

Decompression from a deep nitrogen/oxygen saturation dive—a case report

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Barry PD, Vann RD, Youngblood DA, Peterson RE, Bennett PB. Decompression from a deep nitrogen/oxygen saturation dive—a case report. *Undersea Biomed Res* 1984; 11(4):387-393.—Ten divers participated in a 4.5 d nitrogen/oxygen saturation dive to 165 fsw. There were daily 2 h excursions to 61 msw (200 fsw). The divers breathed air during the excursions and 0.51 bar (0.5 atm) oxygen in nitrogen at 50.3 msw (165 fsw). The final decompression began 6 h after the last excursion. The oxygen partial pressure was 0.51 bar (0.5 atm) from 50.3 to 13.7 msw (165 to 45 fsw), and air was used from 13.7 msw (45 fsw) to the surface. By 6.1 msw (20 fsw), four divers had developed decompression sickness. A fifth diver developed decompression sickness during a commercial air flight 68 h after surfacing. Comparison of ascent rates for this dive and for air or nitrogen/oxygen saturation dives reported in the literature suggests that deeper dives require slower rates of ascent. Dives shallower than 30.5 msw (100 fsw) had a mean ascent rate of 1 msw/h (3.2 fsw/h) and 14 decompression incidents in 107 man-exposures. Dives deeper than 30.5 msw (100 fsw) had a mean rate of 0.76 msw/h (2.5 fsw/h) and 14 incidents in 45 man-exposures.

decompression sickness
saturation diving

nitrogen/oxygen
flying after diving

ascent rates

To determine if man could adapt to nitrogen narcosis, Oceaneering International, Inc., and the National Oceanic and Atmospheric Administration (NOAA) sponsored a nitrogen/oxygen saturation dive in the chambers of the F. G. Hall Laboratory at Duke University Medical Center. This communication describes and discusses the clinical results of the decompression from this dive.

Few studies describing decompression after nitrogen/oxygen saturation diving have been reported (1-5), but this information is of major importance for the development of safe decompression procedures. It is hoped that publication of these data will encourage similar reports of decompression studies from other laboratories.

METHODS

Ten experienced and physically qualified divers (ages 22–42) were compressed at a rate of 18.3 msw/h (60 ft/min) in air to a simulated depth of 61 msw (200 fsw). After 2 h at this depth, the divers were decompressed in 2 min to 50.3 msw (165 fsw) and transferred to another chamber containing 0.51 bar (0.5 atm) oxygen in nitrogen. The nitrogen partial pressure in the storage chamber at 50.3 msw (165 fsw) was equal to that of air at 61 msw (200 fsw). During the next 4 d, the divers were compressed on air once a day to 61 msw (200 fsw) for 2 h and then decompressed to 50.3 msw (165 fsw). After 4.5 d, they were decompressed to the surface in approximately 3.5 d. Figure 1 illustrates the dive profile.

Performance and psychological studies were conducted pre-dive, at 50.3 and 61 msw (165 and 200 fsw), during decompression, and post-dive, but no physical exercise took place. The divers completed questionnaires twice daily to assess their physical and mental well-being. The questions related to the signs and symptoms of nitrogen narcosis, decompression sickness, and general health. The divers also kept daily logs for post-dive evaluation.

The final decompression began 6 h after completion of the last excursion. The proposed decompression schedule is listed in Table 1. Travel time was approximately 1 min between stops and was included in the time at the next stop. An oxygen partial pressure of 0.51 bar (0.5 atm) was maintained until 13.7 msw (45 fsw) after which an oxygen percentage of 21% was maintained to the surface.

To avoid dehydration during decompression, the divers were encouraged to ingest large quantities of fluid. Adequate hydration was ensured by having each diver maintain a urine specific gravity of 1.004 as determined by his own hydrometer measurements. The temperature

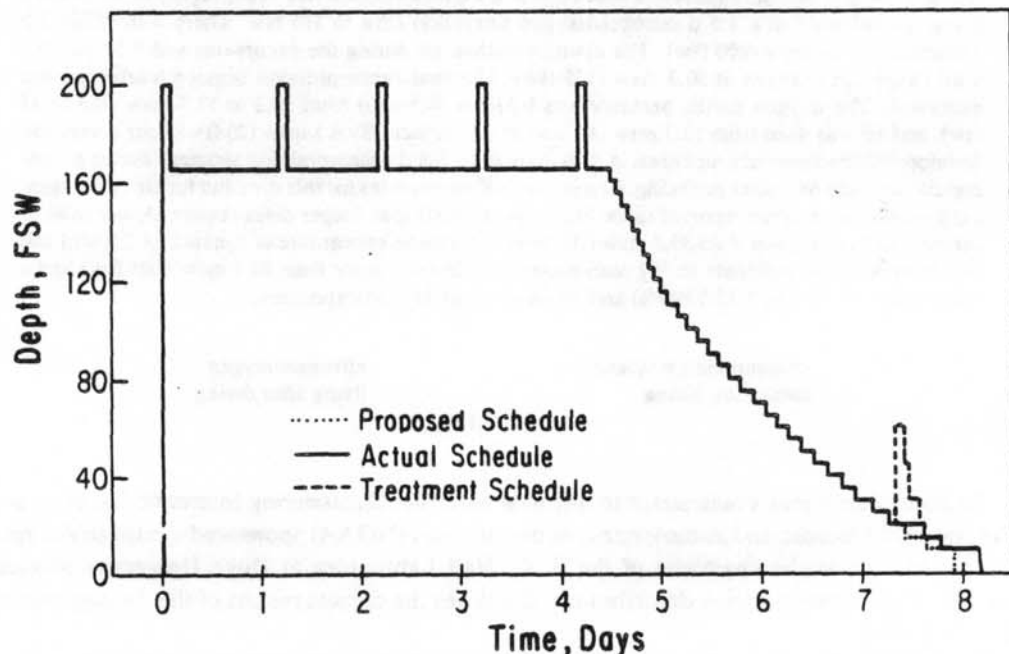


Fig. 1. Dive profile. Breathing gas was 0.51 bar (0.5 atm) oxygen in nitrogen at 50.3 msw (165 fsw) and air at 61 msw (200 fsw). During decompression, oxygen partial pressure was 0.51 bar (0.5 atm) from 50.3 to 13.7 msw (165 to 45 fsw). Air was used from 13.7 msw (45 fsw) to the surface.

TABLE 1
DECOMPRESSION SCHEDULE

Depth, msw (fsw)	Stop Time, min
50.3–35.1 (165–115)	80*
35.1 (115)	90
33.5 (110)	140
32.0 (105)	145
30.5 (100)	145
29.0 (95)	150
27.4 (90)	150
25.9 (85)	150
24.4 (80)	150
22.9 (75)	155
21.3 (70)	160
19.8 (65)	160
18.3 (60)	165
16.8 (55)	190
15.2 (50)	190
13.7 (45)	195
12.2 (40)	195
10.7 (35)	215
9.1 (30)	215
7.6 (25)	230
6.1 (20)	230
4.6 (15)	245
3.1 (10)	525
3.1–0 (10–0)	10

*Time at each 1.5 msw (5 fsw) stop.

in the chamber was 27.8°C–28.9°C (82–84°F) during the day but was raised to 31.1°C–32.2°C (88–90°F) at night to enhance perfusion. Some divers found these higher temperatures uncomfortable.

Precordial Doppler bubble-detection studies were conducted at the 9.1, 7.6, 6.1, and 3.1 msw (30, 25, 20, and 10 fsw) decompression stops and shortly after arrival at the surface. To take Doppler readings, the probe was positioned on the chest of a supine diver and the diver was asked to flex each limb separately. Bubble scores were assigned according to the scale of Spencer (6). All except the postdive readings were taken in the chamber.

RESULTS

Decompression was uneventful until 19.8 msw (65 fsw) where one diver complained of a vague, minor pain in his right ankle. This pain occurred intermittently and became stronger as the 6.1 msw (20 fsw) stop was approached. A second diver reported a sharp pain in the left elbow while traveling from 7.6 to 6.1 msw (25 to 20 fsw). The pain lasted 1–2 min and subsided spontaneously. He also noted mild discomfort in both knees where he previously had a bilateral iliotibial band syndrome. This condition had developed 6 months before the dive but had been

asymptomatic for 2 months. A third diver experienced transient, mild to moderate right elbow pain at 19.8 msw (65 fsw) and slight left knee pain during the move from 7.6 to 6.1 msw (25 to 20 fsw).

A fourth diver, the youngest of the 10, developed fairly severe and constant pain in his right knee shortly before leaving the 9.1 msw (30 fsw) stop. The pain became worse until well into the 6.1 msw (20 fsw) stop where he reported tingling in the right calf, pain in the right leg when walking, and a steady, aching pain behind the right knee and in the right thigh. Neurologic examination by a diving medical officer, who was one of the divers, showed no objective signs of spinal cord involvement.

The four divers who had symptoms of decompression sickness were placed on 100% oxygen and compressed to 18.3 msw (60 fsw) for treatment on a modified U.S. Navy Treatment Table 6. This table was extended at 18.3 msw (60 fsw) to include one extra 20 min oxygen cycle. Six oxygen cycles were given at 9.1 msw (30 fsw). After treatment, the divers were returned to 6.1 msw (20 fsw) rather than to the surface.

Although all divers had 100% relief of symptoms, the diver with the most severe symptoms experienced aggravation of his knee and thigh pain during the first oxygen cycle. He was 90% asymptomatic after the third cycle and completely asymptomatic after the fourth cycle. This diver became dizzy during the ascent from 18.3 to 9.1 msw (60 to 30 fsw), and all divers were taken off oxygen for 15 min at 13.7 msw (45 fsw) for observation. After the dizziness cleared and no other symptoms were reported, decompression to 9.1 msw (30 fsw) was resumed.

The six divers who had not reported symptoms remained at 6.1 msw (20 fsw) and breathed 100% oxygen for 25 min as a precautionary measure. When the four treated divers arrived at 6.1 msw (20 fsw), all divers received five grains of aspirin and again were encouraged to remain well hydrated. Decompression was resumed on the original schedule (Table 1) with two prophylactic oxygen cycles at 3.1 msw (10 fsw) and with oxygen breathing during the 10 min ascent from 3.1 msw (10 fsw) to the surface.

A fifth diver developed decompression sickness during a commercial flight in a pressurized aircraft 68 h after leaving the chamber. Symptoms began 10 to 15 s after take-off. The final cabin altitude is unknown, but commercial cabin altitudes typically fall between 5000 and 8000 ft. The diver's symptoms were weakness and nausea with severe pain in the knees, hips, back, shoulders, elbows, wrists, and jaw. These symptoms persisted after landing.

Although he had reported no symptoms during the dive, the diver's log contained a record of mild, transient muscle pain in the left deltoid and biceps area at a depth of 16.8–15.2 msw (55–50 fsw). He had no other aches or pains during or immediately after the dive. He was not one of the divers treated on the modified U.S. Navy Table 6, but because of nausea did not complete the precautionary oxygen-breathing period given the other divers at 6.1 msw (20 fsw).

During the 10-d period following his flight, he received one U.S. Navy Treatment Table 6, four Treatment Table 5s, and one short oxygen-breathing period at 9.1 msw (30 fsw). Pulmonary oxygen toxicity precluded further hyperbaric oxygen therapy. He also received anti-inflammatory agents and corticosteroids. Transient pains continued with decreasing frequency for 1 yr and 3 months.

All divers had evidence of intravascular bubbles with Doppler bubble grades ranging from 0 to 4, but eight divers had grades of no higher than 2. The diver who experienced left elbow pain when traveling from 7.6 to 6.1 msw (25 to 20 fsw) had a grade of 3 in his left arm at the 6.1 msw (20 fsw) stop. The diver who developed frank decompression sickness at 6.1 msw (20 fsw) had a grade of 4. In all divers with symptoms, the highest bubble grade was associated with the painful limb. Table 2 lists the bubble grades for both treated and untreated groups.

TABLE 2
DOPPLER BUBBLE GRADES

Depth, msw (fsw)	Maximum Bubble Grade		
	2	3	4
9.1 (30)	3(3)*	(3)	1
7.6 (25)	2(4)	1(2)	1
6.1 (20)	2(6)	1	1
3.1 (10)	2(2)	2(4)	-
0 (0)	(1)	4(5)	-

*Number of treated divers. (Number of untreated divers are shown in parentheses.)

TABLE 3
**AVERAGE ASCENT RATES UNTIL THE OCCURRENCE OF DECOMPRESSION SICKNESS FOR
PUBLISHED AIR AND NITROGEN/OXYGEN SATURATION DIVES.**

Dive Name (Reference)	Saturation Depth, msw (fsw)	Rate msw/h (fsw/h)	% DCS (No. DCS/ No. Divers)
Pre-SHAD (2)	15.2 (50)	2.32 (7.60)	100 (2/2)
SHAD 1 (2)	15.2 (50)	1.13 (3.70)	0 (0/2)
SHAD 3 (2)	15.2 (50)	1.12 (3.68)	33 (1/3)
SHAD 2 (2)	18.3 (60)	1.14 (3.74)	50 (1/2)
SCORE (1,5)	18.3 (60)	1.06 (3.48)	15 (7/48)
AIRSAT 1 & 2 (3)	18.3 (60)	1.00 (3.28)	9 (2/23)
SUREX 65 (3)	19.8 (65)	0.64 (2.10)	6 (1/18)
SUREX 75 (3)	22.9 (75)	0.66 (2.18)	0 (0/6)
NOAA OPS 1 (1)	27.4 (90)	1.19 (3.91)	0 (0/3)
AIRSAT 3 (3)	40.2 (132)	0.78 (2.55)	25 (3/12)
AIRSAT 4 (3)	40.2 (132)	0.66 (2.18)	7 (1/15)
OI/NOAA/DUKE	50.3 (165)	0.82 (2.69)	50 (5/10)
NISAT I (2)	60.4 (198)	0.37 (1.23)	0 (0/2)
NISAHEX (4)	60.4 (198)	0.89 (2.92)	83 (5/6)

Although the difference in mean bubble grade between the two groups was not statistically significant, the treated divers tended to have higher bubble grades before recompression. The data are presented here to encourage publication of Doppler measurements from other saturation dives. Statistically significant trends may become evident if enough data are available.

DISCUSSION

The ascent from this unusually deep nitrogen/oxygen saturation dive was uneventful until 19.8 msw (65 fsw), after which 5 of the 10 divers developed symptoms of decompression sickness (DCS). The average rate of ascent from 50.3 to 19.8 msw (165 to 65 fsw) was 0.82 msw (2.7 fsw/h), whereas from 50.3 to 6.1 msw (165 to 20 fsw) the average rate was 0.67 msw/h (2.2 fsw/h). Table 3 shows the average ascent rates until the depth of the first symptoms for this dive and for other air or nitrogen/oxygen saturation dives (1-5). For dives to less than 30.5

msw (100 fsw), the incidence of decompression sickness was 13.1% (14 incidents in 107 man-exposures), and the mean ascent rate was 1 msw/h (3.2 fsw/h). For dives deeper than 30.5 msw (100 fsw), the incidence was 31.1% (14 incidents in 45 man-exposures), and the mean ascent rate was 0.76 msw/h (2.5 fsw/h). The higher decompression sickness incidence and the lower ascent rate for the deeper dives suggest that slower rates of ascent are necessary for deeper dives. Muren et al. (4) propose a similar hypothesis.

Table 1 shows that the ascent rate from 50.3 to 35.1 msw (165 to 115 fsw) was 1.16 msw/h (3.8 fsw/h), whereas the rate from 35.1 to 19.8 msw (115 to 65 fsw) was 0.58 msw/h (1.9 fsw/h). The shallower rate is slow compared to the rates in Table 3 indicating that the faster initial rate may have been responsible for subsequent decompression sickness.

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Barry PD, Vann RD, Youngblood DA, Peterson RE, Bennett PB. Décompression suite à une plongée profonde à saturation avec un mélange d'azote-oxygène. *Undersea Biomed Res* 1984; 11(4):387-393. Dix plongeurs participèrent à une plongée à saturation de 4.5 jours jusqu'à 50 d'eau salée (msw, 165 fsw) avec un mélange d'azote-oxygène. Il y eut des excursions journalières de 2 h jusqu'à 61 msw (200 fsw). Les plongeurs respirèrent de l'air au cours des excursions et un mélange de 0.51 bar (0.5 atm) d'oxygène avec de l'azote à 50.3 msw (165 fsw). La décompression finale commença 6 h après la dernière excursion. La pression partielle de l'oxygène était 0.51 bar (0.5 atm) de 50.3-13.7 msw (165-45 fsw), et de l'air fut employé à partir de 13.7 msw (45 fsw) jusqu'à la surface. Aux environs de 6.1 msw (20 fsw), 4 plongeurs furent atteints de la maladie de décompression. Un cinquième plongeur souffrit de la maladie de décompression au cours d'une envolée aérienne commerciale, 68 h après le retour à la surface. Une comparaison entre les vitesses de remontées dans cette plongée et pour des plongées à saturation avec de l'air ou un mélange d'azote-oxygène, décrites dans la littérature, suggère que les plongées plus profondes exigent des vitesses d'ascension plus lentes. Les plongées moins que 30.5 msw (100 fsw) de profondeur avaient une vitesse de remontée moyenne de 1 msw/h (3.2 fsw/h) et présentèrent 14 incidents de décompression sur 107 expositions humaines. Les plongées supérieures à 30.5 msw (100 fsw) de profondeur avaient une vitesse d'ascension moyenne de 0.76 msw/h (2.5 fsw/h) et 14 incidents sur 45 expositions humaines.

maladie de décompression
plongée à saturation

azote-oxygène
vol après plongée

vitesse de remontée

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