Helium Penalty

In 2003 I attended a Deep Stops workshop in Florida hosted by NAUI, and roomed with Bruce who designed the Shearwater computers. The conference had all the names from around the globe including JP Imbert of Comex,□“ Richard Pyle (teleconference), GIT3, and speaker who I recall quite vividly debunked the entire show as "witchcraft"€• . His name was Dr. Neuman, and he was former USN and worked on the Dopler research. His point was the navy does scientific based □œresearch□, verse a bunch of divers saying "□œthis feels good"□□. It was the "empirical data" that he debunked. It was a sobering point for the show. A couple years later Bruce posted on the DAN doctor who attended the show and set as a goal to study the effects of Deep Stops on technical divers. His findings were reviewed at a DAN clinic, where he stated that he "□œlost his religion" or belief that Deep Stops were the answer. In fact the point may be that divers are over doing deep stops.

At or around 2001 I purchased my first Meg after taking a CCR Cave Course where Leon was my classmate. I had no idea who he was, but it was a cool rebreather. Unfortunately when my unit arrived, Will Smithers who programed the Meg electronics had died in a helicopter crash. My unit was then not able to unlock the helium code and I was left with a deco handset with Air Only Buhlmann algorithm. Ironically when I would dive all of the Great Lakes Deep Wrecks, Cayman Walls, etc my deco was almost spot on with my VR3 helium based deco? Hummmm, helium had virtually no effect?

And when I took my first Trimix training it was the era where divers were told to rocket off the bottom so they could get shallower and get off helium to breath Nitrox mixtures.....

I think of all of these things when I look back over 42 years of recreational, commercial diving, technical diving and now the past 20 of those years diving rebreathers. What I think is only understood by other lab rats as that is what I have been. But I can summarize these thoughts as "with all the voodoo that we do, there is still a reasonably safe record of decompression". Hummmm??? Well, no shit we have done some really amazing dives with the advent of rebreathers. Not that I have been free of DCS as I have my punch card almost full, and my next chamber run will get me a free ride! Yes I have been bent, more than once and yes more than twice. But after decades and thousands of risky dives I can still walk and talk reasonably clear?

The Helium Penalty has been under debate for years as studied by Doolette and published recently. See article posted below by Michael Menduno

ELIMINELIMINATING THE HELIUM PENALTY

Our understanding of decompression science has undergone dramatic revision in the last two years thanks to decompression physiologist David Doolette, Ph.D. and the team at the Navy Experimental Diving Unit (NEDU). Their report, "Decompression from He-N2-O2 (TRIMIX) Bounce Dives Is Not More Efficient Than He-O2 (HELIOX) Bounce Dives," published May, 2015, dispels a belief about mixed gas diving that has persisted since the NEDU developed the first working heliox tables nearly 80 years ago.

Their findings: A bounce diver's decompression requirements depend solely upon the time, depth and level of oxygen (PO_2) over the course of the dive regardless of the fraction of helium and or nitrogen used in the breathing mix. In other words the so-called "helium penalty," i.e. the extra stops and decompression time required when breathing helium mixes on a surface-to-surface bounce dive, does not exist.[1]

The corollary? Virtually all of the existing tables, dive computers and deco software, used by technical divers today, particularly the Buhlmann ZH-L16 algorithm which fixes nitrogen halftimes as 2.65 times longer than those of helium, have a legacy bias that adds increasing decompression time the higher the fraction of helium in the mix. The trouble is that while this helium penalty is fictitious, the "depth penalty," i.e. most algorithms prescribe increasing risky schedules the deeper and longer the dive, is not. However there is no reliable way, a priori, to determine which is which, that is to know which schedules can be reduced and by how much.

How Did We Get Here?

The extra decompression time calculated by various algorithms when breathing a helium mix is a consequence of the long held belief that helium, which is lighter than air, enjoys faster uptake by the body than nitrogen (in the case of the Buhlmann algorithm 2.65 times faster). As a result, current algorithms prescribe a deeper first stop (to clear the helium supersaturation in fast compartments representing tissue like brain or spinal cord) resulting in continued gas uptake in slower compartments and consequently increased total decompression time.

However, there have been some indications that the helium penalty was fictitious. Over the last two decades Global Underwater Explorers' (GUE) divers have conducted record long cave dives at Wakulla Springs and its connecting systems as part of the Woodsville Karst Plain Project (WKPP). CEO and founder Jarod Jablonski told me they discovered that their required decompression was largely independent of the helium fraction used. Other tech divers have also noticed the apparent discrepancy; some trick their dive computers by inputting a lower helium fraction than that in the trimix they are actually breathing in order to reduce their decompression time. Note that this is not a recommended practice for the reasons cited above.

But the real clue was an animal study that Doolette, a cave explorer and member of the WKPP, conducted in the early 2000s at the University of Adelaide prior to coming to NEDU. The resulting paper, "Altering blood flow does not reveal differences between nitrogen and helium kinetics in brain or in skeletal miracle in sheep," which wasn't published until December 2014, found that there were no differences in nitrogen and helium kinetics i.e. uptake and elimination in the ranges studied. Note that the typo in the title, "skeletal miracle," which should have been "skeletal muscle," was discovered miraculously after the paper's publication much to the chagrin of the authors. The paper concluded that it was inappropriate to assign different time constants for nitrogen and helium in all but the slowest compartments used in a decompression algorithm.

Putting Helium To The Test

In recent years, the Canadian Navy and others created trimix research programs, in part due to increasing helium costs, and invited the U.S. Navy to participate. The U.S. Navy has always used heliox as a diluent for mixed gas rebreather diving; it does not conduct open circuit mixed gas scuba diving. Doolette, his colleague Wayne Gerth, Ph.D., the head of NEDU's decompression team, and Keith Gault, Ph.D. convinced their sponsors that a trimix program would only make sense if trimix offered significantly reduced decompression times over heliox,[2] a claim that had never been tested.

The few human experiments comparing nitrox and heliox dives to the same depth were conflicting and did not provide compelling evidence of a difference in decompression requirements. There have been other studies involving trimix, but none were designed to demonstrate a real difference in efficiency between trimix and heliox. Doolette and company designed their experiment accordingly.

Using their Linear Exponential Multigas (LEM) probabilistic decompression model that NEDU had developed for assessing decompression sickness (DCS) risk, the team selected a profile—200 fsw, 40 minute bottom time—that represented the largest difference in estimated probabilities of DCS between trimix and heliox among a range of candidate profiles that were both practical to man-test and operationally relevant i.e. from about 20-60 minutes of bottom time in the 150-300 fsw range. The experiment, which was conducted in NEDU's Ocean Simulation Facility (OSF), was carried out as follows.

Each of the volunteer divers in the experiment was equipped with a Navy MK-16 mixed gas rebreather and full-face mask. The rebreathers were charged with either trimix 12/44 (12% oxygen, 44% helium, 44% nitrogen) or heliox 12/88 (12% oxygen, 88% helium) diluent gases. The divers then submerged and were pressed to 200 fsw, where they completed the 40-minute wet-pot dive pedaling cycle ergometers.

At the end of 40 minutes, the divers were decompressed for 119 minutes according to the Mk-16 constant PO_2 trimix table (see attached), which was not only 15 minutes shorter than the corresponding schedule for heliox but allowed an ascent to the first decompression stop at 70 feet in contrast to 90 feet for heliox. After surfacing the divers were monitored for signs and symptoms of decompression sickness (DCS).

Table 1. Comparison of trimix and heliox* MK 16 MOD 1 decompression schedules

Depth (fsw)	BT	Stops (fsw, mins)								TST	P_{DCS} (%)†	
		90	80	70	60	50	40	30	20		Heliox	Trimix
200	40	5	3	3	2	3	12	11	95	134	2.14	
200	40			4	2	2	6	16	89	119	5.56	2.14

Divers breathe from MK 16 MOD 1 UBA for 30 minutes prior to starting compression.
*The heliox schedule (shaded) is given for comparison only, and was not used in this protocol
†LEM-he8n25-estimated P_{DCS} at descent rate of 40 fsw/min for indicated gas mixtures

According to the LEM and its associated he8n25 database which consists of more than four thousand air, nitrox, heliox and a few trimix dives, divers with the trimix diluent had a 2.14% probability of getting bent,[3] while the heliox breathers had a 5.56% chance, more than double that of trimix. If their decompression model was correct, that is, if decompression from trimix was more "efficient" than heliox for bounce dives, Doolette et al would expect to see a higher incidence of DCS on the heliox dives in the study compared with trimix dives.

The results? Over about a ten-week period, a total of 32 volunteers conducted 50 heliox dives without incident, and 46 trimix dives with two diagnosed cases of DCS, at which point the scientists stopped the experiment. Statistically that means that researchers' Null hypothesis was retained: trimix decompression is not more efficient than heliox. It also means that existing algorithms, including the U.S. Navy's have a legacy bias and need revision.

According to Doolette, though they only tested a single profile, at least in part due to the expense, it is unlikely that testing another profile in the relevant range would have yielded a different outcome because of the way decompression algorithms work. The results should also apply to open circuit diving.

The NEDU is now working to revise the Navy's algorithms to reflect their new findings. This will likely involve adjusting model halftimes for nitrogen and helium for compartments out to 100-200 minutes or more, which Doolette said was a slow process. "All of decompression science is like this. There is rarely a chance to self-correct quickly as seen in this case. It's taken a long time for Buhlmann's gas concepts to be corrected," he said.

So what does this all mean for technical divers?

In the big picture it means that technical divers will likely adopt heliox, which is now arguably superior to trimix, as the preferred diluent for rebreather diving, while deep open circuit dives (Is that still a thing?) will likely stick with trimix because of the cost of helium. Interestingly, it's a prediction that prescient explorer cum engineer Bill Stone, Ph.D. offered in his January 1992 article, "The Case for Heliox: A Matter of Narcosis and Economics," that appeared in *aquaCORPS* #4 MIX.

"In summary," Stone wrote, "the heliox versus trimix debate presently rests with the cost trade-offs inherent in the inefficiencies of open circuit scuba at depth. Eventually as [rebreather] technology becomes widely available, the debate will come to an end and heliox will become the bottom mix of choice for deep diving.[4]" And that was before the helium penalty was found to be nonexistent. At that time, helium cost about $.22/cf3.

Of course, the more pressing issue is, "What algorithm will tekkies use to make their heliox decompression calculations?" The Navy's current Mk-16 MOD 1 tables, which are published in the U.S. Navy diving manual, are one possibility, but as noted above the current version contains a helium penalty. So tekkies will have to wait for NEDU or others like Duke University to publish a corrected algorithm, and then wait for dive computer manufacturers to implement them.

Unfortunately, that won't happen overnight. "Because of funding cycles, it will likely take two to three years, for this work to hit the public domain," Doolette explained.—Michael Menduno

[1] In contrast, it has been proven that decompression from a heliox saturation dive requires less time than from a nitrox saturation dive because nitrogen takes longer to outgas from very slow tissue compartments that control decompression in saturation dives.

[2] Note that heliox is superior to trimix in other ways for rebreather diving i.e. there's zero narcosis, lower density/work of breathing and helium's chilling thermal properties are not an issue in rebreather diving. The one reason to use nitrogen in one's diluent is to ameliorate possible High Pressure Nervous Syndrome (HPNS) for very deep dives, generally beyond 500 f/150 m.

[3] The U.S. Navy MK-16 MOD 1 rebreather tables are ISO-risk tables meaning that the probability of getting bent is the same for all schedules and is set at about 2%. In most tables, and dive computer schedules, the risk, which is not explicitly identified increases proportionally to the decompression times. In addition most tables have a "sweet spot" where the risk is minimal.

[4] Stone's team dived open circuit heliox during his paradigm shifting 1987 Wakulla Springs project, which was sponsored by Air Products.

Written by Michael Menduno

Michael Menduno is an award winning reporter and technologist who has written about diving and diving technology for more than 25 years and coined the term "technical diving." He was the founder and publisher of "aquaCORPS: The Journal for Technical Diving" (1990-1996), which helped usher technical diving into the mainstream of sports diving, and organized the first Tek, EUROTek and AsiaTek conferences, and Rebreather Forums 1 & 2.