SAFE INNER EAR INERT GAS TENSION FOR SWITCH FROM HELIOX TO AIR BREATHING AT 100 FSW DURING DECOMPRESSION

NAVSEA
NAVAL SEA SYSTEMS COMMAND
Navy Experimental Diving Unit

David J. Doolette, Wayne A. Gerth, Keith A. Gault, and F. Greg Murphy
Navy Experimental Diving Unit, Panama City, Florida, U.S.A.

INTRODUCTION

Many commercial and military (but not U. S. Navy) helium-oxygen (heliox) decompression procedures switch from heliox to air or other nitrogen-oxygen (nitrox) mixtures during decompression. Switching from helium-based breathing gas to less expensive nitrogen-based breathing gas can save money. Other hypothetical advantages are not proven. Some decompression models have slower uptake of nitrogen than washout of helium, so that switching to nitrox accelerates decompression compared to remaining on heliox, but this is not proven, see figure 1.

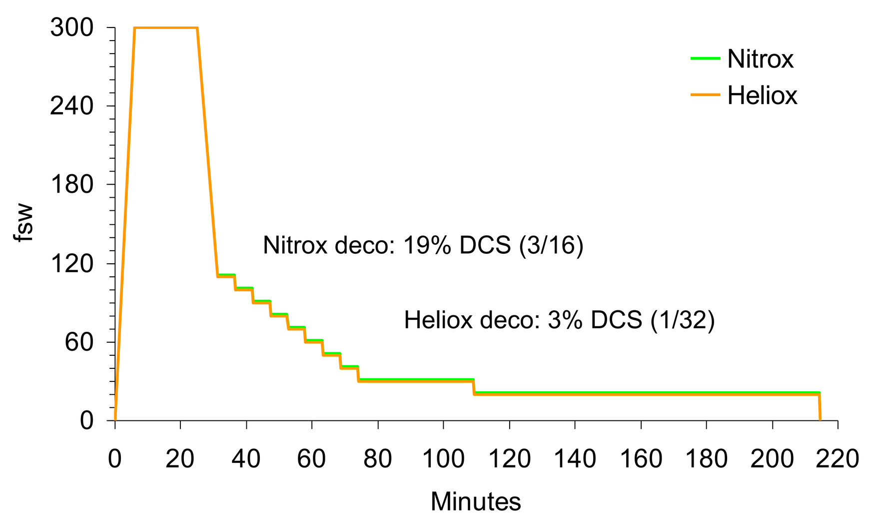

Figure 1. 300 fsw (1.02 MPa) for 25 minute bottom time dive breathing 1.3 atm PO_2-in-helium with identical decompression schedules breathing 1.3 atm PO_2-in-helium or switch to 1.3 atm PO_2-in-nitrogen at 110 fsw. Incidence of decompression sickness (DCS) was not significantly different between schedules.[1]

Switching to nitrox during decompression may result in less Type II DCS than remaining on heliox, see figure 2.

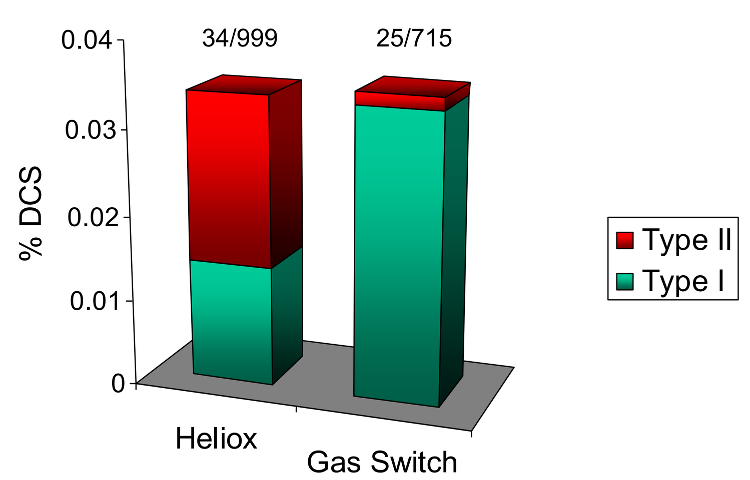

Figure 2. Comparison of incidences of Type I and Type II DCS during development of constant 1.3 atm PO_2-in-helium decompression schedules [1,2], left (Heliox) and during development of surface supplied (84/16 helium/oxygen) decompression schedules [3], right (Gas Switch). Only the latter employ a switch to air breathing during decompression. Although there are substantial differences in these two types of diving, dives were across a similar range of depths and bottom times and resulted in similar overall incidence of DCS. The low incidence of Type II DCS in the Gas Switch dives is noteworthy.

However, symptoms of injury to the vestibular-cochlear apparatus (inner ear), such as vertigo, nausea, tinnitus, and hearing loss, can occur after switching from heliox to nitrox. This was reported with an isobaric switch to a breathing mixture containing nitrogen during a 1200 fsw (3.78 MPa) heliox saturation dive [4] where isobaric counterdiffusion of helium and nitrogen between inner ear structures can cause sufficient supersaturation to produce bubbles.[5] Inner ear DCS is also reported following switches to nitrox (typically deeper than about 150 fsw, 561 kPa) during decompression from heliox bounce dives.[6] At such depths the association of inner ear DCS with the gas switch may be coincidental or may result from counterdiffusion of gas between bubbles and tissue. The U. S. Navy has not used heliox to air breathing gas switches during decompression since the Sealab and Deep Diving Systems programs of the 1960's and 1970's, but has a need to re-evaluate this form of diving.

METHODS

Divers immersed in 80 °F (27 °C) water in the NEDU Ocean Simulation Facility wet pot were compressed to 150, 170, or 190 fsw (561, 622, 683 kPa) breathing 79% helium-21% oxygen or 220 fsw (775 kPa) breathing 84% helium-16% oxygen for a 60-minute bottom time. Divers performed intermittent, 100W, cycle ergometry work while on the bottom. Divers were then decompressed at 30 fsw/min to 70 fsw (316 kPa) from 150 fsw, or to 100 fsw (408kPa) from all other depths. At 70 or 100 fsw, divers exited the water and breathed chamber air for 60 minutes. Following this air stop, divers were decompressed to 20 fsw breathing 50% nitrogen-50% oxygen and then to the surface breathing 100% oxygen.

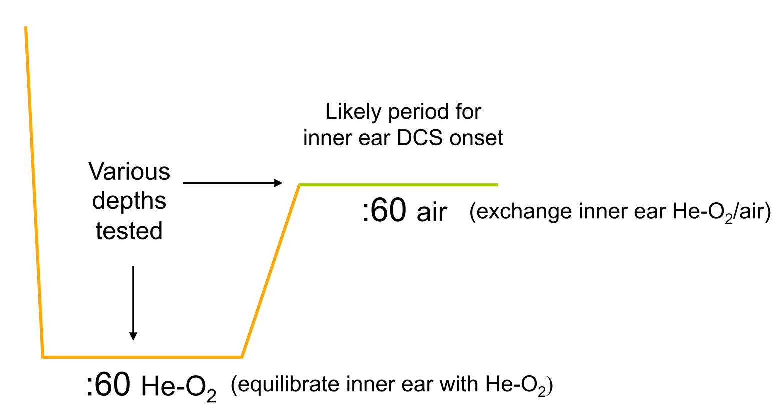

Figure 3. Experimental dive profile. Divers were immersed and breathing open-circuit heliox (brown line) during bottom time and ascent to the first stop. Divers were dry and breathing chamber air during the first stop (green line). Sixty minutes is estimated to allow 99% equilibration of inner ear gas tensions with breathing gas [5].

Profiles were tested in order of increasing maximum depth. Each profile was accepted after 25 man-dives free from central nervous system (CNS) DCS during the air stop. Monte Carlo simulations of this sequential stopping rule [7] estimate that this trial design will detect greater than 0.2% risk of CNS DCS with approximately 3% significance and 96% power.

RESULTS

There was no diagnosed DCS during or following any of the 105 man-dives completed, see table 1. On the 220 fsw dive profile, one diver complained of "fullness" in the ear at the air stop that resolved during subsequent decompression. One diver subsequently admitted to transient, mild shoulder pain (niggles) during decompression from 100 fsw.

Table 1. Heliox excursion depths, air switch depths, and outcomes

Heliox Excursion		Air Switch	DCS/dives
He / O_2	fsw	fsw	
79 / 21	150	70	0/27
79 / 21	170	100	0/25
79 / 21	190	100	0/26
84 / 16	220	100	0/26

Figure 4 shows the inert gas tension predicted for the 220 fsw dive by a three compartment (membranous labyrinth, perilymph, endolymph) model of the inner ear. For clarity, only the membranous labyrinth tensions are shown. The gas switch manifests only as a slight slowing of total gas washout. Total inert gas tension at the end of bottom time and on arrival at the air switch depth are is 639 kPa and 588 kPa, respectively.

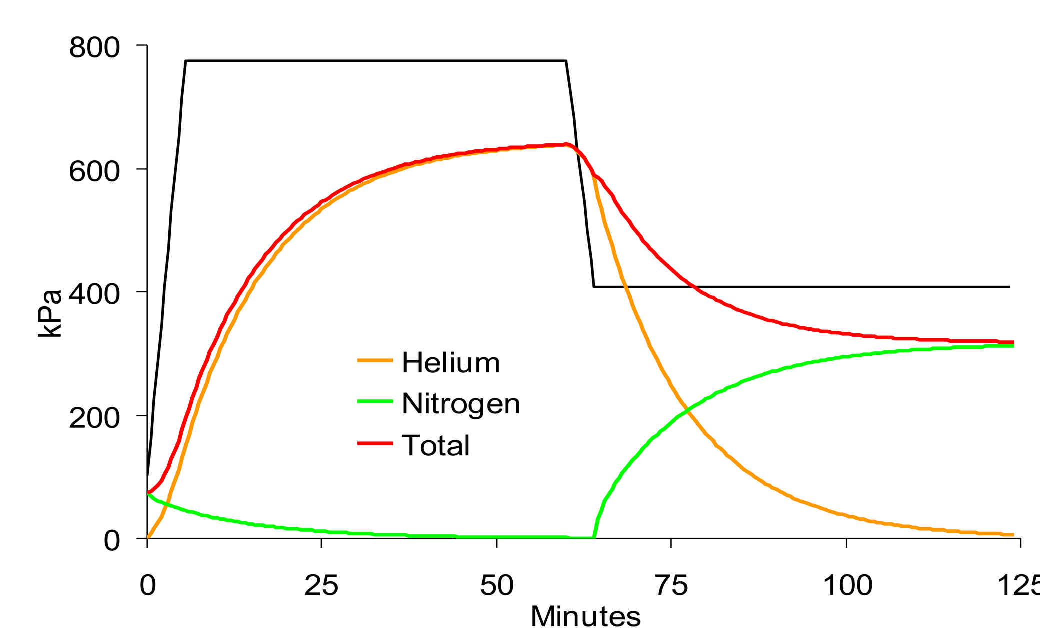

Figure 4. Model predicted inert gas tensions (colored lines) in the membranous labyrinth (perfused compartment) of the inner ear [5] for the 220 fsw experimental dive with 100 fsw air switch. Black line is the ambient pressure

DISCUSSION

The probability or rate of bubble formation increases with supersaturation. Inner ear supersaturation can result from decompression and from counterdiffusion of helium and nitrogen. The counterdiffusion effect is proportional to the magnitude of the increase in inspired nitrogen partial pressure.[5]

Bubbles grow according to the tissue-bubble partial pressure gradients of all gas species and it is possible that a switch to air breathing may result in growth of helium bubbles as has been observed in adipose tissue.[8]

Switch from heliox to air breathing at 100 fsw (408 kPa) with an inner ear inert gas tension of 588 kPa has a low risk of inner ear DCS.

REFERENCES

1. Survanshi SS, Parker EC, Gummin DD, Flynn ET, Toner CB, Temple DJ et al. Human decompression trial with 1.3 ATA oxygen in helium. Technical Report. Bethesda (MD): Naval Medical Research Institute; 1998 Jun. Report No.: 98-09.

2. Gerth WA, Johnson TM. Development and validation of 1.3 ATA PO2-in He decompression tables for the MK 16 MOD 1 UBA. Technical Report. Panama City (FL): Navy Experimental Diving Unit; 2002 Aug. Report No.: 02-10.

3. Tikuisis P, Nishi RY. Role of oxygen in a bubble model for predicting decompression illness. Report. North York (ON, CAN): Defence and Civil Institute of Environmental Medicine; 1994 Jan. Report No.: 94-04. 25 p.

4. Lambertsen CJ, Idicula J. A new gas lesion syndrome in man, induced by "isobaric gas counterdiffusion". J Appl Physiol 1975;39:434-43.

5. Doolette DJ, Mitchell SJ. A biophysical basis for inner ear decompression sickness. J Appl Physiol 2003;94:2145-50.

6. Farmer JC, Thomas WG, Youngblood DG, Bennett PB. Inner ear decompression sickness. Laryngoscope 1976;86:1315-27.

7. Doolette DJ, Gerth WA. Significance and power of sequential Bernoulli trials [abstract]. Undersea Hyperb Med 2009;36 4:257.

8. Hyldegaard O, Jensen T. Effect of heliox, oxygen and air breathing on helium bubbles after heliox diving. Undersea Hyperb Med 2007;34:107-22.