

**OFFSHORE TECHNOLOGY
REPORT - OTO 97 807**

**HELIUM IN DECOMPRESSION
FROM AIR DIVES
AN ISOBARIC SWITCH AT 40 MSW**

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WOLFSON HYPERBARIC MEDICINE UNIT

REPORT

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AN ISOBARIC SWITCH AT 40 MSW**

Sponsors

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HELIUM IN DECOMPRESSION FROM AIR DIVES

AN ISOBARIC SWITCH AT 40 MSW

1. Introduction

The restrictions placed upon diving using compressed air have severely limited the productivity of divers in water less than 50 msw.¹ Nitrox has been introduced with a restriction on the partial pressure of oxygen of 1.5 atm abs. Although the higher oxygen level in the diving gas offers some protection against decompression sickness, it has not eliminated the problem. Unfortunately there is the added risk of oxygen convulsions and a case has occurred after an exposure to 1.31 atm abs for only 30 minutes.

On the basis of the latest military research² and the increased risk of serious decompression sickness associated with an atrial septal defect, the objective of reducing intravascular bubbles on decompression remains as critical as ever in relation to commercial diving. It has been conclusively shown experimentally that the onset of neurological decompression sickness is due to arterial microbubbles.³ After surfacing from an air dive, the activity of the brain was affected before the spinal cord and the authors suggested that, despite assertions to the contrary, the brain is more vulnerable to decompression sickness than the cord. Neuropsychometric testing in divers with decompression sickness⁴ have shown that it is no longer adequate to rely on a physical examination to detect decompression sickness affecting the brain.

This trial was based upon the work already undertaken on the recent British Gas programme.⁵ In these studies helium was introduced to replace nitrogen, either partly, or completely in the decompression on 150 dives. The principle of gas washout using oxygen is well established, but pure oxygen is limited to a maximum depth of 18 msw because of oxygen toxicity.

Three approaches were made introducing helium, switching at 30 msw, at 6 msw and finally at 40 msw isobarically to washout the nitrogen. The object of using heliox as deep as 30 msw was:

- 1) To employ deep stoppages without the uptake of nitrogen as would be the case if air breathing was continued.
- 2) The avoidance of a major initial decompression which creates a driving force for nitrogen elimination, but which also causes the separation of gas from solution.
- 3) To ensure that the inert gas content of the nervous system is as low as possible, so that if bubble embolism does occur there will be minimal growth of the bubble in the tissues.

The evidence indicates that it is the initial upward excursion that gives rise to bubbling after surfacing, as is demonstrated by the bubbles found on surface decompression dives. US Navy schedules have been shown

to produce very high bubble counts under pressure. Deeper stoppages were found to reduce the count.⁶ Switching to heliox creates an even larger gradient than a Haldanian decompression where the absolute pressure is initially halved, because the gas breathed does not contain any nitrogen. The inspired nitrogen partial pressure is therefore zero. In the Haldanian format the formation of gas phase may be the actual reason for the success of the procedure and it is symptomless provided a critical volume is not exceeded. With the dumping of gas into the tissues, the transport of gas in solution in the blood can proceed at a lower rate leaving the elimination of separated gas to take place over a much longer period. This suggestion is supported by the fact that decompression results in a slower rate of nitrogen elimination than washout.

The efficacy of using heliox in the therapy of air divers has been shown in a programme of research on gas switching undertaken by a group working in the Israeli Naval Hyperbaric Institute. In experimental studies, a 50/50 heliox mixture has been shown to be the most effective treatment for gas formed on an air dive. Bubbles have been monitored in tendon, muscle, adipose tissue and the spinal cord. In all cases 50/50 heliox was found to be the most effective way of resolving the gas phase. (Hyldergaard O., personal communication 1993) The Israelis also have published the successful use of 50/50 heliox in the treatment of seven cases of air decompression sickness.⁷

2. The Basis for the Decompression Profile

In vitro modelling has shown that in the absence of the unsaturation from the metabolism of oxygen, a decompression of about 0.7 atm abs is needed to form gas. This can be taken as a worst case for a zone of biological tissue where there is a low metabolic rate and no blood flow. The upward excursion from 40 to 30 msw in the original dives would therefore be expected to produce gas in a worst case situation. From the studies undertaken in the British Gas Trial this proved to be the case. It was therefore decided to study the effect of switching without the initial decompression.

The venous gas values after a gas switch at 40 msw have been published by D'Aoust.⁸

Venous Nitrogen and Helium Saturations after an Isobaric Switch at 40 msw

Time after switch N₂ to He in Minutes

	20	50	80	% Change 80-20 min
N ₂ % Saturation	21.3	13.5	6.5	- 14.8
He % Saturation	77.0	84.3	93.3	+ 16.3

From this data, the venous nitrogen saturation falls by 79% and the helium saturation rises by 77% in twenty minutes. After this time the changes are comparatively small.

The first profile therefore used:-

- 1) An isobaric switch and nitrogen washout of 20 minutes at 40 msw using 50/50 HeO₂.
- 2) Two deep stops at 35 and 30 msw on heliox both for 20 minutes.
- 3) One shallower stop at 20 msw for 30 minutes.
- 4) A helium washout of 90 minutes at 10 msw on oxygen at 10 msw.

2.1 Nitrogen Elimination

The nitrogen washout time is the time on heliox together with the time on oxygen plus the ascent time giving a total of 195 minutes. On the US navy air table, for an exposure of 140 fsw (43 msw) for 90 minutes, the decompression time breathing only air is 166.2 minutes.

2.2 Helium Elimination

The advantage of using helium is that being a much less soluble gas than nitrogen it is easier to remove later in the decompression.⁹ A significant reduction in the uptake of the gas can be avoided by using a raised partial pressure of oxygen, which also increases the inherent unsaturation. Once a diver is breathing a nitrogen-free gas then the time for the elimination of the gas can be equated to the time of a normal decompression. The helium uptake is a function of the partial pressure multiplied by the time. It is equivalent on this decompression to a dive to 40 msw for about 45 minutes. The decompression time for 80/20 heliox for a dive to 135 fsw (41 msw) for a bottom time of 40 minutes would be 62 minutes and for 60 minutes would be 82 minutes. The no-stop decompression time for a dive to 40 msw on 80/20 heliox would be about 25 minutes. The actual helium washout time at 10 msw is 90 minutes on oxygen and 10 minutes on air. the actual decompression time to cover the heliox may be in excess of the time indicated by this simple approach because tissue gas phase may be formed by the initial decompression.

3. Subjects and Methods

Eight professional divers took part in the study. All were in possession of a current certificate of fitness to dive. The divers were pressurised to 40 msw in a chamber at the NHC for a bottom time of 75 minutes. On the first dive the divers then switched to breathing heliox 50/50 on the BIBS using Aga masks isobarically and then followed a staged decompression to 10 msw and switched to oxygen (Figure 1). The second group followed the same profile, but a trimix of 30% helium, 20% nitrogen and 50% oxygen was used in place of the 50/50 heliox (Figure 2). Ultrasonic monitoring of the heart was used in the chamber and after surfacing (Vingmed Sound CF 450, Horten Norway). The divers were trained in the use of the technique and were able to observe the images on a flat screen television in the chamber.

THE PROFILE FOR A DIVE TO 40 MSW FOR 75 MINUTES

a) Heliox and Oxygen Decompression

1) After 75 minutes at 40 msw switch to 50/50 Heliox.

The divers breathe 50/50 heliox for 20 minutes on the BIBS. The partial pressure of oxygen is 2.5 (the same as the 50 fsw stop used in some SD O₂ tables i.e. 2.5 atm abs). The change in pN₂ to pHe is from 3.95 to 2.5. A total P inert gas of 6.45 at an absolute pressure of 5 atm abs, giving a ratio of 1.29 under less than saturation conditions. The divers stay at 40 msw for 20 minutes in which there should be an increase to 77% of the venous saturation value for helium and a reduction of 80% in the saturation value for nitrogen.

2) First Stop

Decompression to 35 msw at 2 msw per minute then 20 minutes on 50/50 heliox

3) Second Stop

Decompression to 30 msw at 2 msw per minute with a stop of twenty minutes.

4) Third Stop

Decompression to 20 msw at 2 msw per minute then 50/50 heliox for 20 minutes

5) Fourth Stop

Decompression to 10 msw at 2 msw per minute, switch to oxygen. Total time at 10 msw on oxygen is 1.5 hours with an air break of ten minutes at 45 minutes

6) Decompression to the surface at 2 msw per minute

Divers breathe oxygen to the surface.

b) Trimix Decompression : 50% O₂, 20% N₂ and 30% He

The divers breathe the mixture of 50% oxygen 30% helium and 20% nitrogen on the BIBS at 40 msw. The pN₂ falls from 3.95 to 1.0 and the pHe is 1.5 at a pO₂ of 2.5. The remainder of the decompression is the same as on the heliox table with trimix substituted for heliox.

**HELIOX AND OXYGEN DECOMPRESSION
FROM A 40 MSW 75 MIN AIR DIVE**

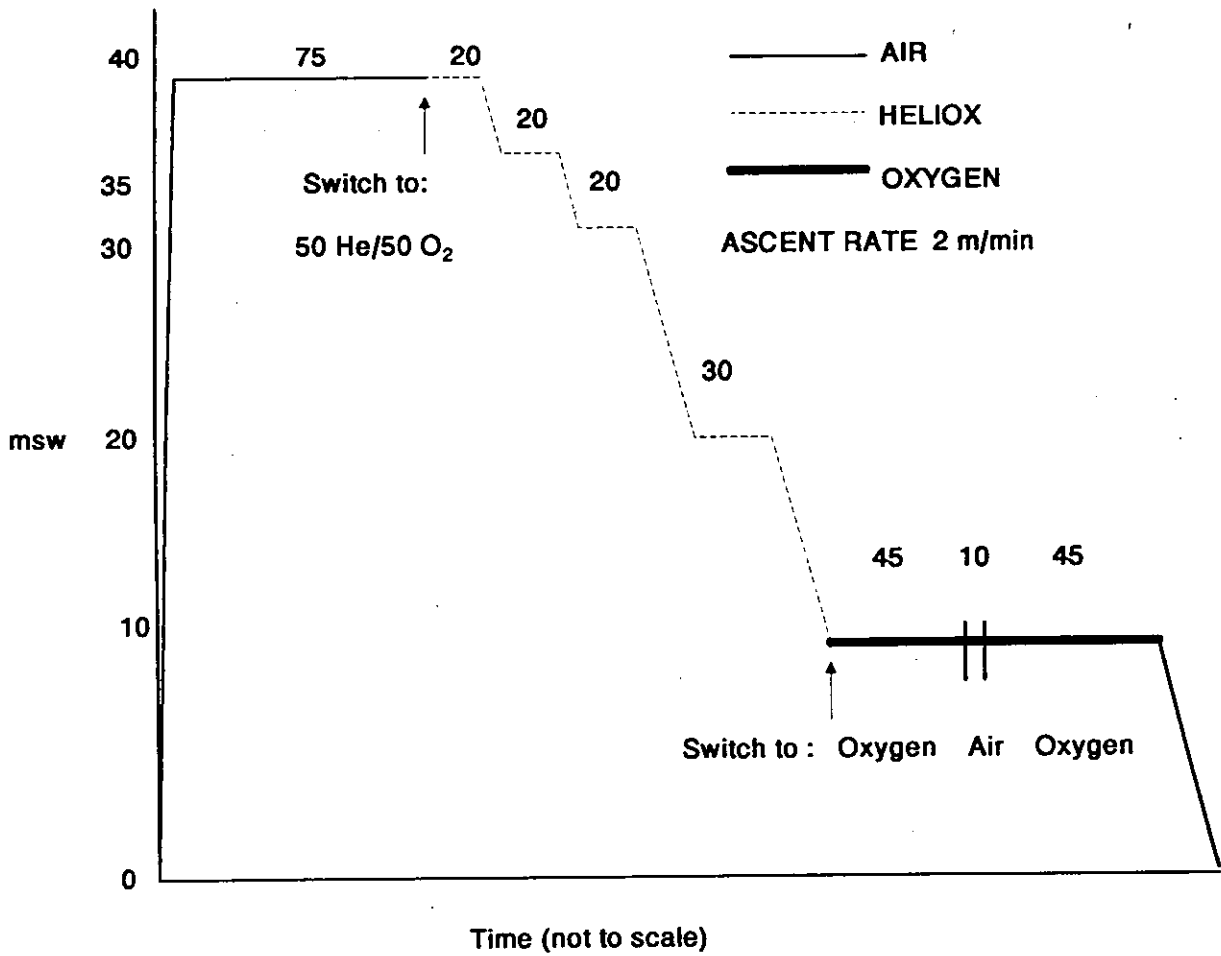


FIGURE 1

**TRIMIX AND OXYGEN DECOMPRESSION
FROM A 40 MSW 75 MIN AIR DIVE**

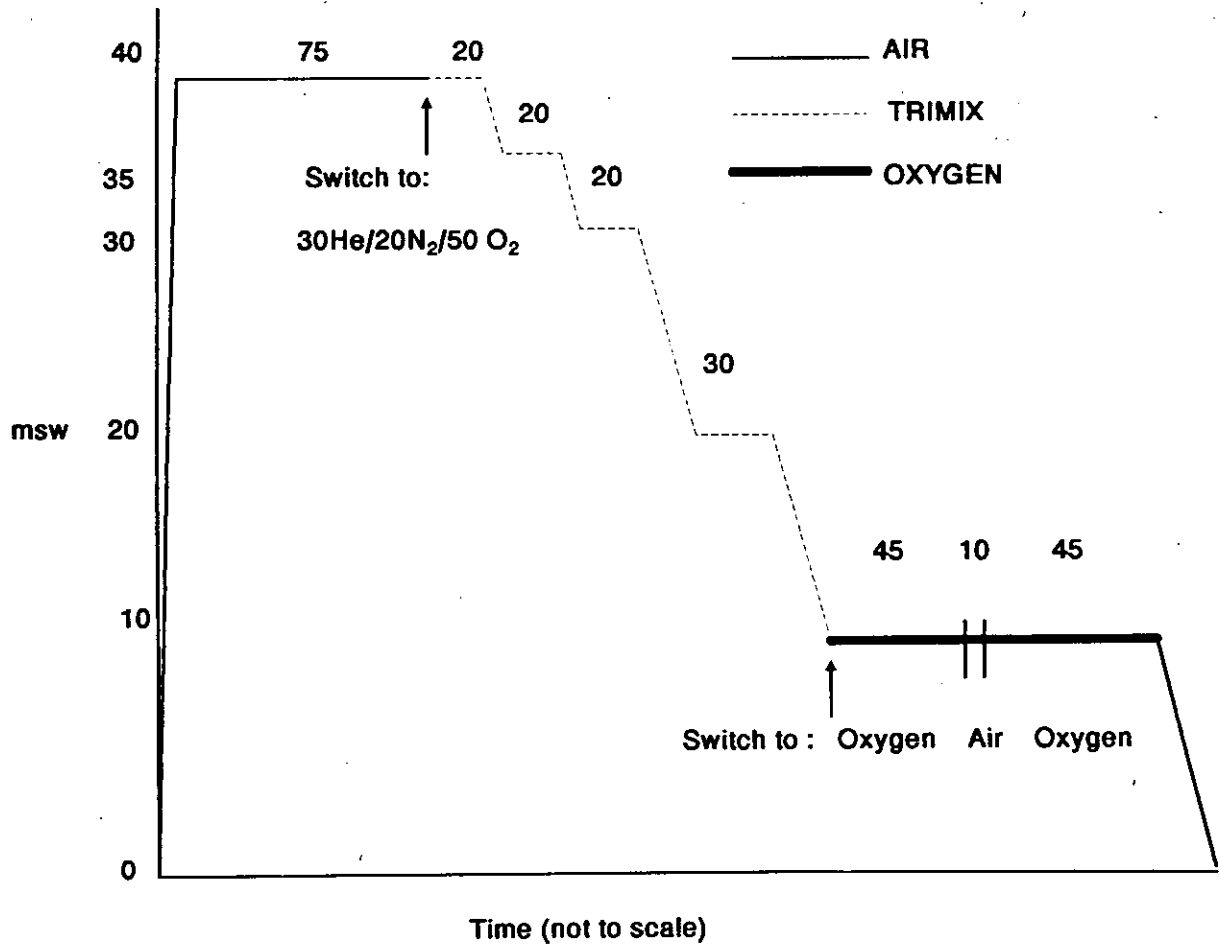


FIGURE 2

3. Results

Of the four divers switched after 75 minutes at 40 msw to 50/50 heliox, three produced bubbles, although there were no symptoms of decompression sickness and the scores did not exceed Spencer Grade 3. The next four divers also undertook a dive to 40 msw for 75 minutes, but were switched to a trimix (30% He, 20% N₂, 50% O₂). The scores are given in Table 1. (The results are preliminary and await confirmation in a final report from the University of Trondheim).

TABLE 1
ISOBARIC GAS SWITCH RESULTS

Dive 1 40 msw for 75 minutes

50/50 He O₂ Switch

Time of Ultrasonic Monitoring

Morning	0-15	20-35	40	60	90	110	120	150	4	6
DS	0	1	3	3	3	3	3	3	3	1-2
DG	0	0	0	0	1-2	1-2	1-3	1-3	1-2	1
CS	0	0	0	0	0	0	0	0		
HM	1	1	1	1	1	0	0	0		

Dive 2 40 msw for 75 minutes

20/30/50 N₂He O₂ Switch

Afternoon	0-15	20-35	40	60	90	110
JG	0	0	0	*	0	0
PM	0	0	0	0	0	0
EM	0	0	0	0	0	0
CS	0	0	0	0	0	0

* possibly two bubbles

4. Discussion

There are good reasons for believing that a switch to a heliox containing 50% oxygen will not produce gas under isobaric conditions at 40 msw. D'Aoust⁸ switched at 40 msw from a saturation exposure on nitrox with the pO_2 at 0.3 atm abs to heliox with the same oxygen level in goats. The switch produced very few bubbles in only three out of seven animals. As the monitoring of the animal was by an implanted probe, it is likely that the detection of intravascular gas was reliable. It was on the basis of this data that the switch was originally made to 70/30 and of course air at this depth is also not normoxic. Clinical evidence to support this animal study has come from many switches undertaken from air to heliox in divers with dysbaric illness. The most dramatic case involved an abrupt switch after 11 hours on air to 80/20 heliox in a diver with mediastinal emphysema. The diver improved and decompressed without problems. (AH Milne personal communication).

The venous saturation changes following a switch to heliox from nitrox indicate that, despite assertions to the contrary, the rates of uptake and offgassing of nitrogen and helium are not substantially different. This suggests that the reason for the gas phase on switching to 70/30 was because the initial decompression had produced gas which was then enhanced by the transient supersaturation from the combination of the tensions of the nitrogen and the helium. In fact, there is clear evidence of the separation of gas in the muscles of the thigh on the initial 10 msw ascent from the ultrasonic scanner. This gas phase in the tissues was not associated with intravascular bubbles detectable by Doppler ultrasound. Also the amount of gas steadily reduced, despite the decompression to 10 msw where pure oxygen was used. It is most important to restate that two divers of the divers switched to 70/30 did not generate gas under exactly the same circumstances. The most likely explanation for this is the inherent unsaturation. In other words, the level of metabolism in the thigh muscles of the two divers without gas formation was greater at that particular time. In total sixteen divers were switched to 70/30 heliox without symptoms. After surfacing monitoring of these divers with Doppler nine out of twelve bubbled. Using a switch to 50/50 heliox only 10 out of 22 bubbled. This indicates that helium was responsible for the difference as the decompression profile was identical. Similarly the revised schedule studied in February 1992 used a further reduction in helium level by spending only 10 minutes at 30 msw before ascending to 20 msw. In the trial undertaken in September 1992 the period of heliox breathing was extended at 20 msw and produced a larger number of bubbles. This is a further indication that the uptake of helium was responsible for the bubbling.

In both the pig experiments in Trondheim and the human exposures at the NHC after the decompression and switch to heliox with a bottom time of 90 minutes, bubbles were found under pressure. The pig experiments at 2 hours mirror the human results at 90 minutes, with bubbles appearing at the 20 msw stop and Grade 3 bubbles being found after surfacing. The short duration of bubbling - most disappear after about one and a half hours - also suggests, as would be predicted, that they are dominantly helium. In contrast after a decompression using air nitrogen bubbling has been recorded for up to sixteen hours.

The effectiveness of switching to heliox at 30 msw on was convincingly demonstrated in the trial conducted in

February 1991, where 19 of 20 divers did not produce any bubbles after dives to 40 msw for one hour. The one diver who did produce bubbles had only a Spencer score of 1 on one reading. From discussions with others experienced in Doppler bubble scoring on air decompressions¹⁰ this result is exceptional, especially in view of the use of the new imaging technique. Unfortunately attempts to extend this profile to a bottom time of 90 minutes produced bubbling in two out of four divers and an episode of Type 1 decompression sickness. The effect of this schedule on a 75 minute exposure was not tested. Other modifications were used and in a total of sixteen dives to 40 msw for 90 minutes, six divers had no bubbles at all, whereas two divers had scanner grades of 4. However in the whole series of 150 dives no diver has developed the Spencer Grade 3 bubble score recorded on the modified RNPL table in the first series.

Switching to trimix produced the best result for a bottom time of 75 minutes, although the number is small. In the case of the modified RNPL table at 75 minutes, only one out of eight divers had no bubbles. The use of trimix has almost certainly answered the question of the bubbling post-surfacing, because, by increasing the level of nitrogen and decreasing the level of helium, the bubbling was reduced in comparison to the identical profile using a switch to 50/50. It is not possible to state what the result would have been given using trimix on the original profiles with the initial decompression on air from 40 to 30 msw. The switch to trimix also reduced the transient supersaturation at the time of the switch which may be another factor in the bubble elimination. Clearly further dives are required to increase the level of confidence from these results, but the indications are that the bottom time can be extended. Given that the bubbling post-surfacing is largely helium, extending the table by allowing the divers to breathe chamber air at about 5 msw may assist in extending the bottom time. This would still keep the total time the divers have to use the Aga masks to 3 hours. This may allow areas of tissue with intermittent perfusion such as tendon¹¹ to off-load their excess gas.

5. Conclusions

1. A switch can be made isobarically to both 50/50 heliox and 30/20/50 trimix without the appearance of bubbles under pressure after an exposure of 75 minutes at 40 msw.
2. The use of trimix followed by oxygen after a bottom time of 75 minutes gave an acceptable result with only a few bubbles possibly being present after surfacing in one diver out of four.

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