CHAPTER II

LITERATURE REVIEW

Source of Energy

Energy should be viewed as the capacity of an athlete to perform work. And work is nothing else but application of force; the contraction of muscles to apply force against a resistance.

Energy is a necessary prerequisite for the performance of the physical work during training and competitions. Ultimately, energy is derived from the conversion of foodstuffs at the muscle cell level into a high-energy compound known as adenosine triphosphate (ATP) which is stored in the muscle cell. ATP, as it name suggests, is composed of one molecule of phosphate.

Energy required for muscular contraction is released by the conversion of high energy ATP into ADP + P. As one phosphate bound is broken ADP + P is formed from ATP and energy is released. There is a limited amount of ATP stored in the muscle cells thus ATP supplies must be continually replenished to facilitate continued physical activity.

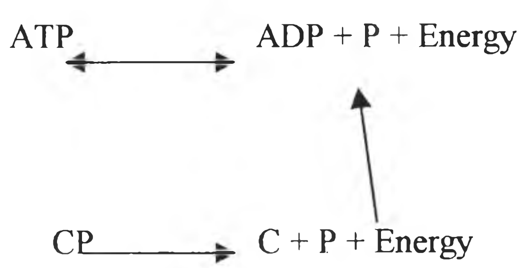
ATP supplies may be replenished by any of two energy systems, depending on the type of physical activity being undertaken as showed in figure 1. They are as follows: 1) The anaerobic system 2) The aerobic system

Energy system for exercise

1. The Anaerobic Systems

1.1 ATP - CP system (anaerobic alactic or phosphagen system)

Since only a very small amount of ATP can be stored in the muscle, energy depletion occurs very rapidly when strenuous activity begins. In response to this, creatine phosphate or phosphocreatine (CP) and phosphate (P). The process releases energy, which is used to resynthesize ADP + P into ATP a summarized as follows:



When these reactions occur without both oxygen and lactic acid, the process is called "anaerobic alactic". This is illustrated in Figure 1. on the 1^{st} line.

Since CP is stored amounts in the muscle cell, energy can be supplied by this system for about 8 - 10 seconds. This system is the chief source of energy for extremely quick and explosive activities such as 100m dash, diving, weight lifting, jumping and throwing events in track and field, vaulting in gymnastics and ski jumping.

1.2 The lactic acid system (anaerobic lactic or anaerobic glycolysis).

For events of slightly longer duration, up to approximately 40 seconds, which are still very intensive in nature (200m, 400m, in sprinting, 500m speed skating, some gymnastic events), energy is provided at first by the ATP - CP system and continued after 8 - 10 seconds by the lactic acid system. The latter system breakdown glycogen, a by-product called lactic acid (LA), is formed (di Prampero, 1981). When high intensity work is continued for a prolonged period of time, large quantities of lactic acid accumulate in the muscle causing fatigue, which eventually leads to a cessation of physical activity. This is illustrated in Figure 1. on the 2nd line and summarized as follows:

Glycogen + Glucose → G-6-P + Energy → Pyruvic acid

↓

Lactic acid

1.3 Anaerobic Power and Capacity

Many sports and every activity have energy demands, which must be met through the anaerobic breakdown of ATP - CP, and muscle glycogen.

Anaerobic power is defined as "the maximal rate at which energy can be produced or work can be done without a significant contribution of aerobic energy production".

Anaerobic capacity is defined as "the ability to persist at the maintenance or repetition of strenuous muscular contraction that rely upon anaerobic mechanism of energy supply VO_2" (Lamb, 1984)

Percent capacity of energy system (%)

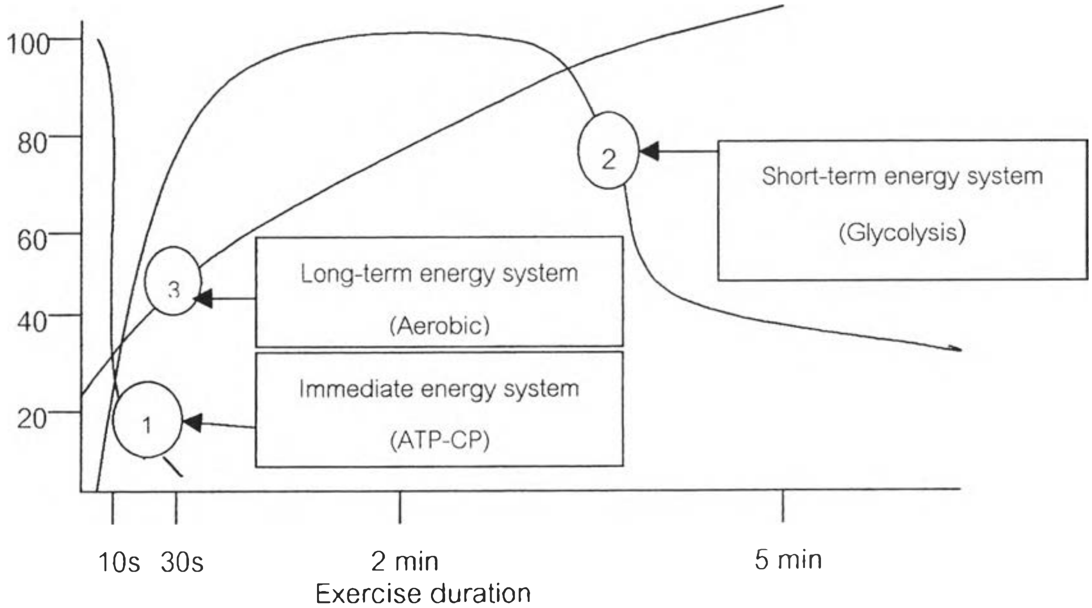
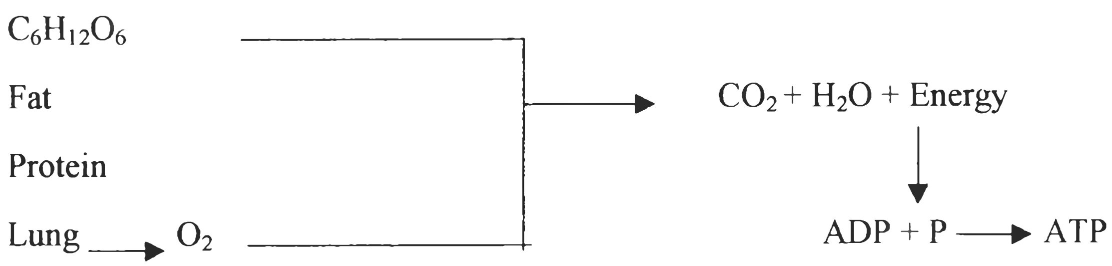


Figure 1. The three systems of energy transfer and their percentage contribution to total energy output during all-out exercise of difference durations. (From McArdle, 1996)

2. The aerobic system

Although energy release in glycolysis is rapid and requires no oxygen, relatively little ATP is resynthesized in this manner. Consequently, aerobic reactions provide the importance final stage for energy transfer, particularly if vigorous exercise proceeds beyond several minutes duration.

The aerobic system required approximately 60 - 80 seconds to commence producing energy for the resynthesis of ATP from ADP + P (This is illustrated in Figure 1. on the 3rd line). The heart rate and respiratory rate must increase sufficiently to transport the required amount of O_2 to the muscle cells in order that glycogen may breakdown in the presence of oxygen. Although glycogen is the source of energy use to resynthesize ATP in both the lactic acid and aerobic systems, the latter breaks down glycogen in the presence of O_2 and thus produces little or no lactic acid, enabling the athlete to continue the exercise for a long period of time. These system can be summarized as follows:



The aerobic system is the primary source of energy for events of duration between 2 minutes and 2 - 3 hours (all track events from 800 m on, cross-count y skiing, long distance running etc.).

The ability to sustain high intensity exercise is recognized to dependence on Maximal oxygen uptake (VO_2 max) and Anaerobic threshold. Many studies have shown that the anaerobic threshold (AT), regardless of its precise definition is a good index of the exercise performance in aerobic events and that it represents the subject is aerobic work capacity in a more accurate way than VO_2 max are highly correlated variables (Wasserman, 1984)

Maximal Oxygen uptake (VO_2 max)

The best approach to the assessment of cardiopulmonary fitness was the direct measurement of VO_2 max during exhausting work such as uphill treadmill running, stepping or pedaling a bicycle ergometer (Bucher, 1983, Jenson and Fisher, 1979).

1. <u>VO_2 max Definitions</u>

Maximal oxygen uptake (VO_2 max) is quantitatively equivalent to the maximum amount of oxygen that can be consumed per unit of time by an individual during large-muscle-group activity of progressively increasing intensity that is continued until exhaustion is called the maximal oxygen uptake (VO_2 max). When expressed in terms of oxygen, it is normally written as the maximum (max) volume per minute (V) of oxygen (O_2) and is abbreviated VO_2max (Lamb, 1984). It is usually reported as an absolute volume per minute (L/min) for sports such as rowing, in which total work output is important, and as a volume per minute relative to body weight (ml/kg/min) in activities such as cross country running, in which the body weight is supported during the performance. (Lamb, 1984)

The term VO_2max was synonymous with the term maximal oxygen consumption, maximal oxygen intake or maximal aerobic power and represented the greatest difference between the rate at which inspired oxygen entered the lungs and the rate that expired oxygen leaves the lung (Lamb, 1984) or the maximal amount of oxygen in the body that could process during exhausting work (Jones, 1985, Jones, 1988). It involved an increase in the oxygen uptake to the highest level of activity, which the ability of individual to utilize the greatest amount of oxygen was reached (Astrand and Rodahl, 1986).

2. VO_2max Determination

The direct measurement of VO_2max was determined by the remaining subjects during graded treadmill walking or jogging or during bicycling. Expired gas was collected and analyzed by using gas analyzer. VO_2max had been determined from the graph of oxygen uptake against of oxygen uptake with an increasing in workload as shown in figure 2. (Yerg et al, 1985).

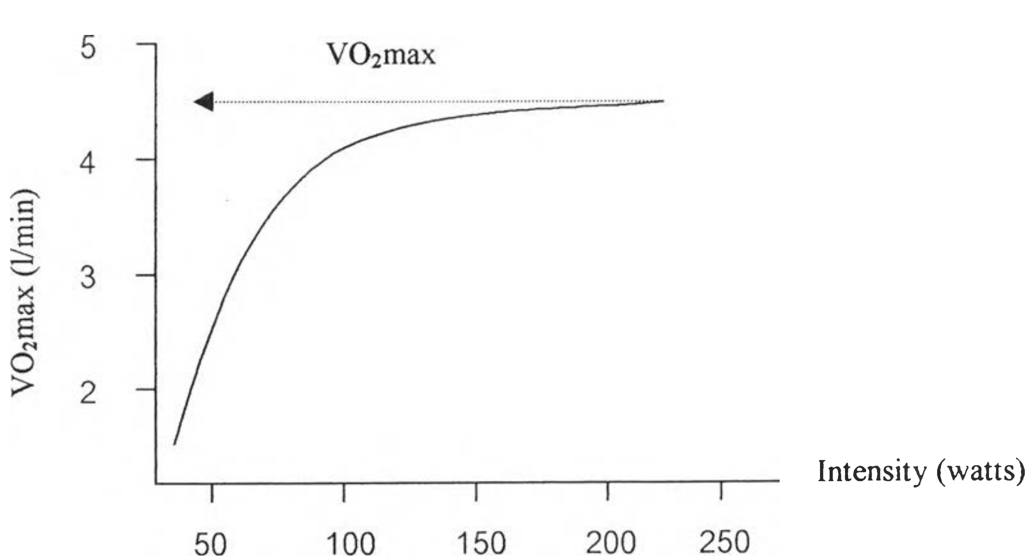


Figure 2. The direct measurement of VO_2max was obtained from oxygen uptake against time (From Astrand And Rodahl, 1986)

Another indirect method, VO_2max was determined by measurement of heart rate at submaximal test (Astrand and Rodahl, 1986) or running/cycling exercise test and detected capacity from time (Cooper, 1970).

Anaerobic Threshold

The anaerobic threshold has become a valuable measurement in the assessment of cardiovascular and pulmonary function, significantly the peak work load or oxygen consumption at which oxygen demands exceed the circulation's ability to sustain aerobic metabolism that effect from endurance training (Jacobs, 1986; Wasserman, 1986; Kumagai, Nishizumi and Tanaka, 1987).

1. Anaerobic Threshold Definitions

Even among texts in English has plethora of terminology used to refer to discontinuities in blood lactate or ventilation during incremental exercise and to the presence or absence of steady-state conditions during constant-load exercise. These terms include lactate threshold (Wasserman 1987, Wasserman and McIlroy 1964), aerobic-anaerobic threshold (Karlsson, 1983), onset of blood lactate accumulation (OBLA) (Farrell et al., 1979), heart rate deflection (Conconi, 1982), and aerobic threshold and anaerobic threshold (Skinner, 1980).

Skinner and McLellan (Skinner and McLellan, 1980) and Kinderman (Kindermann, 1979) have independently suggested that that there are at least two apparent points of discontinuity in the blood lactate/ventilatory response to incremental exercise that may serve as general concepts for many of the terms used by other authors. The first of this in associated with the first sustained increase in blood lactate above resting values and with the first discontinuity in ventilation represented by an increase in VE relative to VO_2. Given the biological "noise" in relation to blood lactate concentration, this point is often consistent with a blood lactate concentration of about 2.0 mM. In the nomenclature of Skinner-McLellan-Kinderman this point is the aerobic threshold (AerT). The second of the discontinuities is represented by a very rapid increase in blood lactate concentration relative to both VO_2 and VCO_2. It is 4.0 mM. In the nomenclature of Skinner-McLellan-Kinderman this point is the anaerobic threshold (AT).

Wasserman and McIlroy introduced the concept of anaerobic threshold by using the respiratory gas exchange ratio to detect the onset of anaerobic metabolism for determining the work load or level of oxygen uptake at which the cardiovascular system failed to supply the oxygen requirement of active muscle (Wasserman and McIlroy, 1964). The basis of this point was that the metabolic acidosis caused by lactate accumulation. Determination could get by gas exchange parameters, which were oxygen uptake, carbon dioxide output and expired ventilation (non-invasive method). Examples include the detection of carbon dioxide from buffering during an incremental exercise test (Wasserman, Van Kessel and Burton, 1967; Beaver, Wasserman and Whipp, 1986). The definition of anaerobic threshold is the level of work of oxygen uptake just below the point of metabolic acidosis and the associated changes in gas exchange was occurred (Wasserman, Whipp, Koyal and Beaver, 1973; Orr, Green, Hughson and Bennett, 1982; Wasserman, 1986; Yeh, Gardner, Adam, Yonotz and Grapo, 1983).

2. Anaerobic Threshold Hypothesis

Anaerobic threshold has been defined as the level of oxygen above aerobic energy production, which is supplemented by anaerobic metabolism (Wasserman, 1984; Stremel, 1984). The hypothesis requires:

2.1. The oxygen requirement by the metabolically active muscle could exceed the O_2 supply to the mitochondria when the workload become sufficiently high.

2.2. The imbalance between the O_2 supply and O_2 requirement (O_2 requirement greater than O_2 supply) brought about a net increase in anaerobic oxidation in the cytosol of the cell with pyruvate conversion to lactate (Figure 3.).

2.3. Lactate was buffered in the cell primarily by HCO_3- (Figure 4.).

2.4. The CO_2 generated from buffering increased CO_2 output while HCO_3- exchanged for lactate across the muscle cell membrane according to the new electrochemical; and

2.5. The buffering and acid-base disturbances produced predictable changed in gas exchange (Mader and Heck, 1986; Wasserman, William and Whipp, 1986; Yoshitake, Zaiki, and Shoji, 1987).

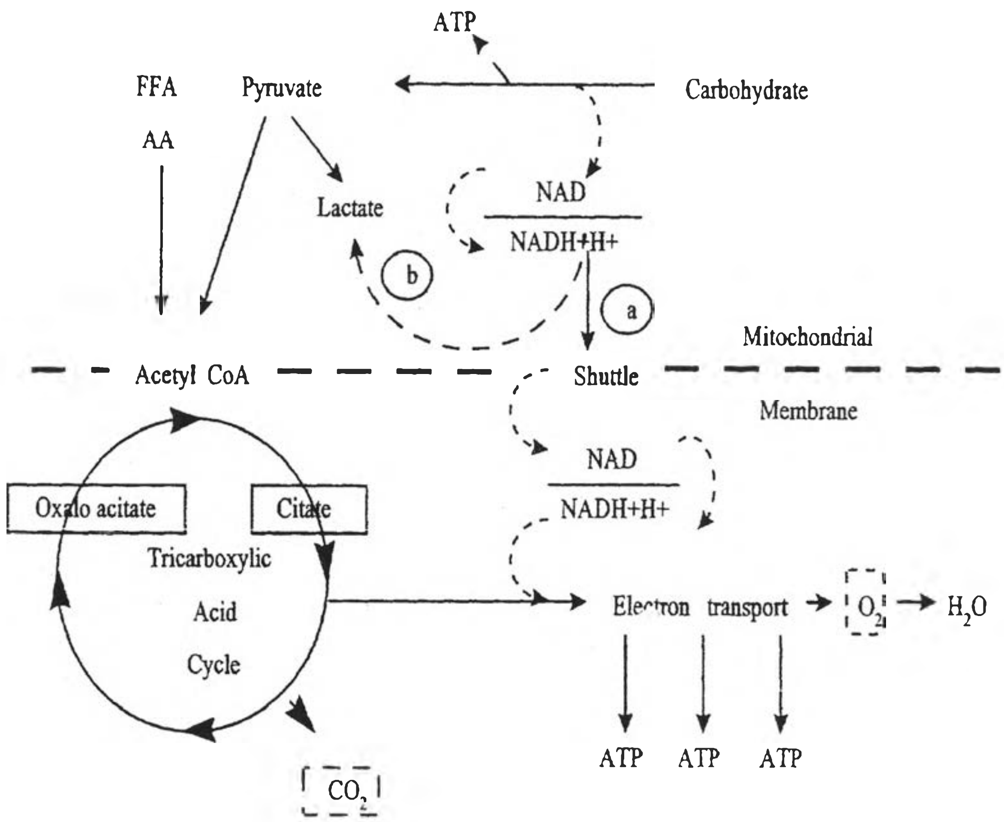


Figure 3. Metabolic pathway leading to production of ATP. Increased cellular production of lactate depends on the mechanism of reoxidation of cytosolic NADH.

(a) : when the O_2 supply to the mitochondrion is sufficient, NADH is reoxidized through the proton shuttle to the mitocondrial membrane.

(b) : when the O_2 supply to the mitochondrion is inadequate for reoxidation by the proton shuttle, pyruvate reoxidizes NADH, resulting in an accumulation of lactate and change in cytosol redoxing state (Modified from Wasserman. 1986).

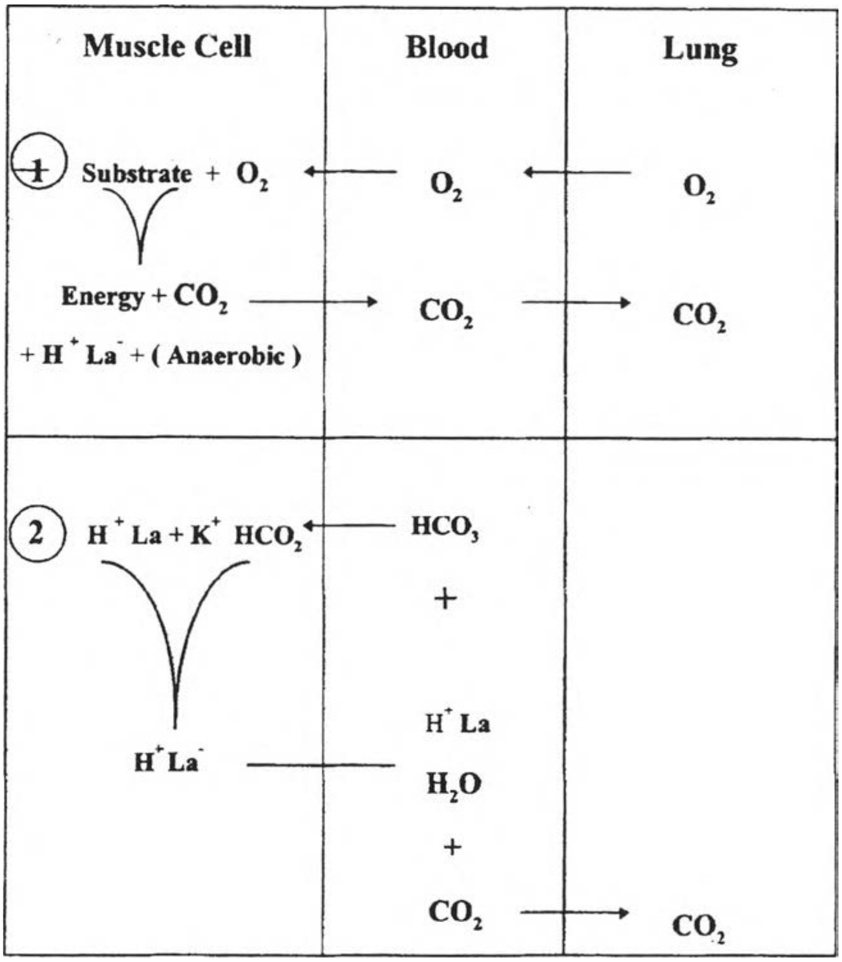


Figure 4. Mechanism of blood bicarbonate buffering.

(1) :aerobic metabolism results in CO_2 production with a proportionality to O_2 consumption.

(2) :cellular buffering of increase in anaerobic lactic acid production, associated with an increase in anaerobic glycolysis, has an immediate by-product of CO_2 .The cellular increase in lactate and decrease in HCO_3- stimulates anion exchange between cellular and extracellular water, causing blood lactate to increase and HCO_3- to decrease (Modified from Wassserman, 1986).

3. Anaerobic Threshold Determination

Research evidence in the area of exercise physiology reveals that there is metabolic threshold during a graded exercise test (Reinhard et al., 1979). The theoretical considerations underlying these thresholds are as follows. Consider an individual who is being administered an exercise test in which the intensity is gradually increased from rest to maximum at regular intervals. Initially, because of the low energy requirement to supply the energy aerobically, without the production of any lactic acid. As the exercise intensity is gradually increased, the energy requirements also increase proportionately, until a situation is reached where the energy requirements of the exercising muscles cannot be supplied completely aerobically. Therefore, apart of the energy is derived anaerobically, resulting in the production of lactic acid (Bhambhani and Singh, 1985).

3.1 Invasive Measurement of Anaerobic Threshold

3.1.1 Lactate Method

At the point anaerobic threshold, energy release from anaerobic metabolism was increased and lactic acidemia resulted. Thus the occurrence of the anaerobic threshold during a progressive exercise bout signifies insufficient oxygen delivery to active muscle (Hollmann, 1985). Many researchers stated that lactate concentration was reached 4 mM in peripheral blood, that was acceptable meaning of blood lactate level at anaerobic threshold point by invasive method (Whipp, Ward and Wasserman, 1986, Stegmann and Kindermann, 1982).

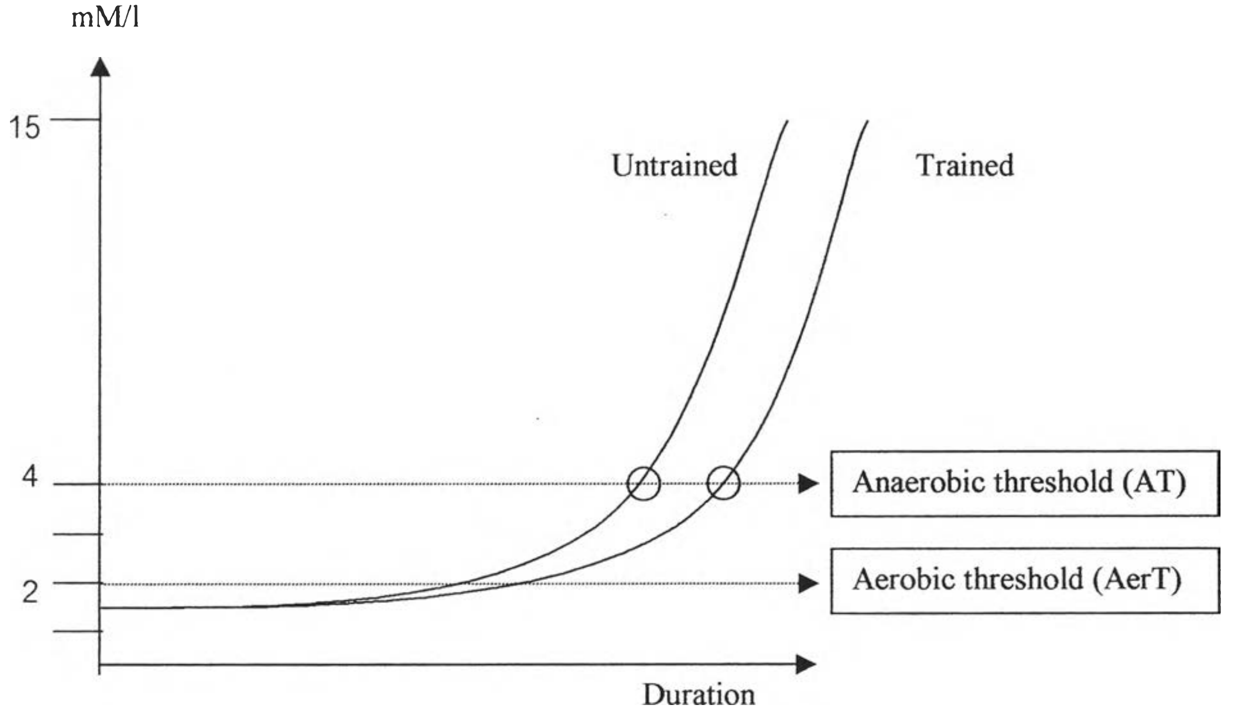


Figure 5. Blood lactate concentration at different levels of exercise expressed as a percentage of duration for trained and untrained subjects. (Modified from Beaver, 1985)

3.2 Noninvasive Measurements of the Anaerobic Threshold

3.2.1 Gas exchange analysis.

Although the onset of metabolic acidosis during exercise had been determined by serial measurements of blood lactate, the abrupt increase in arterial lactate might now be determined by non-invasive methods as gas exchange (Davis et al., 1979; Davis, 1985). This method correlates well with the lactate level and obviates the need to measure lactate in repeated blood samples (Arkarapanth, 1988)

The physiology underlying an anaerobic threshold involves a temporary metabolic acidocid was compensated by a respiratory alkalosis. Lactic acid was produced and buffered by bicarbonate in blood (Wasserman, 1986). Carbon dioxide was released excessively by energy metabolism. As a result of an increase carbon dioxide production (VCO_2), the lower pH of blood, and/or volume of expired gas (V_E) exhibited a break point in linearity. At an anaerobic threshold point, the V_E and VCO_2 increased out of proportion to the work load performance, that they increased more abruptly than expected (Wasserman, 1973; Fukuba and Munaka, 1987). This nonlinear regression was difficult to identify an anaerobic threshold. Recently, a new method was combined in their study for determining an anaerobic threshold (Figure 6 and 7).

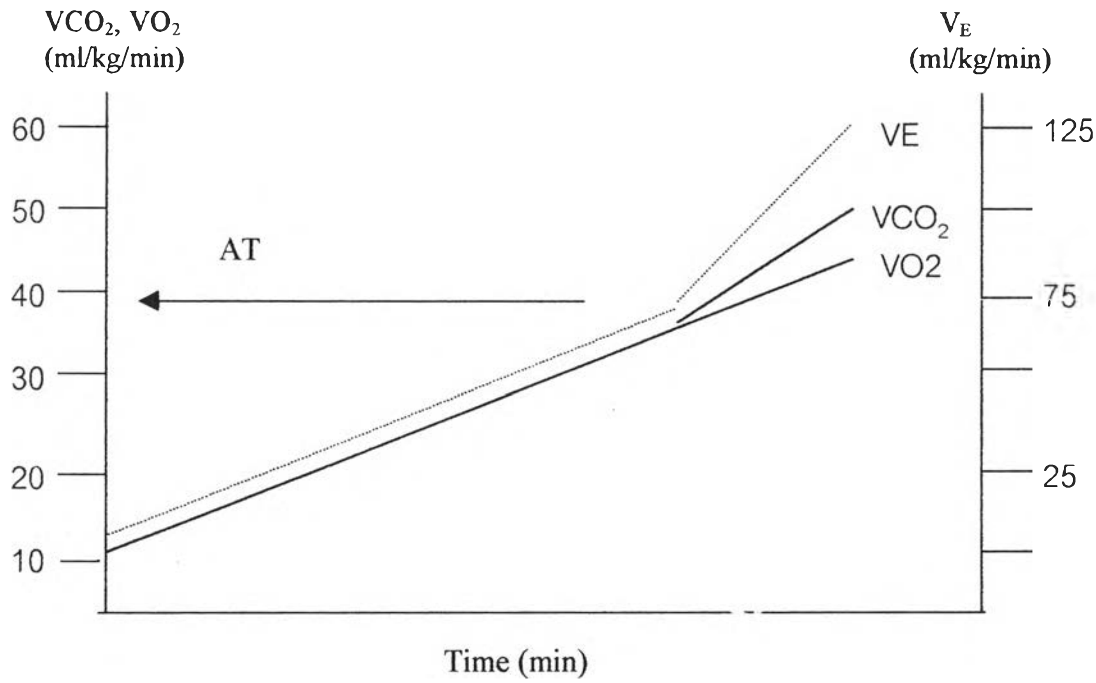


Figure 6. The first criteria used to determine anaerobic threshold was defined as the point that VCO_2 and V_E started to non-proportional to the work load, while VO_2 graph still had a linear increase (Modified from Chick and Somet, 1988).

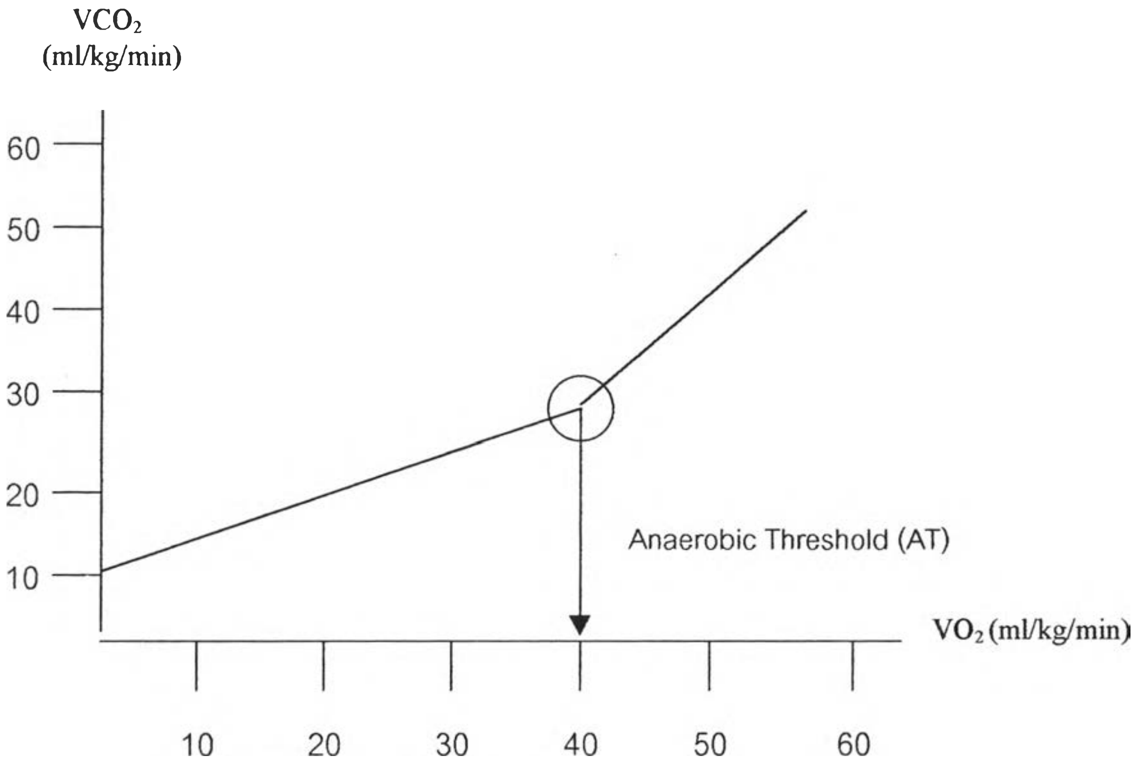


Figure 7. The second criteria used to determine anaerobic threshold was called V-slope method. Anaerobic threshold was determined at the point that the slope VO_2 against VCO_2 graph started to change (Modified from Beaver, Wasserman and Whipp, 1986).

3.2.2 Conconi's Method

Prof. Conconi made use of the existing correlation between exercise intensity and HR (Coconi, 1982; Heck, Mader and Hess, 1985; Probst, 1988; Janssen1989). He found, as other investigators had found before, that with very intense exercise the HR/intensity relationship is no longer linear. The straight line deflects at high intensities. In other words: the intensity may be increased but the increase of HR lags at a certain point (Figure 8). This point is the HR deflection point. The exercise intensity corresponding to this point is the maximum activity that can be done with aerobic energy supply. The deflection in the curve marks the HR or exercise intensity (e.g. the speed of running or cycling) beyond which the athlete obtains a large amount of energy via anaerobic pathways. In this way, Coconi could exactly establish the speed that Moser had to maintain without getting exhausted prematurely.

The deflection point marks the maximum speed that can be maintained for a long period of time. It is the highest speed or HR that can be supported aerobically. If the speed increased further an accumulation of lactate will occur. In this situation, the aerobic energy supplying system does not suffice; the anaerobic system is called upon with the result of an increasing accumulation of lactate. In fact, the anaerobic system is engaged earlier but at this point the balance between lactate accumulation sets in rapidly. A great advantage of Conconi's method is that taking blood samples is not necessary. Therefore this method is also called: the bloodless method of establishing the deflection point.

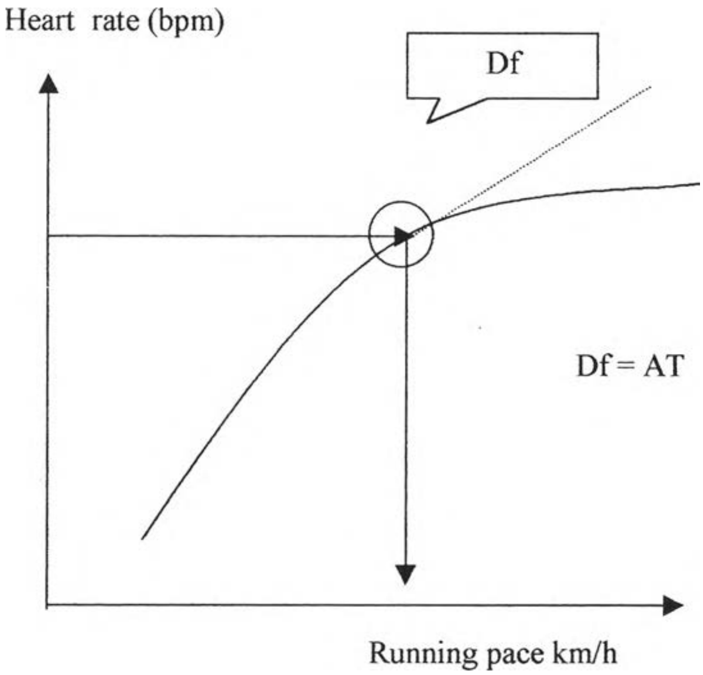


Figure 8. Heart rate against running pace in km/h. The deflection point (Df) is the anaerobic threshold (From Conconi, 1982).

3. Overlap of the Two Energy Systems

During exercise, energy sources a used or depleted to the intensity and duration of the activity. Except for a very short activity, most sports employ both energy systems to varying degrees. Therefore, it is safe to claim that in most sports there is an overlap between the anaerobic and aerobic system.

A good indicator of which energy system contributes the most in a given exercise is the level of lactic acid in the blood. Blood sample may be taken and lactic acid levels measured. The threshold of 2 - 4 mM of lactic acid indicates that the anaerobic and aerobic system (LA-O_2) or transition zone contributed equally to the resynthesis of ATP. Higher levels of lactic acid indicate that anaerobic or lactic acid system (LA) dominates, while lower levels indicate that the aerobic system (O_2) dominates. The equivalent threshold heart rate is said to be AerT = AT - 20 bpm (Janssen, 1989).

Table 1 shows one way of classifying some activies based on the degree to which the energy for these activities is derived from anaerobic source within the working muscles or form aerobic source requiring the transport of oxygen to the muscles (Fox and Mathews, 1974).

Table 1. The energy delivery systems (ergogenesis in percentage) for sports.

Sports or sport Activity	% Emphasis According to Energy Systems		
	LA	LA- O_2	O_2
Baseball	80	20	-
Basketball	85	15	-
Fencing	90	10	-
Field hockey	60	20	20
Football	90	10	-
Golf	95	5	-
Gymnastic	90	10	-
Ice hockey			
a. Forward, defense	80	20	-
b. Goalie	95	5	-
Rowing	20	30	50
Skiing			
a.Slalom, jumping, downhill	80	20	-
b. Cross-country	-	5	95
c. Pleasure skiing	34	33	33
Soccer	60-80	20	10
Tennis	70	20	10
Volleyball	40	10	50
Waterpolo	30	40	30
Wrestling	90	10	-

Modified from Fox and Mathews, 1974.