Health and efficiency in trimix versus air breathing in compressed air workers.

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Abstract

The Western Scheldt Tunneling Project in the Netherlands provided a unique opportunity to evaluate the effects of trimix usage on the health of compressed air workers and the efficiency of the project. Data analysis addressed 318 exposures to compressed air at 3.9-4.4 bar gauge and 52 exposures to trimix (25% oxygen, 25% helium, and 50% nitrogen) at 4.6-4.8 bar gauge. Results revealed three incidents of decompression sickness all of which involved the use of compressed air. During exposure to compressed air, the effects of nitrogen narcosis were manifested in operational errors and increased fatigue among the workers. When using trimix, less effort was required for breathing, and mandatory decompression times for stays of a specific duration and maximum depth were considerably shorter. We conclude that it might be rational—for both medical and operational reasons—to use breathing gases with lower nitrogen fractions (e.g., trimix) for deep-caisson work at pressures exceeding 3 bar gauge, although definitive studies are needed.

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Compressed air tunneling and caisson work decompression procedures: development, problems, and solutions.

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Abstract

Multinational experience over many years indicates that all current air decompression schedules for caisson and compressed air tunnel workers are inadequate. All of them, including the Occupational Safety and Health Administration tables, produce dysbaric osteonecrosis. The problem is compounded because decompression sickness (DCS) tends to be underreported. Permanent damage in the form of central nervous system or brain damage may occur in compressed air tunnel workers, as seen on magnetic resonance imaging, in addition to dysbaric osteonecrosis. Oxygen decompression seems to be the only viable method for safely decompressing tunnel workers. Oxygen decompression of tunnel workers has been successfully used in Germany, France, and Brazil. In Germany, only oxygen
decompression of compressed air workers is permitted. In our experience, U.S. Navy tables 5 and 6 usually prove adequate to treat DCS in caisson workers despite extremely long exposure times, allowing patients to return to work following treatment for DCS. Tables based on empirical data and not on mathematical formulas seem to be reasonably safe. U.S. Navy Exceptional Exposure Air Decompression tables are compared with caisson tables from the United States and Great Britain.


Decompression sickness in the rat following a dive on trimix: recompression therapy with oxygen vs. heliox and oxygen.

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Comment in:


Abstract

Trimix (a mixture of helium, nitrogen, and oxygen) has been used in deep diving to reduce the risk of high-pressure nervous syndrome during compression and the time required for decompression at the end of the dive. There is no specific recompression treatment for decompression sickness (DCS) resulting from trimix diving. Our purpose was to validate a rat model of DCS on decompression from a trimix dive and to compare recompression treatment with oxygen and heliox (helium-oxygen). Rats were exposed to trimix in a hyperbaric chamber and tested for DCS while walking in a rotating wheel. We first established the experimental model, and then studied the effect of hyperbaric treatment on DCS: either hyperbaric oxygen (HBO) (1 h, 280 kPa oxygen) or heliox-HBO (0.5 h, 405 kPa heliox 50%-50% followed by 0.5 h, 280 kPa oxygen). Exposure to trimix was conducted at 1,110 kPa for 30 min, with a decompression rate of 100 kPa/min. Death and most DCS symptoms occurred during the 30-min period of walking. In contrast to humans, no permanent disability was found in the rats. Rats with a body mass of 100-150 g suffered no DCS. The risk of DCS in rats weighing 200-350 g increased linearly with body mass. Twenty-four hours after decompression, death rate was 40% in the control animals and zero in those treated immediately with HBO. When treatment was delayed by 5 min, death rate was 25 and 20% with HBO and heliox, respectively.


Assessment of Extravascular Lung Water and Cardiac Function in Trimix SCUBA Diving.
Abstract

INTRODUCTION: An increasing number of recreational self-contained underwater breathing apparatus (SCUBA) divers use trimix of oxygen, helium and nitrogen for dives deeper than 60 msw. Although it was seldom linked to the development of pulmonary edema, whether SCUBA diving affects the extravascular lung water (EVLW) accumulation is largely unexplored. METHODS: Seven divers performed six dives in consecutive days using compressed gas mixture of oxygen, helium and nitrogen (trimix), with diving depths ranging from 55 to 80 m. The echocardiographic parameters (bubble grade, lung comets, mean pulmonary arterial pressure - PAP, left ventricular function) and blood levels of N-terminal part of pro-brain natriuretic peptide (NT-proBNP) were assessed before and after each dive. RESULTS: Venous gas bubbling was detected after each dive with mean probability of decompression sickness (DCS) ranging from 1.77 to 3.12%. After each dive, a number of ultrasonographically detected lung comets (ULC) rose significantly, which was paralleled by increased pulmonary artery pressure (PAP) and decreased left ventricular contractility (reduced ejection fraction at higher end-systolic and end-diastolic volumes), as well as the elevated NT-proBNP. The number of ULC and mean PAP did not return to baseline values after each dive. CONCLUSION: This is the first report that asymptomatic SCUBA dives are associated with accumulation of EVLW with concomitant increase in PAP, diminished left ventricular contractility and increased release of NT-proBNP, suggesting a significant cardiopulmonary strain. EVLW and PAP did not return to baseline during the course of repetitive dives, indicating possible cumulative effect with increasing the risk for pulmonary edema.


Effects of successive air and trimix dives on human cardiovascular function.

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Abstract

INTRODUCTION: The use of trimix (a mixture of oxygen, helium, and nitrogen) has significantly increased among the diver population. However, data indicating how trimix dives at most common depths affect the cardiovascular function are sparse. The purpose of this study was to investigate the cardiovascular effects of trimix dives and compare them with air dives and to determine whether the repetition of dives in successive days affects their extent. METHODS: Nine professional divers performed four dives in consecutive days where the dive depth was progressively increased to the maximum of 55 m. Divers used air in the first dive, nitrox 25 in the second, and trimix 20/30 in the third and fourth dives. Echocardiography was performed before and after each dive. RESULTS: After each dive, a significantly decreased left ventricular ejection fraction and fractional shortening and an
increased end-systolic volume without a change in end-diastolic volume were found, indicating a depressed systolic function of the left side of the heart. Assessment of the ratio between pulmonary artery acceleration time and right ventricular ejection time (used as an indicator of pulmonary artery pressure (PAP)) revealed an increase in PAP after all the dives. No physiologically relevant cumulative effects of the multiple dives or signs of acclimatization were found. CONCLUSIONS: The current study shows that the cardiovascular effects of trimix dives do not differ from those of the dives with compressed air. However, it suggests that even a very safe and conservative trimix diving profile exerts significant cardiovascular effects.


**The effects of acute oral antioxidants on diving-induced alterations in human cardiovascular function.**


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Comment in:
- **J Physiol.** 2007 Aug 15;583(Pt 1):405; author reply 407.

**Abstract**

Diving-induced acute alterations in cardiovascular function such as arterial endothelial dysfunction, increased pulmonary artery pressure (PAP) and reduced heart function have been recently reported. We tested the effects of acute antioxidants on arterial endothelial function, PAP and heart function before and after a field dive. Vitamins C (2 g) and E (400 IU) were given to subjects 2 h before a second dive (protocol 1) and in a placebo-controlled crossover study design (protocol 2). Seven experienced divers performed open sea dives to 30 msw with standard decompression in a non-randomized protocol, and six of them participated in a randomized trial. Before and after the dives ventricular volumes and function and pulmonary and brachial artery function were assessed by ultrasound. The control dive resulted in a significant reduction in flow-mediated dilatation (FMD) and heart function with increased mean PAP. Twenty-four hours after the control dive FMD was still reduced 37% below baseline (8.1 versus 5.1%, P = 0.005), while right ventricle ejection fraction (RV-EF), left ventricle EF and endocardial fractional shortening were reduced much less (approximately 2-3%). At the same time RV end-systolic volume was increased by 9% and mean PAP by 5%. Acute antioxidants significantly attenuated only the reduction in FMD post-dive (P < 0.001), while changes in pulmonary artery and heart function were unaffected by antioxidant ingestion. These findings were confirmed by repeating the experiments in a randomized study design. FMD returned to baseline values 72 h after the dive with pre-dive placebo, whereas for most cardiovascular parameters this occurred earlier (24-48 h). Right ventricular dysfunction and increased PAP lasted longer. Acute antioxidants attenuated arterial endothelial dysfunction after diving, while reduction in heart and pulmonary artery function were unchanged. Cardiovascular changes after diving are not fully reversed up to 3 days after a dive, suggesting longer lasting negative effects.
[Experimental studies of the effects of enriched air nitrox dive on shortening of decompression time and reduction of risks of decompression sickness]

[Article in Japanese]

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Abstract

Enriched air nitrox diving has been conducted to shorten decompression time as well as to reduce risks of decompression sickness. Nine volunteer divers served as subjects for nitrox (-a: 60% N2 and 40% O2, and -b: 67.5% N2 and 32.5% O2) and air chamber dives of 20 m/60 min, 30 m/60 min and 40 m/60 min. Venous gas emboli (VGE) were examined after surfacing in a series of nitrox dives and of air dives to compare the risks of decompression sickness (DCS). Three divers as a group were compressed in a chamber for each dive. Decompression was carried out according to the Norwegian Navy nitrox decompression tables for the nitrox dives, and for the air dives the Japanese Ministry of Labor tables were used. Decompression time was much shorter in nitrox diving than in air dives for the same dive profiles. All of nitrox-a and air divers showed no VGE nor DCS symptoms after surfacing of 20 m dives. In case of 30 m dives, VGE appeared in one diver (33%) without DCS symptoms in nitrox-a dive but no VGE nor DCS in nitrox-b dive, whereas for the same air dives two subjects (66%) had VGE and DCS symptoms. When the depth was increased to 40 m in the nitrox dive, nitrox-b did not show both VGE and DCS, while the air dive showed one VGE and one DCS. These results suggest that the nitrox dive with suitable decompression schedule reduces the risks of DCS as well as shortening decompression obligation.

Doppler ultrasound surveillance in deep tunneling compressed-air work with Trimix breathing: bounce dive technique compared to saturation-excursion technique.

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Abstract
The Western Scheldt Tunneling Project in The Netherlands provided a unique opportunity to evaluate two deep-diving techniques with Doppler ultrasound surveillance. Divers used the bounce diving techniques for repair and maintenance of the TBM. The tunnel boring machine jammed at its deepest depth. As a result the work time was not sufficient. The saturation diving technique was developed and permitted longer work time at great depth. Thirty-one divers were involved in this project. Twenty-three divers were examined using Doppler ultrasound. Data analysis addressed 52 exposures to Trimix at 4.6-4.8 bar gauge using the bounce technique and 354 exposures to Trimix at 4.0-6.9 bar gauge on saturation excursions. No decompression incidents occurred with either technique during the described phase of the project. Doppler ultrasound revealed that the bubble loads assessed in both techniques were generally low. We find out, that despite longer working hours, shorter decompression times and larger physical workloads, the saturation-exursion technique was associated with significant lower bubble grades than in the bounce technique using Doppler Ultrasound. We conclude that the saturation-exursion technique with Trimix is a good option for deep and long exposures in caisson work. The Doppler technique proved valuable, and it should be incorporated in future compressed-air work.


**Commentary on viewpoint "Heliox, nitrox, and trimix diving; hyperbaric oxygen treatment; and a flaw in Henry's law.**

*Wienke BR.*

Comment on:


**Ultrasonic evidence of acute interstitial lung edema after SCUBA diving is resolved within 2-3h.**


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**Abstract**

Recently, an increase in extravascular lung water (EVLW) accumulation with diminished left ventricular contractility within 60min after SCUBA diving was reported. We have observed previously that diving was associated with reduced diffusing lung capacity for carbon monoxide (DLCO) and arterial oxygen pressure for up to 60-80min postdive. Here we
investigated whether increased EVLW persists 2-3h after successive deep dives in a group of seven male divers. The echocardiographic indices of pulmonary water accumulation (ultrasound lung comets (ULC)) and left ventricular function, respiratory functional measurements and arterial oxygen saturation (SaO(2)) were assessed 2-3h post diving, while venous gas bubbles (VGB) and the blood levels of NT-proBNP and proANP were analyzed 40min after surfacing. Spirometry values, flow-volume, DLCO, SaO(2) and ULC were unchanged after each dive, except for significant increase in ULC after the second dive. Left ventricular function was reduced, while NT-proBNP and proANP levels were significantly elevated after majority of dives, suggesting a cardiac strain. Copyright © 2010 Elsevier B.V. All rights reserved.


**Effect of a single air dive on pulmonary diffusing capacity in professional divers.**

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**Abstract**

The aim of this study was to determine whether venous gas embolism after a single air dive, evaluated using precordial Doppler monitoring, was associated with alterations in spirometry, lung volumes, arterial blood gases, or pulmonary diffusing capacity for carbon monoxide (DLCO). Postdive time course monitoring of pulmonary function was undertaken in 10 professional divers exposed to absolute air pressure of 5.5 bar for 25 min in a dry walk-in chamber. The US Navy decompression table was followed. Venous bubbles were detected by precordial Doppler monitoring. Two types of decompression were used: air and 100% O2 applied for 21 min during decompression stops. Spirometry, flow-volume, and body plethysmography parameters were unchanged after the dive with air decompression (AD) as well as with O2 decompression (OD). A significant reduction in arterial PO2, on average 20 Torr, was found after the dive with AD. DLCO was decreased in all divers 20, 40, 60, and 80 min after diving with AD (P < 0.001), whereas it was not significantly decreased after diving with OD. Maximal DLCO decrease of approximately 15% occurred 20 min postdive. In AD diving, maximum bubble grade for each individual vs. maximum DLCO reduction correlated significantly (r = 0.85, P = 0.002), as well as DLCO vs. arterial PO2 (r = 0.64, P = 0.017). In conclusion, a reduction in pulmonary diffusing capacity is observed in parallel with the appearance of venous bubbles detected by precordial Doppler. We suggest that bubbles cause pulmonary microembolization, triggering a complex sequence of events that remains to be resolved. Measuring DLCO complements Doppler bubble detection in postdiving assessment of pulmonary function.