Bubble Formation and Elimination

by George Irvine

Gas does not transfer from tissues into arteries or veins, it does so into capillaries. The arteries coming from the heart are huge, thick, elastic, pulsing conduits that get smaller as they branch out until they become capillaries, and then the return to the heart is through veins which are also thick and get larger as they combine to return blood to the right side of the heart.

That blood is then sent to the lungs, where the massive network of tiny capillary beds located in about 45,000 square feet of surface area, act as a "filter" for bubbles. The "filtered" and now oxygenated blood which has passed its co2 and other excess gasses to the lung space, goes back to the heart to be pumped through the system again. The whole trip takes about two minutes to happen.

You do not bubble into the arteries. If bubbles get into the arteries it is because they passed the filter or were "shunted" over through a PFO in the arterial walls, or because they were momentarily compressed enough momentarily to get past the lungs and then re-expanded as the pressure dropped prior to reaching the capillaries, in which case they lodge in the smaller and smaller vessels and block them. This occurs in bounce diving, as in doing a dive and then bouncing back down to retrieve something, like a deco bottle. This is why we do not allow bouncing in the WKPP, and why we require our support divers to stay out for 4 hours before diving shallow for support.

Most people get the greatest rush of bubbles from the tissues into the blood stream upon surfacing from 20 feet or so. This is why we do that differently, (information to follow.) Most people tend to bubble for hours after a dive. Most bubbles tend to grow from the surrounding supply of gas before they get smaller and disappear.

If the bubbles are in the tissues, you have pain. The way to prevent bubbles in the tissues is to properly decompress starting deep and at a rate that allows the bubbles to escape to the blood stream. Deep this needs to be done carefully and in solution, shallow you can press the gradient and allow offgassing in bubble form into the blood stream. The difference is that if you screw up shallow, you can go back a little and fix it. If it occurs deep, that makes it impractical and a huge waste of time for nothing. For people with cardiac or pulmonary shunts, offgassing in bubble form is super dangerous. For those without, it is far more efficient. For those with PFO's, the risk is greatest AFTER they get out of the water for the reasons stated above (growth of bubbles and continuation of bubble offgassing.)

I think you can see where I am going to tell you that you need to do your shallowest dives first, do your drills before you do your dives, and why you can basically ignore repetitive dives using the correct deco. You can NOT ignore them with respect to oxygen exposure.

The Decompression Curve

by George Irvine

Decompression is a not linear event: twice the bottom time does not mean twice the deco, and half the bottom time does not mean half the deco. This is fairly intuitive, but for you Marines, the fact is that the fastest movement of gas occurs where there is the greatest differential. When you first go from one ATA to two for instance, there is a fast on gas rush, but as you stay there a while it slows down since the gradient factor powering the movement is lessening, like charging a battery.

On gassing is easy - you do not blow gas into the tissues in bubble form by on gassing. Off gassing is more tricky, as you want to prevent bubble formation in the tissues at all depths, and in the blood deep. Off gassing in bubble form into the blood is extremely efficient time wise and allows faster decompressions that avoid building in one tissue while eliminating in another, but this is for non shunt people only. Unfortunately for the shunts, the greatest incidence of bubbling into the venous blood occurs after you get out of the water.

It takes a certain amount of time to circulate the blood, maybe about two minutes, and it can take as much as five to get gas in solution to begin to come out of solution in bubble form in the tissues or into the blood in response to a reduction in pressure. Most of the short on/offs are handled well by the body in terms of outright pain or obvious symptoms, but they may cause the body's immune system to respond to the insult that is actually occurring, and uneven off gassing from sensitive tendon attachment points and live bone surfaces as well as certain dense muscle may not be able to accommodate the super short cycles. Tissues that are hard to on gas are not as much of an issue on minimum deco, only on longer exposures.

We have found that the short schedules under 30 minutes are inaccurate predictors. What we do is set a shape for the deco as if it were a longer dive, complete with starting the stops at 80% of the profile in ATA's, and merely go to a minimum reading for each stop. The minimum deep stop is 20 seconds at each ten feet, which is effectively 9 metres per minute plus the moving time. The max for these is five minutes for saturation (or anything within 85% of technical saturation, which I assume to occur at 150 minutes bottom time).The stops indicated by the shape of the deco curve higher up need to be done to a minimum number, like 1 minute for the deeper ones and then more when the gas switches come in. Give the gas a chance to work, then go back to the curve with the 1-2 or 3 minute stops. As you get higher up, the fact that you did the deeper part more meticulously will allow some abbreviation in the shallower steps.

In any of these decompressions, do your calculation and then discard the ten foot stop completely from the figures - throw it and its time out completely - that is total bullshit. Then ask yourself how much time do I need at 20. The answer is, enough to make it work if I did the deeper steps correctly. Two minutes on oxygen is not doing anything, ten is more like it. However, what you want to do is incorporate a slow ascent rate into the last 6 metres of the dive, so what was the 6 m stop should be eased up from 6-2 in a steady motion after you have sat at 6 and allowed a full circulation of the blood and the effects of the pressure change and the gas to begin

to work and a relative time based on you real bottom time where the total of the 6 plus ascent to surface is at least equal to your bottom time, again assuming you have done the other steps correctly. Do not waste a bunch of pyramided time at steps where there is little partial pressure advantage, use the gradient more in these cases, again assuming you have conscientiously done the lower steps.

Don't be in any big hurry to get up from the bottom, and do not be in any big hurry to get up from 9 metres to the surface. These two areas need careful attention.

I think that if you discard the 3 metre silliness in any program and the unnecessary time, then put some of that time back into the correct shape and strategy, you will not only prevent the out right DCS, you will prevent the sub clinical DCS and the immune responses.

If you execute deco correctly and are in good shape and have no preconditions, you should be clean and ready for anything 30 minutes after you get out of the water. You can tell if you have not done what I am saying here, you will not feel so good. It will be subtle, but if you want to test it, try going for a run. If you are immediately short of breath, you blew the deco. If you can rock, you did it right. If you get bent trying this, then tough luck, blame JJ. In reality, you will feel a little sluggish and heavy just putting your gear away if you did an inadequate deco.

Now, if there are questions that can help with the understanding, bring them on. If anyone wants to argue with me, save your breath and be ready to show me your logbook, and don't bother with the IANTD, TDI, PADI, DAN or any other form of nonsense that is floating around out there. Nobody understands this like I do, and nobody can execute it like I do, and nobody has done it this way for as long as I have, not even my own team. I know for a fact that this is not only correct, it is correct beyond a shadow of a doubt. I remember getting Exley to get out of the water with me at Wakulla one time on my schedule. That was easy to do with him because he responded very well to peer pressure - I could get him to do anything I dreamed up. He spent the next four hours in the lobby of the Lodge getting FSU to Doppler him over and over just waiting for the big bends hit - never happened. That was nine years ago. We have really perfected it now.

The First Stop / The Deep Stops

by George Irvine

In determining where to start your decompression, the logic is very simple: you want to let gas escape from the tissues prior to bubbling. Once it bubbles, it will not escape. Rising up rapidly from depth is a good way to trap gas in tissues by forming bubbles which will then grow when you are higher in the water column. On the other hand, gas that bubbles into the blood is generally trapped by the lungs, but those with any kind of pulmonary or cardiac shunt are at risk if this occurs. If it occurs too fast, and or the bubbles grow too large, they can block the effective lung function and

will damage the capillary beds of the lungs. From depth, you want to remove gas in solution form.

The best way to do this is to begin your decompression stops at 80% of your profile in atmospheres rounded up. For a ten atmosphere dive, the first stop is 8 atmospheres, or about 70 metres. At the same time, the traveling time between 90 and 70 should be at 90 metres per minute max, so it should take you two minutes to get to 70.

There is a fine line between getting rid of gas and adding gas at this end of the deco. All you are trying to do is buy time to get the gas coming out in solution, and there is a point of diminishing returns for stops in the lower end of the deco range. The maximum deep stop is 5 minutes, the minimum is 20 seconds (9 MPM ascent). The best way to assure your ascent is at the correct speed is to physically stop every 3 m. That will get you your 20 seconds per 3 metres. The range of bottom times that determine the length of the deep stops is 0-150 minutes. For 0, you still have the 9 m rate, for 150 minutes you max out at 5 minutes per stop. Anything beyond this is effective saturation and the maximum applies.

These deep stops are equally divided at all depths up to 65 percent of the profile. At that point you begin lengthening the stops. Between 65% and 45%, the steps slightly lengthen, but max out at 10 minutes. Between 45% and 35%, the max is 20 minutes, between 35 and 25%, the max is 30 minutes, subject to certain parameters.

Going back to the deepest stop, if you switched gases, and 80% is where you need to switch gases on a long dive, you are maximizing the effect. If you use a helium based gas you further improve the results. Air is unacceptable as a deco gas as it causes damage that can not be fixed by decompressing, and further complicates the decompression due to the body's immune response to damage and the stress of rigid red cells jamming through small capillaries.

When you approach a gas change, you should be coming off of back gas. For the first deep switch, this is obviously the case. Having been on a low ppo2 operating gas, you can afford to spike the ppo2 with a deco gas, whereas you do not dare do that without breaking to back gas first. You do not use a full 1.6 ppo2 from any part of deep decompression. The risk is too high. You don't want an oxygen reaction at depth as you will not have any chance of recovering from this, or surfacing and going back down. Be smart and rely on helium and gradient more than ppo2 for these steps. Clearly, a 1.4 or less is preferred for deep stops max, whereas shallower you can do the full 1.6 because you are able to break to a lower effective ppo2 shallow by using back gas. Some people stage a full face mask starting at these stops. JJ does this.

It takes a solid two minutes for gas to make its first pass through the body when you switch. The switch step should be the longest of the series that uses one gas. You are getting the best oxygen window for that gas at this point, and you just came from a low ppo2, and the gradient is not that severe. As you move up, the steps do not need to be longer on the same gas. In fact, you are best served to do your last step before gas switch on back gas and to make it the shortest of the steps. Here you are relying on gradient and the toggle effect.

The toggling effect is simply alternating between higher and lower ppo2s in order to prevent the onset of lung tissue damage, swelling, adding of protective layers, and constriction of the blood vessels. The reduced ppo2, especially the closer it gets to normoxic, will prevent and reverse these effects (other than the damage if it is already done). Using the gradient at this juncture is the best way to rid gas.

As you get up into the shallower areas prior to going to oxygen, you should take a full back gas break - what I call a "cleanup break". For instance, on a sat dive to 90m, I will do 20-30 minutes on back gas at 15 metres. Cleanup breaks are effectively being done on long dives prior to gas switch if you do your last step on a gas by going back to the backgas.

In the 12-9 m range from a deep dive with a long deco, it is unnecessary to extend the 12 and 9 m stops at all. In fact these one can be sharply reduced if you have no shunts. You are better served by bubbling the gas into the blood stream sat these depths, a far more efficient and rapid way to get rid of it. Bubbles trapped here can be fixed by going back down slightly, but doing it just right means that will not happen to a well-perfused diver. For instance, on a sat dive to 90 m that would call for 120-140 minutes at 12 m on any deco program, I do 20 minutes and then move up.

Following each oxygen stint, you must break to back gas. If you were breathing oxygen dry, as in a habitat or trough, you must do a ten minute break before going back into the water. The ascent rate from your oxygen stop to the surface is 0.3 m per minute for a long dive, a scaled down version of that for a short dive. The greatest case of bubbling off-gassing occurs in the move from 3 or 6 m to the surface. You want that to occur under some pressure and to be controlled by the slow ascent, so that when you are up, you will not get the sudden rush of bubbles that could shunt or cause other problems.

For shorter dives, the deco gases are added from the top down. In other words, your shortest dive might have just oxygen as the only different deco gas. A longer dive of the same profile may add the 50% gas. Still longer times would add the 35% gas and so forth. You weigh the advantage of the gas to the problem of carrying it. The effective shortening of the deco is not in play here because a shorter dive hits the minimum deco rules, so you have to do the time anyway. Longer dives demand the extra gases to stay efficient. Toggling and alternating are key to decompression. There is no way you can beat this by maintaining a high ppo2.

Minimum Decompression

by George Irvine

The fastest ongassing occurs in the early stages of any dive, the slowest ongassing as time passes. Whenever you dive, you are loading up rapidly in the first few minutes. This gas needs to be eliminated in the proper fashion, not ignored. Sometimes, the proper fashion is merely a 9 MPM ascent rate, as in diving to 90 m in a total run of 5 minutes and then back up in 10 minutes. As the dive gets

the choices are dependent upon the dive and whether you are doing two decompression mixes or just one (excluding the O2).

For the bottom mix, intermediate mix(es) and O2 dives, most of us do (i.e. not 100m for 5 + hours as completed by the WKPP), we would in general only have to pick the intermediate gas - Our choice of this intermediate mix is driven by three primary points.

- The max PO2 you can experience safely (so the deepest you use it) is dictated by the 1.6 rule (unless it's a deep long dive, when you may not want to use 1.6 as a max at the intermediate stops)
- The narcotic effect of the gas, may drive us to use a Trimix as a decompression gas
- The shallowest you can use it, which is dictated by two things (1) the next mixes MOD and (2) the PO2 this mix has dropped to due to decreasing ambient pressure - if the PO2 drops too low the deco mix is not being efficient anymore, if you can't get to the next mix in your plan you need to put in another mix

So what is the lowest we want to let a mix drop to before we consider a change, experience shows that a deco gas should never drop below about a PO2 of 1bar - this drives us to choose 50/50 as the travel/deco mix (it has a PO2 of 0.95 at 9m), used before the Oxygen - this can be started at 21m - if we compare this to the other "common" choice which is 35% - this can indeed be started at 36m - but the difference of 0.95 PO2 of the 50/50 against 0.67 of the 35% at the 9m stop which is probably as long (in time) as the stops between 36 m and 21 m added together would mean that we have utilized the O2 to the maximum we could.

Generally for deeper stuff, where you are needing O2 and two other decompression mixes (i.e. a 4 mix dive - possibly more) - the current thoughts are to NOT consider Air as any of the choices. The WKPP believe that the mere presence of helium in a mix alters the way nitrogen effects the rigidity of red blood cells, and reduces or eliminates the microcirculatory damaged associated therewith. As such they have adopted a 21/21 mix (also playing with other similar mixes instead of the air they previously used) this they use up to 50 % Nitrox which is used up to the 100% O2 - also they do not spike the oxygen after a long bottom exposure, so move the gas switches up a deco stop over what is normal (i.e. drop the 1.6)

When you get to the O2 remember to taking back gas breaks at a regular interval, including these breaks will greatly reduce the risk of seizure on the one hand, and greatly reduce the pulmonary damage on the other. We break every twenty five mn for five mn.

What redundancy should you carry for decompression mix

Take the example of two divers - each with three mixes Back, Nitrox and O2 - they each have the same back and Nitrox and same deco so they are running the same plans - diver A looses Nitrox - he will travel to deco gas on his back gas - this means

GUE Standard Mixes

G.U.E Standard Bottom Mixes		
Depth	Gas	(O2/He/N2)
1 - 30m	EAN32	(32% O2 / 68% N2)
30 - 45m	21/35	(21% O2 / 35% He / 44% N2)
45 - 60m	18/45	(18% O2 / 45% He / 37% N2)
60 - 75m	15/55	(15% O2 / 55% He / 30% N2)
75 - 120m	10/70	(10% O2 / 70% He / 20% N2)

G.U.E Standard Deco Mixes		
Depth	Gas	(O2/He/N2)
6m	Oxygen	(100% O2)
21m	EAN50	(50% O2 / 50% N2)
36m	35/25	(35% O2 / 25% He / 40% N2)
57m	21/35	(21% O2 / 35% He / 44% N2)