Rethinking Oxygen Limits

by Dr. R.W. Bill Hamilton

The devastating series of diving accidents this past summer demands a rethinking of all safety practices associated with technical diving, especially those related to oxygen. At least two fatalities are strongly suggestive of being due to oxygen toxicity, a couple of others could be, and one near miss is well established as an oxygen problem. It is not clear that new "limits" need to be imposed, but the whole question bares a close look beginning with a discussion of limits themselves.

The Concept of Limits

When dealing with disciplined groups such as the military or university diving organizations it is often convenient and effective to set "limits." However, just as with the "yes" or "no" nature of decompression tables, these limits may not have a real physiological meaning. A limit for exposures has practical use, but the implication that one is perfectly safe on one side of the line and totally doomed on the other is really not correct. A limit is a solid line drawn through a wide "gray" area of increasing risk. Under a given set of conditions, not all of which can be known, it is possible that a single "limit" may make sense, but in the overall scheme of things this is usually not the case. Limits should be regarded as wide gray areas of increasing risk.

Why bother to dwell on this? To remind people again what this means on a physiological level. Traffic laws may say that the speed limit is 55 mph, but safety does not get out of the car and walk at that point, nor is it guaranteed below it. But the law draws a hard line, and even 56 mph may be enough to get you a fat ticket if you get caught. Being over the O2 line may be just fine today, but not so good tomorrow. Unfortunately, it is a lot more costly than a speeding ticket to get caught on this one.

There is another point to the speeding analogy that's important here. The average highway speed in the U.S. is probably somewhat over 60, but the speed limit is 55 mph. Do we have to set O2 limits below what they should be in order to keep divers out of trouble? Let's hope not. The policeman is the diver, and the diver has to suffer the consequences of violation. Oxygen limits are not not the same thing as a speed limit, and that is the whole point of this essay.

In short, a limit is a point considered to be where acceptable risk ends and unacceptable risk begins, under normal circumstances. If conditions are not normal in any way, then the risk may be much higher below the limit, and the consequences are even greater for violating it. Limits are only a guideline and it makes good sense to stay below them. But there is more to the limit issue below.

The USN Exceptional Exposure Limits

One other point about limits relates to "exceptional exposures." The USN publishes a chart of exceptional limits right besides its standard limits. Many divers believe that because there are some "unphysiological" aspects about the "normal" limits then the exceptional ones are all right. Wrong. In fact they make no sense at all. To begin with they are to be used only in an emergency or equivalent operational contingency. What this says is that when conditions allow the exceptional limits to be used, then the same conditions surely justify violating them. The exceptional limits, if used at face value, represent a much higher level of risk than is acceptable for a technical or recreational dive. Furthermore, the risk is not uniform over the table. Using these limits is ***not*** likely to keep you out of trouble, and is not recommended.

The Cost of Staying Below The Limits:

Another point worth noting in technical diving is to assess the decompression "benefits" of pushing an oxygen limit. It turns out that for short, deep technical dives only a few additional minutes of decompression time is gained by that last tenth of an atm of PO2 in a diver's bottom mix, but the increase in risk may be disastrous. It is much better to take the extra couple of minutes and be in an area of lower risk when working hard on the bottom.

Cost of An Excessive Exposure, or of "Exceeding The Limit"

Next let's review the consequences of exceeding a proper oxygen exposure, of getting an excessive dose. First the whole body (lung or pulmonary) exposure is not likely to be an issue in any but the longest of technical dives and will be more of an irritation or nuisance than a serious risk if these symptoms do develop. This is not to say whole body oxygen toxicity is not a matter of concern, only to point out it is extremely unlikely that it will be a life-affecting factor in technical diving. Leave the details of this to another time.

CNS oxygen toxicity is the primary concern in technical diving. The consequences of oxygen poisoning in the central nervous system is a convulsion, with or without the loss of consciousness. It appears that some victims of CNS oxygen toxicity just go unconscious without having a convulsion, and may not spit out a mouthpiece. However, the typical convulsion throws the whole body into a clonic spasm, the jaws tense up, breathing stops momentarily, and for scuba divers the possibility of spitting out the mouthpiece is unacceptably high. Normally a person in a convulsion has such clenched jaws that even under hospital conditions it is not easy to pry the jaw open at all, certainly not enough to reinsert the mouthpiece. A convulsion may occur without warning, and this is the way to expect it. Sometimes a person has a lip or facial twitching, hears or feels an "aura," or in some way is warned, but quite often it comes without warning. If one is able to avoid the "mechanical" effects (falling, drowning, etc.) then the consequences are minor. There may be a headache, or the diver may bite her tongue or cheeks. Interestingly, subjects who have convulsions during experiments usually return for the next phase; whatever happens it is not so unpleasant to drive them away. But it's not necessary to remind this audience that drowning can spoil your whole day.

In any diving situation, oxygen tolerance is reduced by exercise, breathing resistance, any other factors that might cause an increase in CO2, anxiety, extremes of temperature in either direction, and other presumably lesser factors. These are possible to monitor and avoid, but another major factor is individual variation. These occur for different individuals, and for the same individual at different times. This is discouraging, because we know very little about how to predict or even detect these individual susceptibilities.

If your partner has a convulsion underwater there is really not a lot you can do. Of course holding the mouthpiece in would be helpful. Although it will probably not be possible to reinsert the mouthpiece, one should try. Procedures say to take the subject off oxygen, and this is appropriate, but the convulsion will normally stop if oxygen is not removed. If oxygen is the only available gas, then the diver should go on breathing oxygen. A convulsion normally lasts a couple of minutes, but sometimes takes much longer. Obviously ascending when not breathing is not advisable, but taking a stricken diver to the surface (slowly if possible) may be a better option than letting them drown.

Surviving A Convulsion

What can be done? Prevention by better oxygen exposure control, discussed below, is of course the best thing, but another attractive tactic is to change the environment enough that a convulsion does not automatically result in drowning. One good way to avoid immediate drowning is to wear a full face mask. This has enabled many commercial divers to live to brag about their convulsion. Another benefit of such equipment is that it makes throughwater communications possible. However it also creates the need for

connecting blocks to enable gas switching and the easy sharing of gas from diver to diver in an emergency situation.
A similar alternative is to use a strap that will hold the mouthpiece firmly in place, convulsion or not. A convulsing diver will bite the tabs off a mouthpiece, but if it stays in the mouth then there is a chance. Mine clearance divers in the German Navy use such a device, and experience shows it can work.
Still another trick that will help in some cases is to do the high oxygen part of the decompression out of the water. The classic way to do this is by "surface decompression," which may impose other problems and is not suitable for technical diving operations. However, decompressing "out of the water" can sometimes be arranged by use of a inwater "station" (commonly but not-quite-correctly called a "habitat," since no one lives there) which allows a diver to remain all or partly in the dry. This can be done with a "wet bell" or by climbing up inside a small, inflated lift bag or other inverted container, sometimes referred to as a "microbell."

Some divers feel the octopus hose could have an oral mask, one that can be applied over a tightly clenched jaw. How effective this might be is subject to question; documented or anecdotal stories about experiences with this or other methods would be welcome.

Still another slightly different approach is to have an ample team of well-trained and well-equipped surface support divers during potentially stressful or difficult dives.
What Are the "Limits" For Oxygen?

Having condemned the concept of limits, it might be nevertheless worthwhile to mention some of them. The actual charts are intentionally not included here; a diver to whom these limits have personal meaning should most certainly have the appropriate reference materials available (the U.S. Navy Diving manual, and the Third Edition of the NOAA Diving Manual). The "infamous" USN limits should head the list. These were prepared for "mixed gas diving." Another set of limits are for pure oxygen diving typical of "combat swimmers." These limits are higher, allowing longer exposures to higher doses. This is because the diver is necessarily nearer the surface (usually shallower than 25 fsw), and has lower gas breathing density and presumably less CO2 buildup. In fact almost all of the testing of oxygen limits has been done with exposures to 100% O2, and the transfer factor to use this data for exposures to high oxygen levels in diving with mixtures is not really known.

At the deep end the limit is 20 min. at 1.6 atm; this is an entirely reasonable limit, and is recommended. This chart does not allow any exposures above 1.6 atm. At lower exposure levels the USN chart becomes unrealistic *as a CNS limit,* and longer times than allowed by the chart can be tolerated without nearly so high a risk. But note that no time is allowed for exposures above 1.6 atm PO2. The combination of an exposure limit partial pressure over an exposure time is a "dose," this is a critical matter.

The new NOAA limits allow a dose of 45 minutes at a PO2 of 1.6 atm. For a diver in good condition and without factors that can cause an increase in CO2 this is also reasonable, but this is pushing things when conducting a deep dive. The NOAA limits were formulated primarily with no-stop enriched air diving in mind, where depths are not so great. Depth increases breathing gas density and reduces the performance of most regulators, increasing the potential for CO2 buildup. It also increases the distance to the surface and hence makes rescue or escape far more difficult. It seems especially unwise to push oxygen limits on deep dives. As with the USN limits, the NOAA limits do not allow diving at an oxygen level greater than 1.6 atm. PO2.

Another authority is about to enter the picture. DCIEM, publishers of the very popular DCIEM 1983 air tables, are about to issue criteria for enriched air diving using the partial pressure equivalent principle, or "equivalent air depths" method. They have accepted the NOAA limits up to 1.5 atm (for 120 minutes) but consider the range of 1.5-1.6 atm as "exceptional."

A couple more points about limit numbers should be mentioned. First, when a limit says "1.6" it doesn't mean 1.6. It means less than 1.6. This is a fine point, but one that is often overlooked. With a mindset focused on "1.6," it is hard to keep in mind that this limit is beyond where one should go, not the target. Another more important detail is that the limit has a time associated with it, since an exposure level (a partial pressure) and an exposure time make up a dose. All exposures above normal contribute to your reduction of tolerance, or as Dick Rutkowsky would say, *"your oxygen clock is running."* Bottom time is usually not the only exposure to elevated oxygen levels. High oxygen levels are typically a part of the decompression procedure as well. Unfortunately at present there is no clear-cut rule for dealing with multi-level or fractional exposures. Interpolation is possible, but no one really knows how valid it is. DCIEM recommends using the worst case value for the entire range (dive) in much the same way that one uses maximum depth for a decompression schedule. The important point is that all exposures be considered, even those from a prior dive. Several researchers are working on how long it takes to "unwind the oxygen clock," but so far we do not have much handle on this. For the time being consider that it may take many hours if the exposure is severe, and will most certainly take a few hours following even a minor dose to be back to initial tolerance level.

Conclusions

This is a brief and incomplete review of this important subject but it points out some of the aspects of the oxygen picture. It is not to be taken lightly. Oxygen is still the best means of improving decompression, but it is not without a price. A good practice, until equipment improves enough to make a convulsion survivable, is to keep PO2s below 1.5 atm during the working and travel (descent and ascent) phases of the dive, and any time when more than very light work is being done. The practice of taking "air breaks" (breathing air or a low PO2 mix for five minutes every 25 minutes or so when breathing oxygen during decompression) is also recommended as it decreases the diver's sensitivity to convulsion. Allow plenty of time to recover resistance to oxygen as well as to outgas during intervals between dives. In addition, make sure that the breathing resistance on your equipment is as low as it can reasonably be, and keep entilation rates up during exertion. Finally, be prepared if at all possible to survive a convulsion if these measures fail, both with a guaranteed breathing mechanism and with inwater and surface support. Above all, if you are not willing to do it right, don't do it.

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