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Experiment of Nitrox Saturation Diving with Trimix Excursion

Shi Zhnog-yuan

Chinese Underwater Technology Institute

Abstract. Depth limitations to diving operation with air as the breathing gas are well known: air density, oxygen toxicity, nitrogen narcosis and requirement for decompression. The main objectives of our experiment were to assess the decompression, counterdiffusion and performance aspect of helium-nitrogen-oxygen excursions from nitrox saturation. The experiment was carried out in a wet diving stimulator with "igloo" attached to a 2-lock living chamber. Four subjects of two teams of 2 divers were saturated at 25 msw simulated depth in a nitrogen oxygen chamber environment for 8 days, during which period they performed 32 divers-excursions to 60 or 80 msw pressure. Excursion gas mix was trimix of 14.6% oxygen, 50% helium and 35.4% nitrogen, which gave a bottom oxygen partial pressure of 1.0 bars at 60 msw and 1.3 at 80 msw. Excursions were for 70 min at 60 msw with three 10-min work periods and 40 min at 80 msw with two 10-min work periods. Work was on a bicycle ergometer at a moderate level. We calculated the excursion decompression with M-Values based on methods of Hamilton (Hamilton et al., 1990). Staged decompression took 70 min for the 60 msw excursion and 98 min for 80 msw, with stops beginning at 34 or 43 msw respectively. After the second dive day bubbles were heard mainly in one diver but in three divers overall, to Spencer Grade III some times. No symptoms were reported. Saturation decompression using the Repex procedures began at 40 msw and was uneventful: Grade II and sometimes III bubbles persisted in 2 of the four divers until 24 hr after surfacing. We conclude that excursions with mixture rich in helium can be performed effectively to as deep as 80 msw using these procedures.

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Keywords: nitrox saturation diving, trimix excursion, bubble detection

Introduction

The project objective is to extend the capabilities of long duration, saturation-based shallow-water diving techniques. Though nitrogen-oxygen saturation diving with deeper air excursion can increase underwater work efficiency, but the limitation in capabilities when using air as the breathing gas during excursions is nitrogen narcosis and oxygen toxicity. Recently other approaches to self-contained diving in more deeper range have shown the benefits of using a trimix of helium, nitrogen and oxygen for effective performance and efficient decompression (Mount and Gilliam, 1993; Juvenspan and Thomas, 1992; Palmer, 1994). Relevant experience with excursion using helium from nitrox saturation is limited. In underwater work divers saturated with air at 14 msw excursed to 24 msw breathing 15% oxygen in helium (Peterson et al., 1980). The 14 msw depth was calculated to be the deepest saturation depth that would allow excursion without creating supersaturation; outcome was satisfactory. One Experiment, Nisahex, tested helium trimix excursions from nitrox saturation (Muren et al., 1984). This experiment involved saturation with nitrox at the relatively high pressure of 60 msw and excursion with helium-nitrogen-oxygen to 80 and 100 msw with no Doppler bubbles detected and no decompression or counterdiffusion problem.

The main objective was to prepare procedures and assess the decompression aspect of vertical excursion from nitrox saturation using helium-based breathing mixture. Determining the counterdiffusion aspect of the use of the two gases was a part of this goal. A corollary aspect of the project was to prepare provisional decompression tables and procedures for excursions using helium-nitrogen-oxygen gases from relevant saturation storage depths, based on the result of the experiment.

Methods

The experiment was conducted at the Chinese Underwater Technology Institute in Shanghai. A 5-compartment chamber complex was used. Four divers livet in the main chamber. The entry lock served as a toiled room with wash basin and thermoregulated shower. The lower part of the work chamber was filled water and in this chamber the wet excursion were made, and the top "igloo" is used for the dive station. Two horizontally oriented, dual-lock living chambers are attached to the

Table 1 The characteristics of divers-subjects

Diver ID	GJ	WK	WX	ZY
Age, yr	33	43	38	34
Weight, kg	64.0	57.0	72.0	63.0
Height, m	1.73	1.68	1.70	1.69
Fitness level	Very good	Good	Very good	Very good
Daily exercise	1 hr per day	0.5 hr per day	0.5 hr per day	1 hr per day
Smoker?	Yes	Yes	Yes	Yes
Diving school	Yan Tai Diving School	Diving training in Chinese Navy	Diver training, 11 mo, Comex, 1979	Yan Tai Diving School
Years professional	17	23	19	17
Approximate number of dives	50 times per year	50 times per year	50 times per year	50 times per year
Previous DCS	Once in 1983	Once in 1985	No	Twice, 1983, 1994
Previous skin bends	Once in 1983	Once in 1985	No	Twice, 1983, 1994

Table 2 The schedule of dives and divers

	60 msw		80 msw		60 msw		80 msw	
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
Morning	GJ wet WK dry	ZY wet WX dry	WX wet ZY dry	WK wet GJ dry	GJ wet WK dry	ZY wet WX dry	WX wet ZY dry	WK wet GJ dry
Afternoon	WX wet ZY dry	WK wet GJ dry	GJ wet WK dry	ZY wet WX dry	WX wet ZY dry	WK wet GJ dry	GJ wet WK dry	ZY wet WX dry

igloo, the living chamber used for this project is equipped with bunks in one lock and the other lock is used for physiological monitoring. The system is controlled and monitored from a nearby control room. Auto control system maintains ambient pressure and oxygen partial pressure and can decompress on a precise linear curve. The life-support system for the living chamber kept the temperature at 25–26°C, the relative humidity was 50–70%, and the oxygen partial pressure between 0.30–0.38 bar, the nitrogen partial pressure between 3.12–3.20 bar throughout the stay at saturation pressure.

Four fit, professional divers selected from a competition were examined and qualified medically. Their characteristic are given in Table 1. The four divers performed one dive per each day. They were divided into two teams of two divers each, and each team performed one dive per day while other remained in the living chamber. Divers were carried out the excursion in the morning and afternoon. Excursions were done in the igloo and the wet pool beneath. For each dive both divers of each excursion team were dressed for diving; on dive the working diver went in the water wearing a Superlite Motel 17 and performed work on the ergometer, while the other diver remained dry, breathed by full-face mask, and acted as a tender for the working diver. Both divers breathed the trimix gas during the excursion. The wet chamber for excursion was compressed with air. We chose 60 and 80 msw as the depths for the excursions and planned four days of 60 msw dives and four days of 80 msw dives, starting with the presumably easier 60 msw excursion for the first two days, then did 4 days of 80 msw followed by 2 final days at 60 msw. This put 60 msw excursions on the final days, so that we would be fairly sure to complete the deeper excursion. We distributed the exposure and duties uniformly over the eight dives, with the results that each diver had to do each type of dive in each position. This gave a diver 4 dives at each depth, two working and two tending, for a total of 32 man-dives on the saturation days. The overall schedule is summarized in Table 2.

The breathing gas for excursion was 14.6% oxygen, 50.0% helium and 35.4% nitrogen. The same gas was used for both 60 and 80 msw excursion. We made Doppler measurements 15, 30, 45 and 60 minutes after the end of excursion, with additional readings at 90 and 120 min if bubbles were still being. Doppler monitoring was continued during the saturation decompression using Spencer method (Spencer, 1976).

Results and Discussion

The project was carried out as planned. All the excursions were a total of 32 man-times. The results of the experiment show that the main objectives were met in that trimix excursions successfully with no decompression illness being reported and bubble counts as detected by Doppler ultrasound were within acceptable limits. A profile of the entire project is shown in Fig. 1.

The objective of our experiment was to develop the

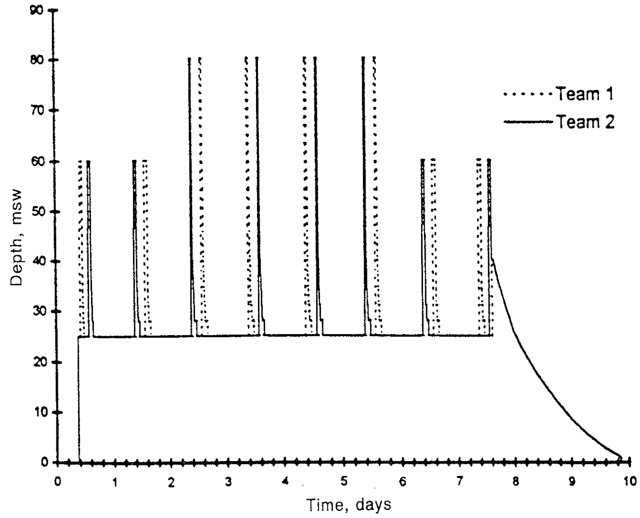

Fig. 1 Profile of the experiment.

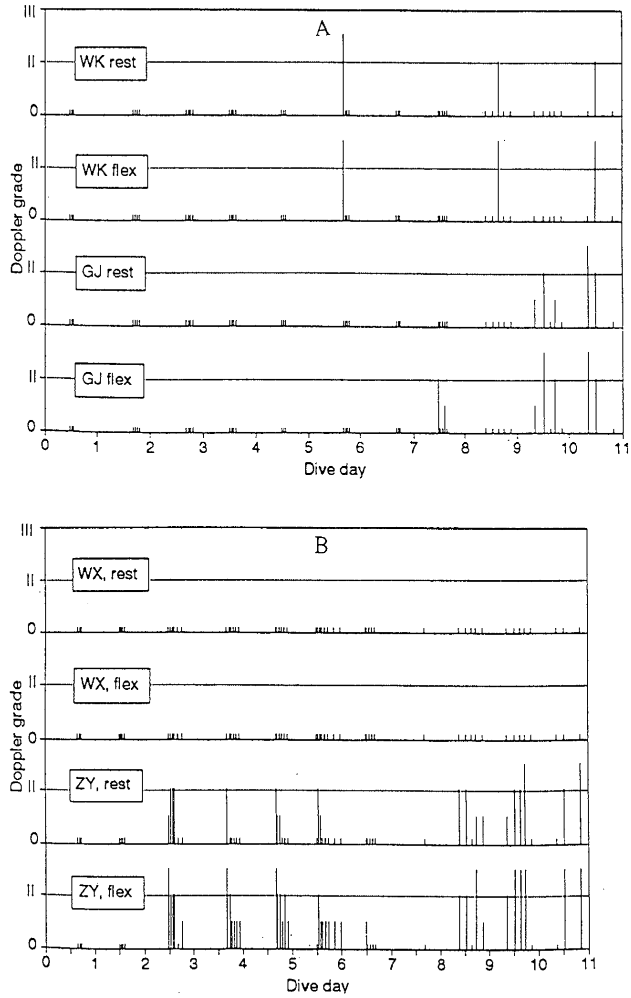

Fig. 2 Doppler results on Team 1. Divers GJ and WK (A) and Team 2 Divers ZY and WX (B). Upper trace in each pair is readings taken at rest, lower ("flex") is after two or more knee bends. Small ticks indicate no bubbles.

basis for decompression table for excursion with helium mixtures from a nitrogen-based habitat atmosphere. This involved a gas switch with potential for supersaturation due to counterdiffusion. The basis for new excursion procedures fitting this requirement is nonexistent or at best limited. Accordingly, we had make some guesses on a small bank of information, then put them to the test, we can discuss as if it were a single, definable limit. Given the exposures, the evidence suggests that is about right. We got bubbles, but not too many: one Grade III after flexing and that one isolated-out of 30 exposures and 86 reading is quite acceptable for operational table. No symptoms of decompression illness and counterdiffusion response were reported. It is well known that an isobaric switch from heavy, slowly-diffusing gas to a lighter, more rapidly diffusing gas can lead to symptoms of counterdiffusion resembling those of decompression sickness (Lambertsen, 1989). One of the objectives of our experiment was to evaluate the benefit of simultaneous compression to offset the possible supersaturation due to this switch. We used the computational method which monitors deep tissue counterdiffusion as well as decompression and the result shows a supersaturation or violation of M-values from isobaric counterdiffusion of appropriate gases should that situation occur. But we calculated the procedure of trimix excursions based on commercial heliox criteria. There were no symptoms of decompression illness and counterdiffusion. This means that using our helium-nitrogen-oxygen mixture can avoid the counterdiffusion problems by sufficient additional compression at the time of switching gases.

We used the Repex saturation decompression procedure (Hamilton et al., 1988). This method required less total time than holding at storage depth, but it does require some gas and chamber manipulation. This initial part of the decompression is called the "precursory" decompression: it was tested again in our experiment. The precursory decompression table required 560 min from the start at 40 msw until leaving 25 msw at the end of 25 msw stop. The total decompression took 3230 min or 53:50 hours. The Auto Control System did a splendid job of tracking a linear path for the saturation decompression. It followed the stair-stop stage decompression pattern leaving each step at the time called for in the table. After completing a 200 min interval going from 2 to 1 msw the chamber was surfaced in 5 min from 1 msw. No symptoms of decompression sickness were reported, the divers remained in excellent spirits throughout the decompression.

Where possible we made Doppler measurement after the end of each excursion, and Doppler monitoring was continued during the saturation decompression. There were some Doppler bubbles as shown in Fig. 2. These show a graph for each diver at rest and after flexing. The

Doppler Grades are shown as vertical lines. For example, no bubbles at all were heard during the first two days. After that, beginning with first 80 msw excursion on Day 3 diver ZY began to produce Doppler bubbles, he reached Grade III in at least one reading following his excursions on Days 3, 4 and 5. On Day 6 he had Grade II, and on Day 7 showed only a Grade I after flexing on the first reading. He began the saturation decompression during which from his last excursion on Day 8 so on Doppler reading was taken. He showed bubbles though most of the saturation decompression, usually Grade II at rest and Grade III after flexing.

From the results of our research we conclude that trimix excursion which breathing gases rich in helium can be performed effectively to as deep as 80 msw using these procedures. Bubble data and decompression results show general tolerance for the use of trimix from nitrox saturation. These results also add further verification to the algorithms used for the other excursion table, and provide a firm foundation for continuing this to other diving operational ranges.

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Correspondence to: Shi Zhong-yuan, Chinese Underwater Techonology Institute, 1500 Longwu Rd., Shanghai 200231, P.R. China