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diving MEDICINE

WORKING PERFORMANCE UNDERWATER

On one of my first dives to the Cumberland wreck (100m) with the Sydney Project team I remember relating how incredibly hard I had found the swim across the bottom to find the ship's bow. These complaints backfired on me somewhat when we later viewed the video of the dive, and I looked like I was out on a gentle "Sunday swim". That was a real eye-opener to me. The dive felt hard and I was panting away on my rebreather, but to an observer we looked like we were just idling along!! This raises the important issue of the factors that limit working performance underwater. Failure to appreciate these limitations can lead to problems ranging in significance from unpleasant to deadly! Most of the relevant factors can be considered under environmental, equipment, and physiological headings.

ENVIRONMENTAL FACTORS

1. Depth

Diving affects our ability to move air or other gas in and out of the lungs. As depth increases, so too does the density of the gas we are breathing. Increased gas density promotes turbulent flow in the airways and this in turn increases the work of breathing. As you might predict, we are simply not able to shift as much gas at depth. Indeed, the maximum voluntary ventilation (MVV) (the amount of gas you can breath in and out per minute if you pant as hard as you can) during air breathing at 4 ATA (30m) is 50% that at the surface. Increasing depth is not the only factor that may reduce ventilatory capacity (see equipment below), but this change in MVV alone is sufficient to ensure that our work capacity at depth is much less than at the surface.

A reduction in our ability to ventilate is one potential reason why divers may develop high levels of carbon dioxide (CO_2) during periods of work at depth no matter whether they are using open circuit or rebreather equipment. Getting rid of CO_2 from the blood is entirely dependent on ventilating the lungs adequately and this relationship is illustrated by the following equation:

$PaCO_2 = VCO_2 / VA$

Where: $PaCO_2$ = CO_2 tension in the arterial blood

VCO_2 = CO_2 production

VA = alveolar (lung) ventilation

This equation implies that if alveolar ventilation falls and CO_2 production rises (as could happen with hard work at moderate depths where ventilation is impaired as described above), then arterial CO_2 will increase, causing unpleasant symptoms such as headache and shortness of breath. Provided the diver is able to reduce work output (and therefore CO_2 production) and either maintain or increase ventilation, most situations like this can be brought under control. However, you will also immediately appreciate the critical danger of a diver putting himself in a situation where he works hard while being unable to ventilate sufficiently to eliminate the CO_2 produced by the work of his task and the work of breathing. He may enter a deadly spiral of increasing CO_2 production (from desperate efforts to breathe) and decreasing ventilation (from inefficient rapid, shallow breathing). If the $PaCO_2$ becomes high enough the diver will eventually become unconscious, stop breathing, and either drown or suffer a cardiac arrest (or both!). This sounds like an extreme and even fanciful scenario, but there is very good reason to believe that this has occurred in at least one recent diving accident at extreme depth.

Another issue with depth is that the narcotic potency of nitrogen will increase with depth. Clearly, a narcosis impaired diver will be less able to perform work, especially if it involves cognition or dexterity. Deep divers substitute non-narcotic and vastly less dense helium for nitrogen in breathing mixes in order to reduce both the narcosis and the work of breathing on very deep dives. This is effective for these purposes, and will certainly increase the work capacity of the deep diver.

2. Temperature

Cold temperatures reduce dexterity, and as any occupational diver will attest to: being cold does not facilitate hard underwater work, either from a physical or psychological point of view!

3. Visibility, swell, and current

In general, the harsher the conditions under which the dive is conducted, the more difficult it is to perform meaningful work for a variety of reasons. For example, current or swell often mean that the diver has to expend considerable energy just to maintain position, let alone carry out any tasks.

EQUIPMENT FACTORS

1. Breathing resistance

Underwater breathing equipment almost inevitably imposes an extra resistance to breathing in addition to that imposed by merely increasing depth. This varies with the configuration and tuning of the equipment used. For example, suboptimal tuning of a regulator may result in greater diver-initiated pressure changes required to open valves. Similarly, poor design may see dense gas at depth having to flow through tubes that are narrower than necessary (= greater resistance) or that change direction in such a way as to create turbulent flow. In either case this will translate into greater work of breathing. Indeed, any diver with a moderate amount of experience will be able to relate experience with regulators that "breathed easily" compared to others that "breathed hard". Extra breathing resistance imposed by equipment will reduce work capacity and increase the chance of increases in CO_2 as described above.

Equipment may also impose breathing resistance of another sort. In physiology we recognize that work of breathing has several components. One is the work required to overcome "airways resistance" (resistance to gas flow through airways) which is analogous to the depth and equipment related changes in gas flow resistance discussed above. We also speak of the work required to overcome elastic forces which are mostly imposed by the elastic nature of the lung, and to some extent the chest wall. This too can have its parallels in equipment if, for example, the diver wears a suit, weight belt or harness that is too tight or restrictive.

2. Dynamic efficiency of CO_2 scrubbers

For those divers utilizing rebreather equipment, the dynamic efficiency of the CO_2 scrubber is another potentially important limitation on underwater work. It is important to distinguish the predicted duration of a scrubber (which could be called its "static capacity") from its "dynamic efficiency". Dynamic efficiency or capacity is the scrubber's moment to moment ability to remove a CO_2 load presented to it, and this might be exceeded even though there is considerable static capacity remaining. For example, we might start a dive with brand new soda lime in a rebreather scrubber and therefore expect to have a duration of several hours, yet even in the first 5 minutes of diving there could be some CO_2 "breakthrough" into the inhalation hoses if the scrubber's dynamic capacity is overwhelmed by a short period of extraordinarily rapid CO_2 delivery.

Factors that can reduce dynamic capacity include decreased temperature, increased depth, partial flooding, partial expiry of scrubber material and improper packing of the scrubber.

The effect of temperature is easily explained on the basis that the reaction between CO_2 and the scrubber material is slower at low temperatures.

The effect of extreme depth is interesting. All other factors being equal, we still produce the same number of CO_2 molecules irrespective of the depth we are at. However, the deeper we go, the greater the pressure (and number of molecules) of other gas in the rebreather loop. One theory holds that in this setting there may be a lower chance of contact or interaction between the relatively sparse CO_2 molecules and the scrubber material because of "crowding" from other gas molecules.

The effect of partial flooding of the scrubber with wetting of the material is almost certainly to impair contact between the scrubber material and CO_2 molecules.

Diving physician Dr Simon Mitchell was previously Director of the Diving Medicine Unit at the Royal New Zealand Navy Hospital, Auckland, New Zealand and Medical Director of the Wesley Centre for Hyperbaric Medicine, Brisbane. Simon's diving experiences span both sportdiving (including being a champion spearfisher and a member of the New Zealand Underwater Hockey team) and professional work (including underwater explosives, salvage, underwater construction, and deep heliox diving). He's one of the few doctors who has worked full-time in diving and hyperbaric medicine, and has conducted important research in this field. As a diving instructor he understands the recreational industry well and is widely acknowledged as a knowledgeable, effective and entertaining diving medical educator.

The effect of partial expiry of scrubber material is reasonably obvious. If some of the scrubber material has already absorbed as much CO2 as it can, then there are less actively absorbing particles of material available. The longer the scrubber is used, the more relevant this becomes. This effectively means that the scrubber has progressively less active absorbing surface area available, and the probability of dynamic capacity being exceeded rises with time.

The effect of improper packing is an uneven distribution of scrubber material resulting in so-called “channeling” since gas flow will tend to favour the path of least resistance. This is most likely if the scrubber is packed too loosely, resulting in a gravity-dependent shift in material during the dive. CO2 is less likely to be completely removed if larger volumes of gas are flowing rapidly through a small less resistant area of scrubber.

Obviously, dynamic capacity is more likely to be overwhelmed if CO2 is presented to the scrubber at a greater rate, especially since an increased rate of CO2 delivery is usually accompanied by a much greater flow rate of gas through the scrubber thereby reducing the “dwell time” during which the CO2 from each breath is in contact with the scrubber material.

PHYSIOLOGICAL FACTORS

It should be pointed out that much of the above discussion is “physiological” and it is difficult to know how to classify some of these issues. In general, I have placed emphasis on the primary initiating process or parameter, thus “depth” is responsible for an increase in gas density and resistance to breathing, and a reduction in MVV etc. In reality, however, these are definitely physiological (or perhaps pathophysiological) concepts and could just as easily have been discussed here. With those areas covered above, there is little left to mention that is clearly physiological.

Just as with work on land, there is undoubtedly an aerobic fitness component to the ability to perform underwater work, with those of greater fitness being able to perform more strongly.

DIVER FACTORS

In general, more experienced, better trained, calmer and technically competent divers will make more economic use of a finite gas supply and will perform underwater work more efficiently than a diver who is nervous or agitated, and/ or who has poor buoyancy skills.

SUMMARY

Divers, and particularly deep technical divers, must be very aware that attempts to perform hard work at depth may be frustrated by limitations imposed by both the increased density of the gas they are breathing and their equipment. Put another way, tasks and swim distances that may be easily completed in shallow depths may become very challenging when undertaken deeper. Failure to recognize this, and failure to adjust expectations or plans accordingly, may result in dangerous events such as CO2 toxicity.

DR SIMON MITCHELL IS HAPPY TO ASSIST WITH YOUR QUESTIONS. PLEASE EMAIL YOUR ENQUIRIES TO sportdiving@motpub.com.au