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PHYSICAL FITNESS FOR DIVING

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I have been asked to give a paper on physical fitness for diving. I feel this problem is best approached with first a discussion on physical fitness, on what it means and what effects training can produce. Following this, I feel that there should be a general discussion about the criteria for fitness for diving.

Physical fitness can be defined as the physiological adaptation to exercise demands. There are three elements involved in physical fitness:

1) strength

2) endurance

3) flexibility

With training these are developed gradually, according to the stress applied. Continued exercise increases the capacity for further exercise, however with disuse these elements diminish.

STRENGTH

Strength is the ability to exert muscular force. To understand this, we must first consider the elements present in muscle contraction. As you know, any muscle consists of a number of fibres and a motor unit consists of a motor nerve fibre and all the muscle fibres it innervates. The muscle fibre basically consists of sarcomeres. The sarcomere consists of molecules of actin which slide across myosin filaments. Muscle contraction comes about due to the sliding of actin molecules across myosin fibrils. This requires energy from the phosphagens ATP and phosphocreatine. The reaction is triggered off by the release of ACh at the nerve muscle end plate. The only action the muscle has is to contract. It cannot lengthen actively its resting length. This is obviously an energy consuming process and the energy for this is supplied by the splitting of the phosphogens ATP and creatine-phosphate. The strength of a person's muscles depends somewhat on his genetic make-up. However, physical training can modify this considerably. Changes in muscles brought about by physical training include an increase in the cross sectional size of the muscle and it does appear that the strength of the muscle is proportional to its cross sectional area.

Secondly, there is increased capillary blood supply to a muscle following physical training.

Thirdly, and perhaps very importantly, is the neurological adaptation which occurs with continued training. This is most important in sports involving skillful use of muscles, such as tennis.

The biochemical changes which occur during training, have been studied and will be discussed later in this paper.

ENDURANCE

Endurance may be defined as the ability to sustain intense activity for a period of time, to postpone fatigue and to recover rapidly. Endurance may be seen locally, in a single group of muscles, or generally where many muscle groups are involved. The latter is referred to as cardiorespiratory or aerobic endurance.

There are three sources of phosphagens. These are the suppliers of energy for contraction of muscles. Both muscle strength and endurance depend on a continued supply of these phosphagens. Each of the three sources may be predominant in different activities. The sources are:

1) The muscle stores of ATP and phosphocreatine. These have been measured and the total capacity appears to be 0.6 moles. The power developed by these muscle stores is a maximum of 3.6 moles/min.

2) Anaerobic Glycolysis.
The capacity of this system without super-added oxygen is about 1.2 moles in total. The maximum power developed is 1.6 moles/min.

3) Aerobic Metabolism
Here the capacity is infinity, but the maximum power developed is in the order of 1 mole/min.

The total store of phosphagens is small. For example - a 100 metre sprint at maximum pace requires about 0.43 moles of ATP, ie. over half the muscle store. However, resynthesis of the phosphagens occurs both from anaerobic and aerobic sources.

Anaerobic glycolysis is a method of producing ATP without the presence of oxygen. The biochemical reactions consist of the breaking down of glycogen, first to glucose then to G6P, to F16 DP, eventually to Triose Phosphates. In the absence of oxygen these are metabolised to lactate. One mole of glucose produces 2 moles of ATP in this way. (If oxygen is present the lactate is converted to pyruvate or the reactions may be reversed to reform glycogen in the liver). This reaction produces ATP available for muscle contraction in the absence of oxygen. However the total supply of muscle glycogen is small and sufficient for only 1.2 moles of ATP, ie. about 3 x 100 metre sprints. This system is used predominantly for short, sharp bursts of energy. For an example, in a 1500 metre running race, anaerobic glycolysis and muscle stores would be used at the beginning of a race, during which time an oxygen debt is created. The middle portion of the race would proceed under aerobic metabolism and the muscle stores and anaerobic glycolysis would be used for the increased power needed at the finish of the race. However, in the absence of oxygen, little endurance would be possible. At the end of the race, muscle glycogen is resynthesised, while the oxygen debt is repaid.

Various training regimes can be aimed at increasing total muscle content of ATP and phosphocreatine and improving anaerobic glycolysis. However, the greatest area of potential improvement with exercise training is the improvement of aerobic supply of ATP.

Aerobic production of ATP comes via the Krebs cycle. In this, pyruvate is fed into the cycle of chemical reactions mediated by enzymes with the production of ATP. This is by far the most productive method of formation of ATP and requires the use of oxygen. The source of pyruvate is either from glucose, or fatty acids or occasionally amino acids. The limiting factor to energy production here is the supply of oxygen to the exercising muscles. With aerobic metabolism the total yield of ATP is 38 moles for every mole of glucose metabolized (12 moles of ATP per mole of acetyl consumed). Thus our problem is to convey oxygen from the surrounding air to the mitochondria in the exercising muscles. This depends on a number of factors:

The first is respiration, the transfer of oxygen into the lungs and its transfer across the alveolar membrane into the blood. From thence it must be transferred into the muscles and this depends on the heart and the peripheral blood vessels. Oxygen is carried in the blood chemically combined to haemoglobin and the haemoglobin concentration and blood volume are important here. When the blood reaches the muscles the ability of the muscles to extract oxygen from the blood is important, creating the arteriovenous oxygen difference. Finally the intracellular enzymes at the muscle level are important in oxygen usage.

The maximum amount of oxygen that a person is capable of consuming per kilogram per minute is a guide of his aerobic fitness. At rest oxygen consumption is about 225 ml per minute. With maximal exercise oxygen consumption rises to about 3,500 ml per minute. Physical training can increase the maximal oxygen consumption and it does so in the following ways:

The Lungs

There is evidence of increased vital capacity following physical training, increased minute volume, and there appears to be an improvement in lung diffusion capacity.

The Heart

There is an increase in the heart volume, an increase in the stroke volume and in some cases an increase in attainable heart rate. Maximum cardiac output increases.

The Blood

Physical training causes an increase in the blood volume, an increase in the total haemoglobin and in the haemoglobin concentration.

Thus we see that training improves O_2 delivery to the muscles

The Muscles

There is also a change in the muscles themselves. There is an increase in the muscle mass and a decrease in the amount of fat. Various changes in the muscles have been found using muscle biopsy techniques. There is an increase of skeletal muscle myoglobin, an increased capacity of the muscles to oxidise glycogen to form carbon-dioxide, water and ATP. This seems to be due to an increase in the number, size and surface area of the mitochondria in the skeletal muscles. For example, it was noted that there was 120% increase in the mitochondria of the vastus lateralis muscle after 28 weeks of endurance training. Also, there is an increase in the activity and concentration of enzymes involved in the Krebs cycle and electron transport system. These increased by a factor of two. Training also increases the ability of skeletal muscle to oxidise fatty acids to carbon dioxide, water and ATP. A two-fold increase has been noted experimentally. A trained person uses more fat and less glycogen for a given work load than an untrained person. This results in less depletion of muscle glycogen and less production of lactic acid, which is responsible for many of the features of fatigue.

Also, following training muscle glycogen and triglycerides stores increase by a factor of two. It is also noted that ATP and phosphocreatine stores in muscle increase by a factor of 20 to 40%. There is increased oxygen extraction from the blood by the muscles in the trained individual. This increases the arterio-venous oxygen difference thus supplying more oxygen to the muscles.

By physical training a fit person can increase both the strength and endurance in his muscles. This can be measured objectively. In the laboratory it is possible to measure the maximum oxygen consumption of a person which is a measure of his aerobic capacity. However, the equipment is cumbersome and not readily applicable to day to day testing. Cooper and his co-workers have made studies linking laboratory oxygen consumption studies to performances in the field with running, swimming, cycling and other activities. He has related maximum consumption in the laboratory to a person's ability to run or swim or cycle a certain distance in a certain time. He has constructed several tables enabling one to assess fairly accurately a person's aerobic capacity by running or cycling or swimming a given distance in a certain time. His most popular test is the 12 minute test which can be applied for either running or swimming. The person, after a warm-up, runs or swims as fast as he can for 12 minutes. The distance covered is measured and by consultation with the charts his aerobic capacity can be assessed.

There are six categories of fitness: Very poor, poor, fair, good, excellent and superior. These are classified in the age groups of 13 to 20, 20 to 30, 30 to 40, 40 to 50, 50 to 60 and above 60. For example, in the age group 40 to 49, the poor group has an oxygen consumption of 30 - 33 ml/

kg/min. This sort of person was able to cover only 1.14 miles in 12 minutes. The superior group had a consumption of over 48 ml/kg/min and was able to cover 1.66 miles in 12 minutes.

Similar tables exist for swimming. Thus it is relatively easy to design a simple test to assess the aerobic fitness of a person. A good case can be made for a certain minimum fitness level for diving.

The present levels necessary for certification seem somewhat inadequate. Reasons for insisting on a certain minimal level of fitness are fairly obvious. It improves the diver's safety and also enjoyment.

Incidents can and do occur while diving, requiring a reasonable degree of fitness to overcome them satisfactorily. This is certainly most important in the inexperienced diver and this is the person who will usually be undergoing testing for certification. A more experienced diver can often weather the storm with less expenditure of energy. Obvious examples are currents, loss of way, surfacing a fair distance from shore or boat or encounters with unfriendly ocean inhabitants. Or helping a stranded buddy, etc.

A fit person can enjoy a better dive and is certainly more psychologically prepared for any misadventure which may occur.

I would not be so bold as to suggest which level of fitness one should consider for safe diving certification but I feel that with discussion from the audience that some basic ideas may be formulated.

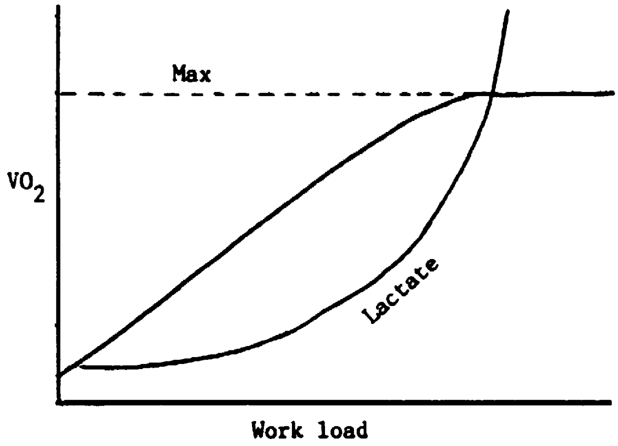
BASIC EXERCISE PHYSIOLOGY

Fred Bove

The state of exercise can best be defined by the whole body oxygen consumption (VO_2). Normal resting VO_2 is about 3.5 ml O_2/kg/min, and during exercise it can rise to 76 ml O_2/kg/min in well trained athletes. If a person is tested with a steadily increasing work load, one finds that VO_2 rises lineally with work load to a maximum (VO_2 max). At VO_2 max, although work load may be increased, no further increment in VO_2 occurs, so anaerobic metabolism in the skeletal muscles becomes dominant, and fatigue develops within minutes.

Figure one demonstrates these relationships. As a person approaches VO_2 maximum, work load becomes greater, dyspnoea is present and a state of generalized discomfort develops. Because of rapid lactate production at or near VO_2 maximum, a metabolic acidosis also develops, and causes further hyperventilation as well as muscle fatigue due to a marked lowering of the local pH in the muscles. Normally, an individual can exercise comfortably up to 50% of VO_2 maximum, and no lactate buildup in blood or

FIGURE 1



muscle will occur. Beyond 50% of maximum, blood lactate will rise to a new steady state, and as VO_2 maximum is approached, the lactate rise is continuous.

If one wished to measure a diver's capacity for exercise, measuring VO2 maximum would provide the most accurate assessment of physical capacity. However, since VO_2 maximum is somewhat difficult to measure, various methods for assessing its value indirectly have been devised. A good alternative to direct measurement is to measure heart rate in a standard protocol. Since for most people, VO_2 and work load are tightly related, VO_2 can be estimated for a standard treadmill work load, and attainment of maximum VO_2 can be assessed by heart rate criteria. For a sport diver to function well in diving, which may include some occasional heavy exercise needed for emergencies, a capability of working at ten times the resting VO2 should be possible. If we want the diver to use ten times basal oxygen for some time, then his maximum should be about fourteen times basal. We refer to these multiples of basal VO_2 as mets. Our sport diver should be able to sustain 10 mets for a brief (four to five minute periods without becoming incapacitated by acute fatigue). His or her maximum should be about fourteen mets. Note that based on body weight, the female sport diver should end up with about the same relative capacity. Male divers will have greater VO_2 values because of greater body weight. If you are concerned about a diver's physical capacity, a treadmill test should demonstrate that the diver can sustain 10 mets of work for 4-5 minutes comfortably, and the heart rate should be about 70% of maximal. If a diver cannot perform at this level, a conditioning programme should be suggested.

It is a simple matter to understand exercise capacity from the above principle. Next, we must discuss variations in VO_2 maximum since work capacity is determined by this value. VO_2 maximum varies with age, sex and state of health. It peaks between 25 and 30, then declines thereafter at a rate dependant on the amount of physical activity. Males generally have higher VO_2 maximum, but much of the difference is due to body size and proportion of adipose