

招待講演 2-2

The High Pressure Nervous Syndrome and Record Dives to 686m

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There is a strong correlation with inert gas narcotic potency and liquid solubility. On this basis, helium would be 4.3 times less narcotic than nitrogen¹⁾. Therefore, it was surprising to find during experiments by the author in 1965, 1967, with rapid compression between 50-100 ft/min to 600ft and 800ft with helium/oxygen, strong decrements in intellectual motor performance accompanied by dizziness, nausea, vomiting and a marked tremor of the hands (Table 1). Unlike nitrogen narcosis there was a marked improvement after 1 1/2 hours. The condition was called "helium tremors" and later the High Pressure Nervous Syndrome (HPNS)²⁾.

	600 ft (6)	800 ft (4)
Sums correct	-18%	-42%
Sums attempted	-4%	-6%
Number of ball bearings	-25%	-53%

Bennett (1965, 1967)

Table 1. First signs of HPNS in 1965, 1967

Subsequent experimental heliox dives by Hannes Keller in Switzerland to 1,000 ft, the author with the British Royal Navy to 1,500ft, the French Comex Diving Company to 2,000 ft and the U.S. Navy to 1,800 ft indicated severe limitations to safe diving with helium oxygen to such depths due to the High Pressure Nervous Syndrome. Indeed the U.S. Navy limited deep diving to 1,000 ft. The signs and symptoms of HPNS are shown in Table 2 below

Tremors of the hands	Animals-convulsions
Myoclonic jerking of the limbs	EEG theta (3-7 hz) ↑
Increased reflexes	EEG alpha (8-13 hz) ↓
Nausea and vomiting	Evoked potentials ↑
Loss of appetite, weight loss	Decrement in performance
Dizziness	Poor sleep, vivid dreams
Fatigue and Somnolence (microsleep)	Visual/auditory hallucinations
	Dyspnea

Table 2. HPNS Signs and Symptoms

Some amelioration of these signs and symptoms was found to be by selection of less susceptible divers, a very slow rate of compression with long stages to permit adaptation, but 1,000 ft remained the limit.

In 1950, Johnson and Flagler observed that on addition of ethyl alcohol to a tank of water containing tadpoles they would full narcotized to the bottom of the tank. However, application of 150 ATS hydrostatic pressure woke them up again. This was called "pressure reversal" of anesthesia. In 1967, the author measured the surface tension effects of an egg phospholipid monolayer, exposed to high pressures of nitrogen argon, carbon dioxide, oxygen, neon and helium (Fig 1). All except neon and helium cause a decrease in the surface tension but neon and helium caused an increase.

The fall in tension indicated an expansion of the monolayer (and inert gas narcosis) and the increase a constriction of the monolayer (and HPNS).

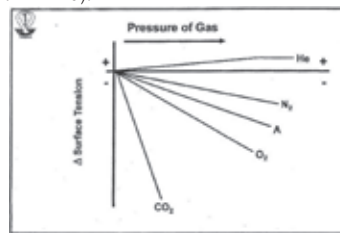


Fig 1. Surface Tension Measurements of Lipid Monolayer Exposed to Increased Pressure of Gases

It was therefore proposed by the author that the correct mixture of helium, nitrogen and oxygen (TRIMIX) would balance this membrane constriction (HPNS) or expansion (narcosis) and permit safe deep diving beyond 1,000 ft with neither narcosis or HPNS. Experiments were started in 1974 to prove the value of TRIMIX at Duke University Medical Center culminating in a series of 4 deep dives called Atlantis. These had either 5% nitrogen or 10% nitrogen in helium and either a fast 12 hour, 30 min. compression rate to 1,500 ft or slow 7 day, 9 hour rate to 2,132 ft. A record excursion was made in Atlantis III to 2,250 ft. Extensive research studies including tremors of the hands, psychological and psychomotor tests, EEG frequency analysis, lung function with arterial blood gases and bicycle ergometer work, hematology, Doppler bubble detection, etc indicated the slow compression rate and 5% nitrogen strongly ameliorated HPNS.

Table 2: Duke/GUSI Compression to 600 m with Trimix 5 (5% N₂, 0.5 ata O₂, Remainder Helium)

Travel 0-180 m	= 5 m/min (36 min)
Stop at 180 m	= 2 h
Travel 180-240 m	= 3 m/min (20 min)
Stop at 240 m	= 6 h
Travel 240-300 m	= 1.5 m/min (40 min)
Stop at 300 m	= 2 h
Travel 300-350 m	= 0.5 m/min (1 h 40 min)
Stop at 350 m	= 9 h
Travel 350-400 m	= 0.25 m/min (3 h 20 min)
Stop at 400 m	= 2 h
Travel 400-430 m	= 0.125 m/min (4 h)
Stop at 430 m	= 2 h
Travel 430-460 m	= 0.125 m/min (4 h)
Stop at 460 m	= 12 h
Travel 460-490 m	= 0.100 m/min (5 h)
Stop at 490 m	= 2 h
Travel 490-520 m	= 0.100 m/min (6 h 40 min)
Stop at 520 m	= 13 h
Travel 520-550 m	= 0.075 m/min (6 h 40 min)
Stop at 550 m	= 13 h
Travel 550-575 m	= 0.05 m/min (8 h 20 min)
Stop at 575 m	= 16 h
Travel 575-600 m	= 0.05 m/min (8 h 20 min)

Later in 1983-86, a German/Duke Medical Center team at the German Underwater Simulator near Hamburg, using the Atlantis IV compression profile (Table 2) made 14 further deep working dives (8 hours welding/day) breathing TRIMIX 5% nitrogen with little or no HPNS to depths between 1,500-2,132 ft. In 1986-1990, 17 more such TRIMIX 5 dives were made with 2,662 man days of saturation and 983 days of welding at 1,500 ft proving the success of TRIMIX for the control of HPNS in deep diving with no evidence of permanent residual signs or symptoms.

References

- 1) Bennett PB, Rostain JC 2003. Inert Gas Narcosis in Bennett & Elliotts Physiology and Medicine of Diving. Ed. Brubakk AO, Neuman TS, pp. 300-322. Saunders. 5th Edition
- 2) Bennett PB, Rostain JC 2003. The High Pressure Nervous Syndrome in Bennett & Elliotts Physiology and Medicine of Diving. Ed Brubakk AO, Neuman TS, pp. 323-357. Saunders. 5th Edition.