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Introduction

Exercise is one of the greatest energy stresses that an organism is likely to encounter. Like other stresses, severe exercise has the potential to disrupt homeo stasis. Every cell requires a certain amount of energy for life-sustaining processes. Thus, any disruption of cellular energy homeo stasis is potentially fatal for the cell. Fortunately, we have evolved several potent mechanisms to maintain cellular energy homeostasis. Nearly every change in our body's physiology during exercise is cantered on maintaining cellular energy homeostasis. For example, the increases in ventilation and cardiac output are meant to increase oxygen delivery to the mitochondria in active tissues, where oxygen serves as the final electron acceptor in the electron transport chain. The importance of energy metabolism during exercise is also illustrated by the fact that many of the possible causes of fatigue are related to cellular energy metabolism.

The energy that allows us to perform life-sustaining processes, accomplish work, grow, and maintain body temperature ultimately comes from our food stuffs. However, the energy contained in our food stuffs is not readily accessible as a source of energy for the energy requiring processes of the cell. The energy from our food must first be converted to a common energy currency; ATP or Adenosine triphosphate. It is thus, ATP that serves as the immediate energy source for muscular work. Because muscle ATP concentrations are very low, during exercise, the production of ATP, sometimes at very high rates, is of the highest priority.

If exercise physiology were a story, the plot would centre on energy and work. It is thus of extreme importance for exercise physiology students to understand the basic principles and concepts related to exercise metabolism. By this time students have already learned in their introductory biology, human physiology, and exercise physiology courses about the following basic cellular metabolic processes: the ATP-PC system, glycolysis, glyco-genolysis, gluconeo genesis, lipolysis, beta oxidation, the tri-carboxylic acid cycle, and the electron transport chain. It is recommended that students review these processes before coming to lab. These processes will only be discussed briefly in order to help students understand the "big picture" of exercise metabolism; a complete review of these processes is beyond the scope of this lab. Today's laboratories experiments are meant to help students better understand those factors (e.g. exercise intensity, duration, etc) that determine what fuel sources and metabolic pathways are contributing to an exercise bout.

Exercise as a Metabolic Stress

At rest, almost all of our energy is coming from aerobic metabolism, and results in an oxygen consumption of around 3.5 ml/kg/min, or about 0.25 L/min in an average human. Assuming a caloric equivalent of 5 kcal/L, this means that, at rest most of us expend about 1 to 1.5 kcal/minute. An average college age male can reach energy expenditures of 15-20 kcal/minute at maximal exercise. Olympic rowers average 36 kcal/min during a simulated 2000m race (5-7 minutes) and can attain energy expenditures up to 40 kcal/min during training and competition – a 40-fold increase in energy expenditure above rest! Of course these high rates of energy expenditure cannot be sustained for long periods of time. Among the highest recorded daily energy budgets to be maintained for more than a few days are for cyclists participating in the Tour de France where daily energy expenditure was around 7,000 kcal/day for 22 days. This is almost 4.5 times the typical basal metabolic rate (1,600 kcal/day) for these athletes. Clearly, exercise places extreme demands on the body's energy systems. For example, it has been demonstrated that flux through the citric acid cycle or Krebs cycle can increase over 100-fold during moderate to high intensity exercise.

Sources of Energy

The only direct source of energy for triggering muscular contraction and hence movement is adenosine triphosphate or generally called ATP. ATP cannot be stored in the cells in large quantities. Therefore, it is in short supply in the muscle cells and it must be constantly recreated or resynthesized. This process of resynthesis of ATP after it has been broken down to adenosine diphosphate ADP in the process of triggering movement also requires energy. The most commonly used sources for this acid is creatine phosphate. In the final analysis, most energy fuel for this purpose is derived from carbohydrates and fats.
With the use of energy from these sources, the resynthesis of ADP and ATP is accomplished through either one of three systems. These systems are:

1. The ATP-PC systems,
2. The oxygen system (aerobics)
3. The lactic acid system (anaerobics).

Ultimately, oxygen is needed for the release of all the energy sources.

The Energy Pathways of Exercise

Muscle cells are unique with respect to their capacity to use oxygen. Which one of the resynthesis systems or energy pathways used at any given time depends on several circumstances including the amount of oxygen present at that time. For example, aerobics means muscular work in the presence of oxygen while anaerobics implies in the absence of oxygen. The aerobic processes can use all of the sources of energy listed in the above unit except creatine phosphate. The anaerobic system can use only glycogen. The ATP-PC system is the simplest and most direct and uses only creatine phosphate.

However, all three systems operate in a similar manner. When the energy resulting is used to re-form or resynthesize ATP. There is a continuous cycle as fast as ATP is broken down to ADP during muscular work, it is being resynthesized from the ADP by the energy liberated by one of the three systems mentioned above.

Both the chemical or metabolic pathways (the lactic acid system and the oxygen system) operate through the process of glycolysis. This is the chemical breakdown of glycogen to pyruvic acid to produce energy for the resynthesis of ATP. As long as there is sufficient oxygen in the cells for oxidation, aerobic glycolysis is employed and all three sources of foods (glucogen, glycerol and fatty acids) are broken down. When the demands of metabolic processes exceed the oxygen available, anaerobic, glycolysis prevails. In this case, glycogen is the only source of blood used.

The ATP-PC System

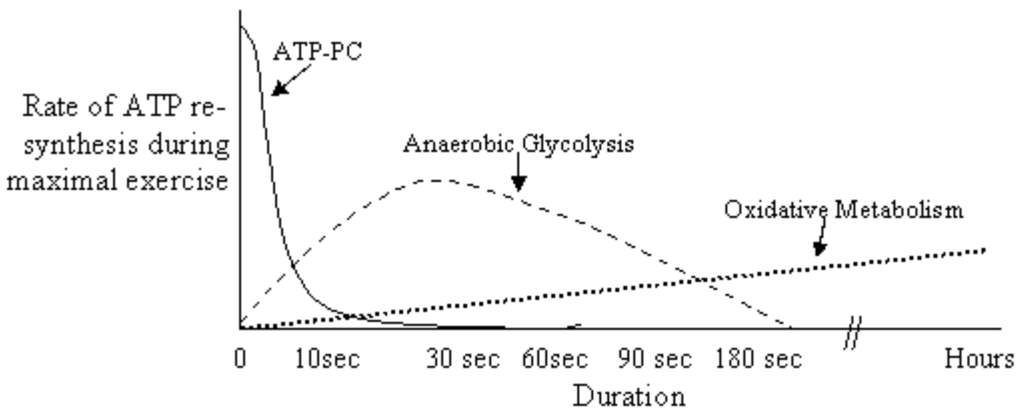


Figure 1. Relative role of the different energy systems in making ATP during maximal exercise of different durations.

The simplest of these systems is the ATP-PC system since it oparates in the absence of oxygen without a build-up of lactic acid. The energy derived from this process is a result of the breakdown of phosphocreatine with phospate and creatine as by-products. However, phosphor-creatine, like ATP, is in short supply and can soon be depleted after a short period of time, usually one minute or less. It is like ATP in another way. It, too, has a phospate group and when its bound are broken, a large amount of energy is released. Therefore, it can provide immediate powerful bursts of activity but such activity must be followed by rest to replenish the phosphor-creatine. Normally, rest periods must be from three to four times longer than the duration of the activity until other systems can take over.

The Oxygen System (Aerobic)

In the process of aerobic glycolysis, glycogen is broken down to furnish the energy to replenish ATP. During this process, water and carbon dioxide are librated to be transported to the elimination centres. As long as an adequate supply of oxygen is available for combustion in the oxidation cycle, exercise can continue indefinitely because the triggerer of muscular contraction. ATP, is continuously being resynthesized within the minute power stations of the muscle tissue called mitochondria. In this process there is little accumulation of lactic acid in the muscle tissue because in the aerobic processes the energy used to resynthesize ATP is derived from a breakdown of glycogen to pyruvic acid. pyruvic acid then goes through chemical reactions in the mitochondria known as the Krebs Cycle where oxygen is used continuously for energy to re-form ATP. In this matter ATP can be replenished constantly without the accumulation of lactic acid, and the three foods can be broken down completely yeilding a large amount of ATP molecules.

To further complicate the picture of energy release, neutral fats instead of glucose may be used in the aerobic glycosis process to provide the needed energy for ATP resynthesis. Tri-glycerides are broken down into glycerol and fatty acids. Glycerol then enters the glycolytic pathway and in the usual manner as glycogen, is used for purpose of resynthesis. Fatty acids, however, must go through the Kerbs Cycle for oxidation similar to pyruvic acids before they can be used for regeneration of ATP.

The Lactic Acid System

For longer periods of exercise without oxygen and too long to be handled by the ATP-PC system, the Lactic Acid system using anaerobic glycolysis prevails. In this case during the process of resynthesizing ATP, glycogen is broken down to pyruvic acid. Since sufficient oxygen is not available, anaerobic glycolysis continues to break down glycogen but pyruvic acid spills over in the tissues and accumulates as lactic acid. Lactic acid leads to fatigue shortly and eventually to exhaustion.

There is something unique about the body's use of oxygen. While other body cells do not have the capacity to tolerate a deprivation of oxygen even for a short time, muscle cells do. Therefore, they are different because they have the capacity to tolerate a temporary deprivation and incur an "oxygen debt." When the intensity or duration of the exercise require more oxygen than can be made available by the cardiovascular-respiratory system, the muscular metabolism system achieves an anaerobic state so that exercise may continue for a period of time without sufficient oxygen. However, during such exercise, there is an accumulation of lactic acid which eventually results in muscular fatigue and exhaustion. Also, the amount of energy released by anaerobic glycolysis is approximately 20 times less than that produced by aerobic glycolysis.

The process of converting glycogen into lactic acid is reversible. The major portion of the glycogen used in anaerobic glycolysis during exercise can be resynthesized during rest by the liver, but this process takes time. During exercise and afterwards, the lactic acid diffuses out of the cells and into the blood stream. Some of it may be temporarily neutralized by buffers in the blood and some is carried to other parts of the body remote from the exercising part. Smaller amounts may be excreted by the elimination centres. However, since the first two of these are temporary measures, eventually all lactic acid in the body must be oxidized. Much of it is carried to the liver for re-synthesis into glycogen to be disturbed into the blood-stream once again.

The foregoing explanation indicates why an aerobic activity can be carried on for a longer period of time than an anaerobic activity-the build-up of lactic acid is much less. However, in the anaerobic processes following a rest or during mild activity, the deficiency in oxygen can be overcome and the oxygen debt can be re-paid through increased activity of the cardiovascular-respiratory system.

In summary, under a "crest" load type of exercise, oxygen requirements of the muscle cells equal the oxygen uptake, and the respiratory system effectively exchanges oxygen and carbon dioxide to meet the needs of the cells. Little lactic acid will be formed in the tissues because there is an adequate supply of oxygen in the mitochondria for oxidation in the Krebs cycle for aerobic processes. However, when the intensity of exercise is increased beyond the "crest" load, the demand for

Oxygen, which cannot be stored in the cells, is not transported by the circulatory system fast enough for the aerobic processes to prevail alone. Pyruvic acid continues to be broken down through glycolysis to resynthesize ATP but the lactic acid which is not oxidated in the mitochondria spills over into the cells and accumulates as lactic acid. Consequently aerobic glycolysis becomes a secondary source of energy production while anaerobic glycolysis predominates. Rasch and Burke suggest that both aerobic and anaerobic processes prevail during muscular activity but one or the other generally predominates.

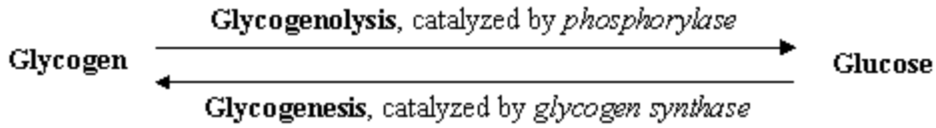
Implication of the Energy Pathways

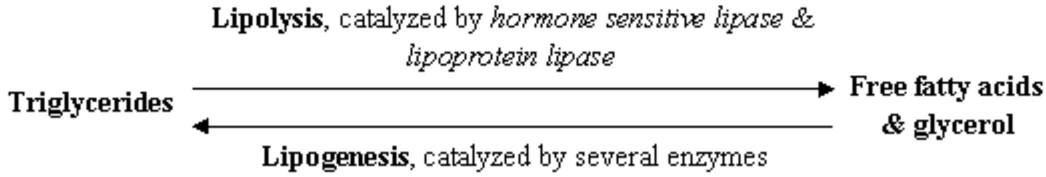
First, it is apparent that a trainee or performer does not require an immediate supply of oxygen for movement. In the absence of oxygen, the energy for synthesis of ATP can be derived from anaerobic sources.
Also, the ATP-PC system has no involvement in the lactic acid system but, of course, it can be employed only for brief bursts of activity before periods of rest in order to replenish phosphocreatine. For longer periods of activity in the absence of oxygen, the anaerobic lactic acid system prevails. However, if the activity extends beyond a few minutes and if the circulatory training effects are to be elicited, the major energy source would be aerobic glycolysis utilizing the oxygen-transport system.

Muscle glycogen depletion is a possible cause of fatigue during exercise lasting over 90 minutes. Thus, sparing muscle glycogen would benefit individuals during endurance exercise. Exercise training tends to increase the use of fatty acids as a fuel source, thus at any given intensity a trained individual has to rely less on glycogen; sparing their glycogen stores. There is some evidence that caffeine may spare glycogen stores by increasing reliance on fat metabolism (however there is also evidence that caffeine does not spare muscle glycogen). Carbohydrate ingestion during exercise also tends to spare glycogen by providing another source of glucose for glycolysis.

The fatty acids used to produce energy by skeletal muscle are derived primarily from adipose tissue tri-glycerides, and to a lesser extent from intramuscular triglycerides. It should be noted that triglycerides (TG) must be broken down before they can be used as a fuel substrate. The degradation of TG into fatty acids and glycerol is called lipolysis. Inside the cells, lipolysis is catalyzed by the enzyme hormone sensitive lipase (HSL). A different lipase, lipoprotein lipase (LPL), catalyzes the breakdown of TG in the circulation and allows adipose cells to take up fatty acids from these circulating TG. Once fatty acids have been taken up by adipose cells they can be stored as TG, this is called lipogenesis. While both LPL and HSL are involved in triglyceride breakdown, they play very different roles in fat metabolism. LPL tends to increase storage of fatty acids in adipose tissue, whereas HSL mobilizes fatty acids so they can be used as an energy source by other tissues.

Summary of the storage and breakdown of carbohydrate and lipid fuel stores:





With this we end to todays lecture. I hope this must have added up your knowledge.thank you very much. Have a good day.