British diving magazine *Diver* (August 1996) there were offered computers by Aladin (5), Bridge, Cochrane (4), Oceanic (7) and Sea and Sea. Shuman's book covers computers by Cochrane, Oceanic (2), Scubapro (3), Sea and Sea, Uwatec (Aladin in the UK) and US Divers (3). It appears that he has chosen them as examples of three types of dive computer, basic, air integrated and adaptive.

The majority of computers in use fall into his basic category, being able to give information about depth and time, no-stop time remaining, nitrogen out-gassing and next dive schedules. The newer ones record a number of dives for playback and show time to flying.

Air integrated computers are the author's middle category. Showing how much longer the air supply will last is an excellent advance and making this or no-decompression time remaining the warning setter should provide safety. However divers can fixate on the air time remaining figures and ignore the decompression requirements.[1] In the discussion on hoseless air integrated computers no mention is made of the problems some have when the diver is in the "line of sight" between the transmitter and wrist worn computer, which is no longer receiving the transmissions.

The final category is adaptive decompression computers which adjust the calculation of nitrogen uptake and excretion for such things as rapid ascent, cold water and heavy work-load (calculated from air consumption).

The real value of the book is the first chapter. Here the author discusses how American sports divers really dive, taken from personal observation. He categorises 6 safety related skills for divers, dive planning, establishing accurate bottom time, controlling the rate of ascent, performing safety stops, measuring dive depth and group reliance. Group reliance is a concept that I have not met before and from the discussion it is obviously an "unsafety" factor. One example quoted is where a dive guide looked for the computer with the longest available second dive in the group and then used that person's available dive time for the group. Reading the stories of "experienced divers" diving from boats off California and Hawaii should be compulsory for all those interested in safe diving. No wonder the author states "Many divers ignored (or were deficient in) key safety-related skills". The author uses the frightening casualness of his fellows to emphasise that a computer will provide accurate depths and times, help with dive planning and ascent rate control and enable a diver to dive more safely. Seeing that only one of his unsuspecting observed divers ascended the last 4.5 m (15 ft) in 15 seconds I am surprised that he did not recommend using a computer with an audible ascent rate warning.

No book on diving computers can be up to date for more than a few months as new versions appear at short intervals and different algorithms are slipped into the new models of earlier computers. This book is an honest attempt to offer one person's views on computers in general and 11 in particular. There is a chapter on the down-side of computers emphasising that computer users often increase their risk of decompression illness by going longer and deeper. This theme runs through the book.

This book should be read by all those interested in diving safety.

John Knight

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ENERGY EXPENDITURE IN DIVING.

Marius Coetsee

Key words.

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In order to understand energy expenditure during diving it is necessary to have a sound knowledge of the energy systems of the body. Therefore a brief discussion of the energy systems and how they interact with each other is given at the start of this paper to assist readers.

All energy for muscular activity is derived directly from the high energy phosphates stores (ATP and CP) in the body. However, this pool of stored energy is relatively small and must be replenished continually by means of energy production. ATP and CP together would account for less than 10 seconds of all-out exercise. It follows therefore, that activities of a high intensity, lasting longer than 10 seconds. must rely heavily on the adequate production of energy. This would include all the activities of diving.

Replenishment of the energy stores is accomplished through production of energy by the anaerobic and aerobic energy supply systems of the body (Fig 1). During anaerobic production of energy, glucose is used as substrate

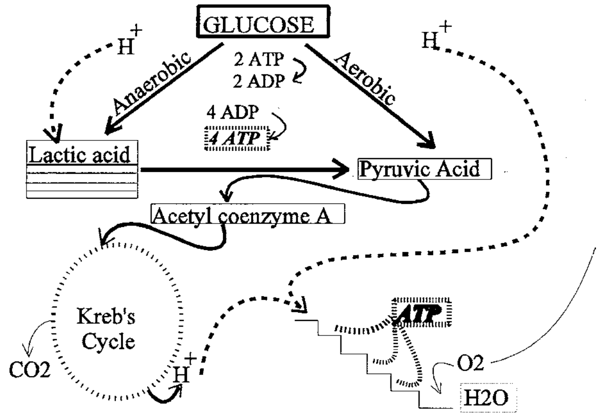

Figure 1. Production of ATP

and is broken down to lactic acid in a process termed glycolysis. During glycolysis two ATPs are consumed but four ATPs are produced, therefore there is a gain of 2 ATPs per glucose molecule. Aerobic energy production through glycolysis can also proceed without the formation of lactic acid, provided oxygen is available in sufficient quantities. Glucose (pyruvic acid) as well as fats and protein can further enter the Kreb's cycle to be metabolised. Hydrogens are released by the chemical reactions in the Kreb's cycle and glycolysis. These hydrogen ions are transported to the electron transport system where, by means of a series of reactions, they release energy in the form of ATP. At the end of the electron transport system hydrogen binds with oxygen, supplied via the aerobic support systems, to form water. If oxygen is unavailable, however, this process will immediately cease to produce energy, thereby leaving only anaerobic glycolysis for energy production with the resultant accumulation of lactic acid. The advantages and disadvantages of the anaerobic and aerobic energy systems are summarised in Table 1.

The demand on the energy systems of the body depend very much on the type of activity to which the body is subjected. The capacity of the energy systems to respond to the demand in turn depend on a variety of factors. By manipulating these factors an individual can optimise the ability to utilise energy effectively.

A high partial pressure of oxygen (PO_2) at cellular level together with other factors such as the availability of substrate, sufficient concentrations of oxidative enzymes to catalyse the chemical reactions, optimal pH and temperature all play a crucial role in determining the capacity of the aerobic system to meet the energy needs of the body and therefore determine the relative contribution of the aerobic and anaerobic systems (Fig 2). It must be remembered that if an individual is using more energy than the aerobic system can produce at any specific time, this energy is supplied by the anaerobic system with the resultant accumulation of blood lactate. Unchecked accumulation of blood lactate would soon lead to exhaustion.

TABLE 1

ADVANTAGES AND DISADVANTAGES OF THE ANAEROBIC AND AEROBIC ENERGY SYSTEMS

Anaerobic	**Aerobic**
Quickly available	Requires up to 2 minutes to function fully
Functions in the absence of O_2	Requires O_2 to function
Limited capacity	Very large capacity
Produces lactate which leads to exhaustion	Produces no lactate

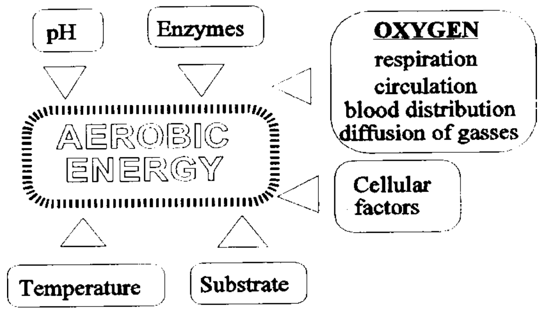

Figure 2. Factors determining the capacity of the aerobic system

In the light of the above discussion of the energy systems of the body, a description of energy expenditure during some aspects of underwater diving follows:

Scuba diving

The average recreational scuba diver always attempts to keep the intensity of the activity as low as possible, to improve air endurance. Therefore, most of the energy is derived from the aerobic system without using the full capacity of this system. The anaerobic system do not play an important role in a normal relaxed scuba dive. This observation is supported by research showing that the peak oxygen consumption (VO2 peak) and peak ventilation volume (VE peak) of scuba trained individuals are significantly lower ($P<0.001$) during all out scuba fin swimming than the maximal oxygen uptake (VO_2max) and maximal ventilation volume (VEmax) as measured during all out running on the treadmill.[1] The absence of adaptations to the respiratory parameters suggest that the intensity of recreational scuba diving is insufficient to induce adaptations to the aerobic energy system.

However, this does not mean that aerobic and anaerobic fitness should be neglected by recreational scuba divers. Emergencies, such as having to cope with strong currents, will require a much higher reliance on both the aerobic and anaerobic systems and therefore scuba divers are strongly advised to specially train for aerobic and anaerobic endurance. As endurance is highly specific to the muscles that are active, it follows that such training should be fin swimming. Physical fitness remains one of the major contributors to safe diving.

Scuba diving where underwater work is performed or where special circumstances apply such as with very deep diving, brings into effect factors that affects the relative contribution of the energy systems and the ability of these systems to meet the energy needs.

Shore entries through surf can be dangerous to unfit individuals, especially if they also possess relatively low aerobic capacities. While battling through the surf the energy need of the working muscles could easily be higher than can be supplied by the aerobic system, with the resultant accumulation of lactate in the blood. This in turn would tend to lower the pH of the blood. In an attempt to buffer the change in pH, respiration will increase causing a sensation of shortness of breath. This does not only lead to a much greater air consumption but also poses a real danger of panic developing. Proper warm up of the aerobic support systems and especially aerobic fitness would greatly help to prevent this situation from developing.

Underwater hockey

Contrary to common belief, research has shown that energy is derived not from anaerobic but mainly from aerobic sources during underwater hockey.[2,3] Experienced underwater hockey players have a distinct pattern of play, i.e. 10 seconds of submersion and 10 seconds of recovery on the surface.[4] Submerged periods rarely exceed 1O seconds. The intermittent nature of underwater hockey allows for sufficient recovery of the oxygen stores in the body during the 10 second surface interval for the aerobic system to adequately support energy consumption. During maximum intermittent exercise, such as found in an underwater hockey match, the oxygen saturation of arterial blood is maintained above 91.5%.[3] Blood lactate levels of underwater hockey players after 12 minutes of intermittent exercise are about 5.1 mmol/l indicating only a moderate contribution of the anaerobic system to energy supply.[2] Performance (underwater time) seems to be limited by an increase in the urge to breath caused by a significant ($P < 0.001$) increase in $PaCO_2$.[3]

Scuba orienteering

The aim of scuba orienteering is to cover a distance of approximately 600 m in the shortest possible time.

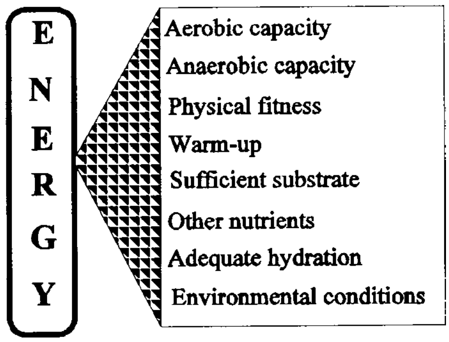

Figure 3. Factors affecting energy supply

Therefore it is understandable that both the aerobic and anaerobic systems would contribute significantly.

Spearfishing

Long underwater breath hold periods during spearfishing necessarily place a much greater emphasis on the anaerobic system for energy supply. The spearfisherman however always tries to conserve energy by limiting physical activity to the minimum.

Discussion

In underwater sports, particularly where a possible shortage of energy might lead to life threatening situations, proper knowledge and effective control of the factors affecting a sufficient supply of energy are very important. The following aspects must be considered by participants to ensure safe and effective participation in exercise (Fig 3):

l Each individual has a maximum potential for oxygen consumption (VO2max) and therefore, for producing energy via the aerobic system. This potential is determined by hereditary factors and can be adapted only moderately through exercise. The physical working capacity of two individuals who are equally fit can differ substantially. Working in a group could mean that some individuals are working at an easy level without getting exhausted while some might be working at a level which, for them, would quickly lead to exhaustion. Instructors and trainers should be particularly aware of this and not expect the same performance from every individual in a group. During group work the pace should be set by the weakest individual in the group. Individuals with relatively low hereditary aerobic potentials should compensate by being aerobically fitter than their "aerobically endowed" counterparts if they wish to achieve the same results.

2 Physical fitness can greatly increase an individual's performance capabilities. Not only do the metabolic systems adapt to become more proficient in producing more energy with the same oxygen consumption but the mechanical efficiency also improves. This means that the available oxygen is used more economically and therefore more work can be performed with the same oxygen consumption.

Unfit individuals can exercise up to approximately 55% of their maximal aerobic capacity before blood lactate starts to accumulate faster than it can be metabolised, with a resultant accumulation of blood lactate concentration. Fit individuals may exercise at a level as high as 85% of their maximal aerobic capacity before lactic acid will start to accumulate in the blood. It must, however, be remembered that adaptations of this nature are highly specific to the type of activity or sport and that very little cross training occurs. In order for divers to improve this capacity they must engage in fin swimming under conditions simulating those conditions they want to get fit for.

3 Proper warm-up plays an important role in the optimal functioning of the aerobic system. Aerobic energy production depends on a sufficient supply of oxygen reaching the muscle cells. However, the systems responsible for the delivery of oxygen to the cells function only at the level required by the intensity of exercise at the time and require time to adapt if the intensity of exercise is changed. If the exercise intensity is suddenly increased, the anaerobic energy system will supply the energy which the aerobic system is temporarily unable to supply and lactic acid accumulates. Provided the increase in exercise intensity is not too great and remains submaximal, the oxygen supply systems will soon adapt to allow sufficient oxygen to reach the cells for the aerobic systems to supply the total energy needs. However, if the intensity increase is too great, sufficient lactate would accumulate to compromise efficient functioning of the aerobic energy system and exhaustion would follow. A proper graded warm-up procedure on the other hand would allow the aerobic system to adapt gradually, with the result that very little lactate accumulates.

In most underwater activities it is easy to warm up by simply starting at a slow pace and gradually increasing the intensity of exercise. During most recreational scuba dives the intensity of the entire dive is low to moderate and therefore there is no need to warm-up. Other dives, e.g. a shore entry, however, would necessitate prior warm-up as the initial activity itself might be so strenuous that no warm-up is possible during the actual activity.

4 Energy production also depends on the presence of sufficient substrate at cellular level. Activities of very high intensity rely mainly on carbohydrate and as the carbohydrate stores of the body is fairly limited it follows that such activities, if carried on for extended periods, might result in hypoglycaemia developing. Intermittent activities, such as found when a number of games are played per day, as in an underwater hockey tournament, may lead to hypokinetic conditions developing if not compensated for through the intake of carbohydrates. Prolonged spearfishing might also result in a shortage of blood glucose developing.

5 Other nutrients such as vitamins, minerals and proteins all play an important role in the production of energy. A shortage in any of these could compromise the production of energy and lead to a reduction in performance. A shortage in these nutrients normally takes some time to develop and a balanced diet should prevent it happening.

6 In order to maintain an optimal medium for metabolic processes, adequate hydration is of utmost importance. Dehydration could severely compromise exercise performance by, amongst others, adversely affecting energy production. Most diving activities comprise lengthy outings in which the individual is subjected not only to environmental factors contributing to dehydration, but also to circumstances that can lead to insufficient intake of water. Diving itself leads to an acceleration of dehydration.

7 Environmental factors such as heat or cold could also affect energy production by creating intra-cellular conditions unfavourable for the chemical reactions of metabolism.

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