougher. The connective tissues within the muscle itself also increase in amounts. These changes not only enable the muscle to become stronger but also better able to withstand the strain of hard work and emergencies.

Along with the increase in the size of the muscle, there is also an increase in the strength of the muscle since strength is in proportion to the muscle's effective cross-sectional units. The stronger the muscle, the more likely work will be performed by parts of the muscles acting in relays while other parts rest. This permits some muscle units to rest and recover, while other units carry the

load, and thus enables the individual to do more work over a longer period of time.

Exercise enhances the quality of the muscular contraction. It functions more smoothly and contracts more forcefully with less effort, thereby developing the ability to sustain effort. With the increase in size and strength of a muscle there is a gain in endurance that is out of proportion to its gain in size.

The trained muscle becomes more efficient in using oxygen and more effective in combating fatigue through utilizing more efficient chemical reactions. Both aerobic and anaerobic capacity is increased. Since fatigue is produced by waste products building up in the muscles and by a lack of oxygen in the cells, the more efficient cardiovascular system can prolong the time for the onset of fatigue. There is less of the main by product of exercise (lactic acid), and also there is more efficient resynthesizing of lactic acid for reuse. There are also greater amounts of glycogen in muscle cells for energy.

Also, through exercise the postural muscles can be kept toned and strengthened; this can lead to improved posture and reduced fatigue. In this regard an important point is that although one's body type is an inherited characteristic, one's "figure" is built through exercise and diet control.

Intracellular Regulation of Energy Metabolism During Exercise

The cell's metabolic pathways are regulated by multiple complex mechanisms, including both intracellular and endocrine regulation. Dozens of enzymes catalyze the important steps involved in the cell's metabolic pathways. The most important sites of energy system regulation are at the rate limiting steps of these energy systems. A rate limiting step is the slowest step in a series of reactions. For example, consider a series of reaction in which A is converted to D in a series of steps:

$$A \rightarrow B \rightarrow C \rightarrow D$$

If the rate limiting step in the following series of reactions is the formation of C from B, then speeding up, or slowing down, the transition of A to B or C to D will have no effect on the overall process. The only reaction that has the potential to speed up or slow down the conversion of A to D is the rate limiting step (B to C). The enzymes that catalyze the rate limiting steps of metabolic pathways are therefore referred to as rate limiting enzymes. For example, the rate limiting enzyme for glycolysis is phospho-fructo-kinase (PFK). If PFK is stimulated then glycolysis proceeds more quickly, if PFK is inhibited then glycolysis proceeds more slowly.

Benefits to Other Vital Organs and the Nutritive System

The benefits of exercise and training are not relegated to the cardiovascular, respiratory, and muscular systems. Exercise tends to benefit other organs and functions. The digestive system along with the excretory system increases in efficiency as greater demands are placed on them through exercise. There is not only an increase in efficiency of these organs, but also an increase in size so that digestion, assimilation, absorption, and elimination are all improved.

The endocrine glands are related to the effects of exercise. The adrenal glands increase in size and efficiency. The epine-phrine and norepine-phrine secreted by these glands enable the individual to sustain muscular activity more efficiently over a longer period of time, Epine-phrine activates the muscular functions more efficiently and the higher output of norepine-phrine provides increased energy. Exercise also enhances the output of hormones from the pituitary gland, which in turn aids in the further production of epine-phrine.

Muscular exercise increases the capacity of the cells to build their nutritive powers. Use of the muscles and the functioning of the power-building cycle are closely related. Through exercise the glycogen is burned. Heat and energy are released. This brings on a demand for more oxygen and food materials from the blood. There is an increased efficiency in the elimination of waste. The economy in function of the internal organs increases since them all share either directly or indirectly in this power building cycle.

Even the nervous system, acting as a controller to the patterns of movement involved, is strengthened and receives many other benefits from protracted exercise. In childhood and youth, exercise and physical activity are the chief means by which the mental powers develop (See Chapter 14). Throughout life, physical activity is perhaps the best antidote for tensions and stresses brought on by complex living behavior, and thus it enhances mental health.

With this we come to end to todays lecture. I hope this must have enhanced your knowledge about this important topic.thank you very much. Have a good day.