1.0 INTRODUCTION

The FISA CDP booklet titled BASIC ROWING PHYSIOLOGY provided information about the energy requirements of a rowing race. The information included a description of aerobic and anaerobic metabolism with an emphasis on the major systems and components of aerobic metabolism.

As this booklet will expand and not extensively review that material, the reader is encouraged to review the FISA CDP Level I booklet.

This booklet will present more information about metabolism. The reader is encouraged to review the FISA CDP Level I booklet and components of aerobic metabolism with an emphasis on the major systems and components of aerobic metabolism. The information included a description of aerobic and anaerobic metabolism of a rowing athlete and the energy requirements of a rowing athlete.

2.0 ENERGY FOR ROWING

The human body acts as an engine to propel the rowing boat across the water. The boat is propelled forward across the surface of the water by an athlete seated in the boat, applying force which propels the boat forward and backward on a sliding seat. The body, acting as an engine, produces power by the application of force which propels the boat forward. (See Figure 1.)
This process results in the production of energy for the muscle.

In the absence of oxygen, the muscle cells can produce energy via glycolysis. The process involves the breakdown of glucose to produce ATP and pyruvate. The pyruvate can then be converted to lactate in the absence of oxygen. This process is known as anaerobic glycolysis.

3.0 THE REPLACEMENT OF ATP

The replacement or resynthesis of ATP is generally considered to involve three processes:

1. ATP-CP Reaction
2. Anaerobic Glycolysis
3. Aerobic Metabolism

3.1 The ATP/CP Reaction

The stored CP in the muscle cell is a high energy substance similar to ATP. It can provide the energy to resynthesize ATP rapidly in the absence of oxygen and does not produce lactic acid. The process is considered to be anaerobic and is referred to as anaerobic metabolism.

3.2 Anaerobic Glycolysis

The production of energy in the absence of oxygen, which does produce lactic acid, is referred to as lactic anaerobic metabolism. This process was presented in BASIC ROWING PHYSIOLOGY as an important source of energy during the start and finish phases of the race. Although this process will provide energy for the start phase of the race, its contribution is a small percentage of the total energy requirements of the body during the rowing race.

3.3 Aerobic Metabolism

The process of energy production in the presence of oxygen is referred to as aerobic metabolism. This process involves the breakdown of glucose and other substrates to produce ATP and other end products. The end products of aerobic metabolism include carbon dioxide and water.

4. INTERMEDIATE ROWING PHYSIOLOGY

Figure 2. Production of Energy

Force is applied by the contraction of muscles which requires energy. The source of this energy is the breakdown of chemical bonds stored in the muscle cells. These chemical bonds are provided by chemical substances stored in the muscles:

1. ATP (adenosine triphosphate),
2. CP (creatine phosphate),
3. glucose (stored as glycogen), and
4. fats.

ATP is the only substance that can directly supply energy for muscle contraction. As the muscle cells contain enough ATP for only a few seconds, it is necessary to replace the ATP with other substances. The other substances are indirect sources of energy since they supply energy for the resynthesis of ATP.
It takes about 60-90 seconds to activate these two systems to provide sufficient oxygen to aerobically meet the energy requirements of the muscle cell during a rowing race. The systems of glycolysis and the breakdown of glycogen are either eliminated to the atmosphere or partially retained (water) to assist in body functions.

It should be noted that aerobic metabolism is actually two processes:

1. Lipid metabolism (the breakdown of fats), and
2. Aerobic glycolysis (the breakdown of glycogen).

Since lipid metabolism provides abundant energy, it is an important source of energy for training, but due to the fact that the reactions are very slow, it is generally not useful during a 2,000 meter rowing race. For this distance, aerobic glycolysis and its complete breakdown of glycogen is utilized.

As this process depends on the rate of oxygen in the muscle cell, they are utilized during the start and finish phases of the race. Although this system may provide energy for up to 2-3 minutes, it will only provide about 20-25% of the energy requirements of the rowing race.

Aerobic metabolism provides about 75-80% of the energy requirements of the rowing race. It involves the combustion of fuel in the muscle cell in the presence of oxygen. The energy is released from the breakdown of glycogen and the breakdown of fats stored elsewhere in the body and delivered to the muscle cell through the circulatory system (see figure 3).

Although the process is utilized primarily during the start and finish phases of the race, it is also used for prolonged periods. Therefore, the respiratory and cardiovascular systems must be capable of delivering oxygen from the air we breathe to the muscle cell.
The maximal total aerobic metabolic rate is an important measurement because of the relative importance of aerobic metabolism to rowing. This is demonstrated by the research findings illustrated in figure 3.

Another measurement that may be used to gauge the fitness level of the athlete and is useful in providing training assistance is the anaerobic threshold. Essentially, the energy requirements of the body exercising at a training load below this threshold will be met primarily by aerobic metabolism whereas exercising at a training load above this threshold places an increasing demand on the anaerobic glycolytic process. This is illustrated in figure 5.

The replacement of ATP during a rowing race is dependent on the interaction of the three processes:

1. the ATP-PC Reaction (less than 5%)
2. anaerobic glycolysis (20-25%)
3. aerobic metabolism (75-80%)

These three processes do not operate in isolation or independently but occur simultaneously and are integrated to provide the necessary energy to satisfy the requirements of the rowing race. This is illustrated in figure 4.
Although the determination of this measurement is not necessary to produce world class rowers, it does provide information to:

1. Assess the suitability of an athlete for the sport.
2. Determine the effect of a training programme.
3. Measure the athlete's rate of improvement.

The use of measuring physiological factors in determining the effect and rate of improvement due to a training programme has been illustrated in figure 6. The determination of maximum oxygen intake for international athletes in rowing is illustrated in figures 7 to 10.

Although the direct method is better, an indirect measurement method may be used to predict VO2 max. The prediction is made from the results of submaximal exercise and is based on the assumption that a relationship exists between VO2 and the rate of metabolism. The determination of VO2 max may be used to predict VO2 max. The prediction is as follows:

1. Step test: a test requiring a step up to and step down from a bench (33 cm and 40 cm high for women and men, respectively) at a rate of 30 steps per minute. The heart rate is monitored for two minutes following the minute, then the heart rate is used to read from the Astrand nomogram to predict VO2 max (see Appendix A).
2. Bicycle test: a test requiring a ride on a bicycle ergometer for a given submaximal work load that is sufficient to maintain a heart rate in excess of 120 beats per minute. The average pulse rate over the two minutes is used to read from the Astrand nomogram to predict VO2 max. This procedure is repeated for different work loads and the prediction can be made by extrapolation. The step test and bicycle test provide useful information, particularly for club level programmes. The step test is easy to administer and requires minimal equipment, and the bicycle test is more accurate for high VO2 max levels.

It is obvious that the purpose in training for rowing would be to increase the maximum oxygen uptake and ability to use a greater percentage of this level of performance. The scientific measurement of the energy system enables the coach to assess the athlete's training status and provide feedback. Some other methods to measure these processes and comments about the effects of training will be presented in the following sections.

4.0 MEASUREMENTS

The scientific measurement of the energy system generally requires the use of expensive equipment and experienced researchers. However, through the use of some simple techniques, useful information can be provided to the athlete and coach. The most common method used in rowing is to measure aerobic metabolism.

**4.1 VO2 Max / Testing of Aerobic Metabolism**

The most common method of determining the maximum oxygen uptake is to measure the VO2 max. The direct determination of VO2 max requires the use of expensive equipment and the assistance of an experienced researcher.
It should be remembered that the anaerobic energy system provides energy for short-term, intense exercise from the breakdown of glycogen and energy-rich substances. It is possible to test the capacity of this system using simple tests to provide some information about the capacity of this metabolic system. The testing procedures could be:

1. alactic anaerobic capacity: a maximum effort for about 10 to 15 seconds.
2. lactic anaerobic capacity: a maximum effort for about 30 to 90 seconds.

The method used would be to either compute the amount of mechanical work that can be performed in the specified time or record the time required to perform a given amount of anaerobic work by the use of:

1. lifting barbells,
2. performing exercises/calisthenics, or
3. using a rowing or bicycle ergometer.

The computation of the amount of mechanical work is generally the preferred method and is a simple procedure that may also be correlated with a more complicated procedure of the anaerobic capacity test. This latter procedure must be performed from the plateau of immediate oxygen uptake after the end of the effort to measure the lactate production of lactic acid produced during the test anaerobic effort. This procedure may be considered a more complicated procedure of the anaerobic capacity test.

The general method and a simple procedure may also be used. The computation of the oxygen of mechanical work is generally:

1. the lifting or bicycle ergometer.
2. the performance of exercises/calisthenics, or
3. the time of completion.

The work of the leg of the test is the amount that can be performed in the specified time of mechanical work. The method used would be to either compute the amount of aerobic work performed or record the time required to perform a given amount of aerobic work. The leg of the ergometer may be considered a maximum effort for about 90 seconds.

2. peak anaerobic capacity: a maximum effort for about 10 to 15 seconds.
3. peak anaerobic capacity: a maximum effort for about 30 to 90 seconds.

If the ergometer system is used, the testing procedure could be:

1. the ergometer test.
2. the bicycle test.

Some simple tests are provided in the appendix of the test procedure. It is possible to perform some simple tests to provide some information about the capacity of oxygen uptake and energy use in the body. This information can be used to improve the performance of the athlete.
4.3 Testing of Anaerobic Threshold

Anaerobic threshold, as explained in section 3.4, is a metabol-ic response to an increasing work load when aerobic energy production is augmented by anaerobic energy production to meet the energy needs of the body during rowing. The anaerobic threshold is a controversial scientific measurement, yet its determination may have some practical applications in the sport of rowing.

The anaerobic threshold is observed by determining the change in lactate accumulation in the blood or the change in ventilatory response during periods of increasing work loads. (The volume of air going into and out of the lungs is called ventilation.) Although not as exact, another method is recording heart rate during increasing work loads. This non-invasive technique is based on the principle that, during continuous and progressive increasing work loads, the heart rate will change (or exceed) the anaerobic threshold. The increase in heart rate is a result of increased work loads. This increase in heart rate is observed by an increase in work per minute. Another method is observing heart rate by placing a sensor on the wrist or neck, or by inserting a catheter into the blood stream.

The increasing work load may be either an increase in work performed on an ergometer (rowing or cycling) or an increase in velocity in rowing, skiing, or running. Again, this procedure is of practical assistance, particularly during training. This assistance will be explained in the next section.

5.0 TRAINING METHODS

The FISA CDP has emphasized the importance of training the aerobic metabolic system as this system provides about 75-80% of the energy needs of the body during a rowing race. In BASIC ROWING PHYSIOLOGY, the following training advice was presented:
2. Interval training at high training loads with sufficient rest periods to remove all or most of the accumulated lactate improves the body's ability to tolerate lactate accumulation. Since the alactic anaerobic metabolic system accounts for limited contribution to the energy requirements of the rowing race, the training of this system is generally restricted to late ... by multiple intermittent work periods of 10-15 seconds with recovery periods of 30-60 seconds between each work period. Further information about training methods for these systems is presented in the booklet titled SPECIFIC FITNESS TRAINING of the FISA CDP Level II programme.

6.0 SUMMARY

You should now have expanded your understanding of the physiological requirements of the sport of rowing. With this information, you will be able to provide better assistance to your athletes in the design and implementation of training programmes.

7.0 APPENDICES

7.1 Appendix A. Astrand Nomogram

The adjusted nomogram for calculation of maximal oxygen uptake from submaximal pulse rate and oxygen uptake values (cycling, running or walking) is shown. The middle curve represents the maximal oxygen uptake in the submaximal test on a work load of 200 watts. The adjusted nomogram is adapted from Textbook of Work Physiology, 2nd ed., by Per-Olof Astrand and Kaare Rodahl from McGraw-Hill Book Company, 1977.