

## **CYCLING PERFORMANCE TIPS**

# **EXERCISE PHYSIOLOGY: THE CARDIOVASCULAR SYSTEM & CONDITIONING**

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### **DELIVERING OXYGEN TO THE MUSCLE CELLS**

- cardiac output (transporting oxygen to the cells)
- VO<sub>2</sub> (oxygen consumption with exercise)
- measures of cardiovascular fitness
- skeletal muscles
- changes in CV physiology with age

Regular exercise (walking, running, cycling, etc.) stimulates changes in the cardiovascular system, lungs, and muscle cells which improve work capacity - for both endurance and sprint activities. Added health benefits include a decrease in resting heart rate and a lowering of maximal blood pressure with submaximal exercise. These changes can be measured with an exercise program that elicits 60% of your maximum heart rate for 30 minutes, 4 times a week. Understanding the physiology behind this training effect will help you in developing your own training program.

The cardiovascular (heart and blood vessels) and pulmonary (lungs) systems work together to deliver the oxygen necessary for efficient (aerobic) energy metabolism to the exercising muscle. Oxygen is extracted from air in the lungs and then transported in the blood to the cells where it is extracted and utilized. The byproduct of energy production, carbon dioxide, is then transported back to the lungs by the circulating blood and leaves the body in expired air.

### **CARDIAC OUTPUT**

The major reason for an increase in exercise capacity with an aerobic training program is the rise in the maximal cardiac output (amount of blood pumped by the heart per minute). It plays a bigger role in increasing maximal exercise performance than does the increase in oxygen uptake and utilization by the skeletal muscle cells. Since our maximal heart rate does not change, and may even be lower, following exercise training, this increase in cardiac output is the result of a higher stroke volume (amount of blood pumped per heart beat). Cardiac output = stroke volume x heart rate.

The increase in stroke volume is a result of both a hypertrophy (enlargement) of the left ventricle muscle (athlete's heart) as well as an enhancement of the heart's contractile state, probably mediated by the autonomic nervous system.

### **THE LUNGS**

The lungs job is to exchange (extract) oxygen from air drawn into the microscopic air sacs (alveoli) for carbon dioxide, a waste product of metabolism. Normally a half liter of air is drawn into the lungs with each breath (which for the average cyclist is about 3.4 to 4 liters per minute - respiratory rate x air exchanged per breath). A competitive cyclist can exchange an additional 2 liters (6 liters per minute) while the legend Miguel Indurain was reported to have a respiratory capacity of 8 liters per minute. Although our respiratory capacity is relatively fixed (as a result of inherited factors such as body habitus and the size of our thoracic cavity), you can, with practice, increase your lung capacity to some degree.

## OXYGEN CONSUMPTION (VO<sub>2</sub>)

VO<sub>2</sub> is the amount (expressed as a volume or V) of oxygen used by the muscles during a specified interval (usually 1 minute) for cell metabolism and energy production. Maximum oxygen consumption (VO<sub>2</sub>max) is the maximum volume of oxygen that can be used per minute, representing any individual's upper limit of aerobic (or oxygen dependent) metabolism. It can be expressed as an absolute amount (again as a volume per minute) or as a % of each individual's personal maximum (%VO<sub>2</sub>max).

VO<sub>2</sub> max. depends on:

- lung capacity (getting oxygen from the air we breath into the blood which is passing through the lungs)
- cardiac output (the amount of blood pumped through the lungs, and of course the muscles as well, per minute)
- and the ability of the muscle cells to extract oxygen from the blood passing through them (the arterio-venous or A-V O<sub>2</sub> difference)

Each of these factors improves with aerobic training and results in an increase in VO<sub>2</sub>max. The arterio-venous (A-V) O<sub>2</sub> difference results from oxygen being delivered and extracted from the blood being delivered to an organ (usually muscle), the arterial concentration, and the blood leaving, the venous concentration. Oxygen extraction) and thus the A-V O<sub>2</sub> difference, increases with exertion (almost doubling at maximal exercise versus at rest) as well as with training (increasing for any set level of exertion).

At levels of exertion greater than the VO<sub>2</sub> max., the energy needs of the cells outstrip the ability of the cardiovascular system to deliver the oxygen required for **aerobic metabolism**, and oxygen independent or **anaerobic energy production** begins. Anaerobic metabolism is not only less efficient (less ATP is formed per gram of muscle glycogen metabolized) resulting in more rapid depletion of muscle glycogen stores, but also results in a build up of lactic acid and other metabolites which impair muscle cell performance (even when adequate glycogen stores remain). The build up of excess lactic acid will be ultimately be eliminated when exercise levels decrease to an aerobic level and adequate oxygen is again available to the muscle cell. The build up of lactic acid (and amount of oxygen which will ultimately be needed to eliminate it) during anaerobic metabolism is responsible for oxygen debt (the period of time required to remove the excess lactic acid) and recovery phase that follows anaerobic exercise.

## MEASURES OF CARDIOVASCULAR FITNESS

**VO<sub>2</sub> max.** or maximum oxygen uptake, is considered the gold standard of cardiovascular, pulmonary, and muscle cell fitness. It is usually standardized per body weight and expressed in milliliters of oxygen per kilogram of body weight per minute, and is the maximum amount of oxygen your body (basically your muscles) can utilize. The VO<sub>2</sub> max for an elite cyclist can range from 70 to more than 80 ml/kg/minute. It is generally measured on a treadmill or bicycle ergometer at a sports medicine clinic with the appropriate equipment. Exertion at or beyond 100% VO<sub>2</sub>max can be sustained for a few minutes at most. With training, you will increase your VO<sub>2</sub>max. as well as the ability to ride for longer periods at any % of your VO<sub>2</sub>max.

The following all indicate that an individual's VO<sub>2</sub>max has been reached:

- VO<sub>2</sub> plateau - no further increase in oxygen use per minute even with an increase in work performed
- heart rate within 10 beats of the age predicted maximum heart rate -this is the basis for using your maximum heart rate as a surrogate for your VO<sub>2</sub> max when designing your personal training program)

- plasma (blood) lactate levels > 7 mmol/liter

For those of you interested in the mathematical expression of VO<sub>2</sub>max, it is the product of the arterio-venous oxygen difference (the oxygen content of blood leaving the heart minus that returning to the heart and thus the amount being extracted by the working skeletal muscles) and the maximal cardiac output (the maximal heart rate times the volume of blood pumped per beat). This is called the Fick equation.

### RANGES FOR VO<sub>2</sub> MAX - BY AGE AND SEX

#### Female (values in ml/kg/min)

Age	Very Poor	Poor	Fair	Good	Excellent	Superior
13-19	<25.0	25.0 - 30.9	31.0 - 34.9	35.0 - 38.9	39.0 - 41.9	>41.9
20-29	<23.6	23.6 - 28.9	29.0 - 32.9	33.0 - 36.9	37.0 - 41.0	>41.0
30-39	<22.8	22.8 - 26.9	27.0 - 31.4	31.5 - 35.6	35.7 - 40.0	>40.0
40-49	<21.0	21.0 - 24.4	24.5 - 28.9	29.0 - 32.8	32.9 - 36.9	>36.9
50-59	<20.2	20.2 - 22.7	22.8 - 26.9	27.0 - 31.4	31.5 - 35.7	>35.7
60+	<17.5	17.5 - 20.1	20.2 - 24.4	24.5 - 30.2	30.3 - 31.4	>31.4

#### Male (values in ml/kg/min)

Age	Very Poor	Poor	Fair	Good	Excellent	Superior
13-19	<35.0	35.0 - 38.3	38.4 - 45.1	45.2 - 50.9	51.0 - 55.9	>55.9
20-29	<33.0	33.0 - 36.4	36.5 - 42.4	42.5 - 46.4	46.5 - 52.4	>52.4
30-39	<31.5	31.5 - 35.4	35.5 - 40.9	41.0 - 44.9	45.0 - 49.4	>49.4
40-49	<30.2	30.2 - 33.5	33.6 - 38.9	39.0 - 43.7	43.8 - 48.0	>48.0
50-59	<26.1	26.1 - 30.9	31.0 - 35.7	35.8 - 40.9	41.0 - 45.3	>45.3
60+	<20.5	20.5 - 26.0	26.1 - 32.2	32.3 - 36.4	36.5 - 44.2	>44.2

**Anaerobic Threshold (AT;** also known as lactate threshold) is the level of physical performance at which the muscles produce more lactic acid than can be removed (by the liver and muscle enzyme systems). It is expressed as a percentage of VO<sub>2</sub> max - or as indicated above as a % of its surrogate or maximum heart rate. At levels of exertion approaching VO<sub>2</sub>max, there is a rapid increase in blood lactate levels. Cr. Concini, a physiologist, suggested that it can be identified as the *pulse rate deflection point* with increasing exercise (see the Concini test below). Your AT limits your rate of maximal exertion (remember it can be exceeded for only a few minutes as you build up oxygen debt) and thus can be assumed to be reflected as the maximum physical effort you can maintain continuously for 30 to 60 minutes. The more you exceed your LT or AT, the more quickly lactic acid will accumulate and thus limit further increases in your performance. As most cyclists don't have access to lab facilities, you can estimate your AT with a 30 minute (about 10 mile) time trial. The average heart rate you can maintain is a good approximation of your AT.

*An individual's AT will improve with training, and cyclists with a higher AT can work at a higher level of energy expenditure for longer periods, defeating opponents of equal (or even greater)*

physical strength but with lower ATs. This concept explains why interval training, which is generally anaerobic, will improve performance.

**Concini Test** Another method of measuring your AT (and LT) is the Concini test. As a cyclist's efforts increase, their heart rate generally increases in a direct relationship to the energy expended (a linear relationship). But at some point the heart rate begins to level off even as the speed (and energy expenditure) continues to increase. This is the anaerobic threshold, that point at which oxygen cannot reach the muscles fast enough, lactate accumulates, and performance suffers. After an appropriate warm up, using a single gear and a relatively high speed, the rider gradually increases his or her speed by 1 km per hour every 300 meters or so. Heart rate is graphed versus speed, and the break point on the graph is the AT.

**Lactate Threshold** Recent work has focused on the blood lactate threshold (LT) as a reflection of an individual's level of training. The lactate threshold is that % of  $VO_2$  max. at which the cardiovascular system can no longer provide adequate oxygen for all the exercising muscle cells and lactic acid starts to accumulate in those muscle cells (and subsequently in the blood as well). At high levels of activity (but below 100%  $VO_2$  max), there are always a few muscle cells (not entire muscles, but a small number of cells within those muscles) that are relatively deficient in oxygen and thus producing lactic acid. But this lactic acid is quickly metabolized by other cells that are still operating on an aerobic level. At some point, however, the balance between production of lactic acid and its removal shifts towards accumulation. This point is the LT. It is usually slightly below 100%  $VO_2$  max., and will improve with training (move closer to 100%  $VO_2$  max). Those with an increased LT not only experience less physical deterioration in muscle cell performance for any level of % $VO_2$  max, but also use less glycogen for ATP production at any level of performance. Thus an improvement in LT allows the individual to perform at maximal levels for a longer period of time before running out of adequate energy (glycogen) stores.

**Resting heart rate**, your heart rate on awakening in the morning, is a simple but effective indicator of your level of training. It will fall as you train, but then begin to rise again with overtraining.

## THE SKELETAL MUSCLES

There are two types of fibers: type I, or slow twitch, and type II or fast twitch. The slow twitch fibers are more energy efficient and use both fats and carbohydrates as an energy source. They are the major muscle fiber in use at 70-80%  $VO_2$  max. Fast twitch fibers on the other hand are less efficient, use mainly glycogen as fuel, and are called into action for sprints as the athlete approaches 100% of maximum performance. Although the ratio of slow to fast twitch fibers is generally controlled by genetic (inherited) factors, this ratio does change (often over years) with an ongoing training program.

Along with these visible changes in the muscle cells, there are microscopic and metabolic changes at the muscle cell level with training. These include an increase in the size and number of the muscle cell mitochondria, an increase in the activity of various metabolic enzymes in the muscle cells, and an increase in the number of capillaries in the muscle that supply blood to the individual muscle cells. The net result is an increase in the amount of oxygen extracted from the blood in a single pass through the muscle (the arterial - venous oxygen difference).

## SUBMAXIMAL EXERCISE

Endurance training (usually defined as training at less than 60 - 70%  $VO_2$  max) improves the overall efficiency of the cardiovascular system as reflected in a smaller increase in heart rate for

any given exercise intensity, and is also thought to promote a shift towards the use of fat as an energy source (more efficient with 9 Cal per gram versus 4 Cal per gram with carbohydrates). This is supported by the observation of a smaller increase in the plasma free fatty acid levels (indicating enhanced fat oxidation) at these activity levels.

### **CHANGES IN EXERCISE PHYSIOLOGY WITH AGE**

Aging results in a progressive decline in the functional capacity of various body systems, and is reflected in a 9 to 10% decrease in maximal aerobic exercise capacity in sedentary individuals. It is well documented, however, that endurance training can attenuate this age related decline to about 5% per decade, and can also improve exercise performance in older men and women. And if you are more than 40, it may be time to consider cardiac stress testing for asymptomatic coronary artery disease.