Measurement of helium elimination from man during decompression breathing air or oxygen

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Kindwall, E. P. 1975. Measurement of helium elimination from man during decompression breathing air or oxygen. Undersea Biomed. Res. 2(4):277-284.—Air breathing was compared with oxygen breathing during decompression from an 80-20% helium-oxygen dive to a depth equivalent to 120 fsw (4.6 ATA) in a dry chamber to see which was the most efficient gas for helium elimination. Helium elimination was measured in a closed circuit system for 90 min at the 40-fsw (2.2 ATA) stop. No significant difference was found in the efficiency of helium elimination breathing either air or oxygen in the five subjects tested.

breathing mixture
gas elimination
closed circuit breathing apparatus

Since the inception of helium-oxygen diving in the late 1930's, the breathing of oxygen during the latter stages of decompression has been used routinely for speeding the elimination of helium from the body. This is done so as not to introduce a second inert gas into the body. Air breathing, however, has been used during decompression from some helium-oxygen dives, both experimental and commercial (Zinkowski 1971). Whereas oxygen breathing does not introduce nitrogen into the body, oxygen breathed at high pressure does cause vasoconstriction which may impede helium elimination (Willmon and Behnke 1941).

To further understand the effect of oxygen breathing versus air breathing in helium elimination, we conducted experiments measuring actual helium elimination during decompression breathing either air or oxygen.

METHODS

The five subjects (one repeated twice) were nonsmokers, had normal pulmonary function tests, had an average weight of 75.3 kg, and were clad in light cotton jumpsuits. They made a total of 12 dives breathing helium-oxygen (80:20%) via Scott demand mask for 40 min at a depth equivalent to 120 fsw (4.6 ATA) in the dry chamber. All remained in the same position breathing helium-oxygen at depth and then were decompressed over a 3-min period to 40 fsw (2.2 ATA). The nominal depth was 120 fsw but all dives were adjusted to absolute helium pressure, which took into account the barometric pressure at the time of the dives and the exact percentage of helium in the breathing gas. All depths and pressures were verified with a dead-weight piston gauge and mercury barometer. Repeat dives were made not less than 2 days apart.

At 40 fsw the subject switched to open-circuit oxygen or air for 3 min to accomplish a lung rinse and then was shifted to closed-circuit breathing connected by a scuba mouthpiece and tubing to a spirometer (Fig. 1). The spirometer was filled with approximately 50 liters of either air or oxygen. Make-up oxygen was added at 1-min intervals to keep the fractional concentration of O_2 in the inspired gas ($F_{I_{O_2}}$) relatively constant. Measurements of the accumulated helium in the closed-circuit system were made every 5 min over a 90-min wash-out period using the MS-8 Medical Mass Spectrometer manufactured by Scientific Research Instruments, Baltimore, Md. This machine was modified to measure inert gases to 1/100th of 1% (100 ppm) with reproducible accuracy and was recalibrated every 5 min just before each measurement was taken. Calibration gas, analyzed to an accuracy of 100 ppm for helium, carbon dioxide, and nitrogen, was obtained from Matheson Gas Products of Joliet, Ill. To insure internal consistency within the experiments, each succeeding bottle of calibration gas was cross-checked against its predecessor using the MS-8 Mass Spectrometer. After the 90-min measurement period, all subjects were decompressed directly to the surface regardless of whether they had breathed air or oxygen. No symptoms of decompression sickness were observed.

Temperature was maintained at 28°C at both 40 and 120 fsw during the inert gas measuring phase. Humidity was not measured or controlled. The temperatures peaked at a maximum of 38°C during the 2.7-min compression to 120 fsw. Temperature was controlled

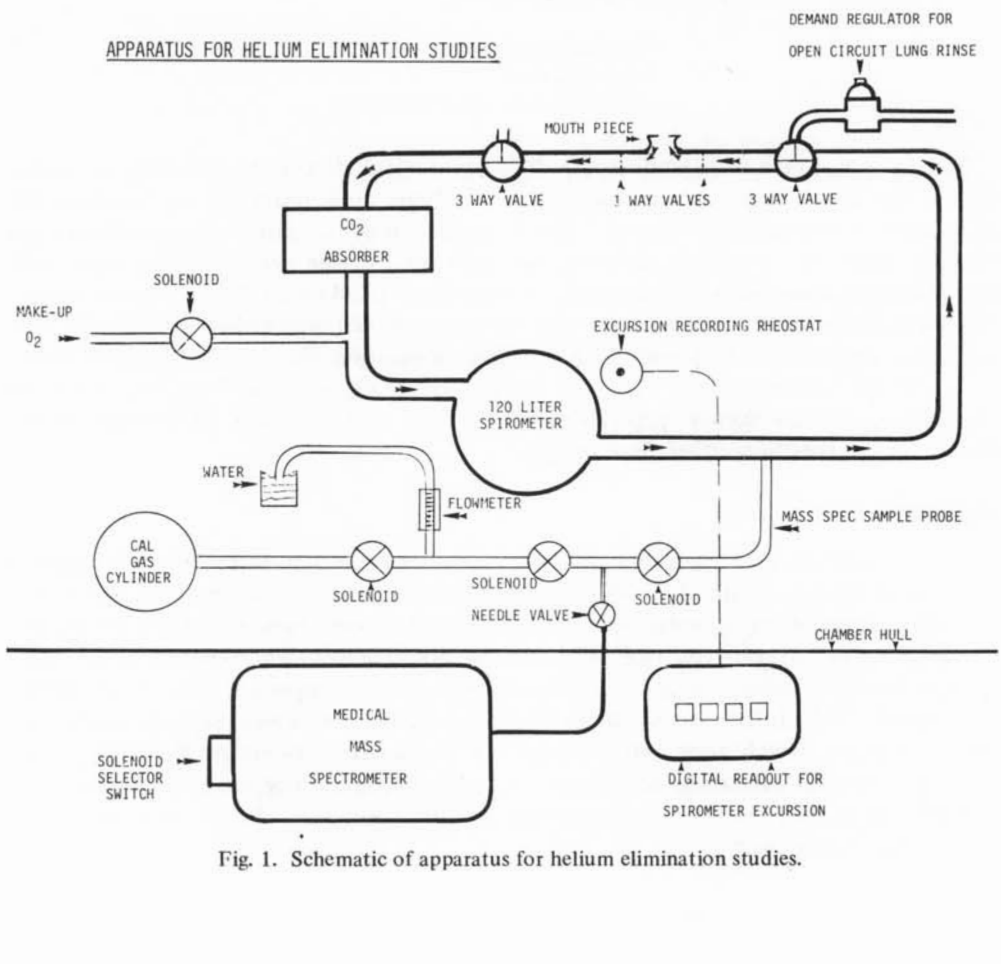

Fig. 1. Schematic of apparatus for helium elimination studies.

by cooling and heating coils and fans under the chamber floor. Within approximately 3 min of reaching 120 fsw the temperature had returned to 28°C. During a 3-min decompression to 40 fsw the temperature dropped to 14° or 15°C, but it returned to 28°C within approximately 3 min after reaching 40 fsw. Chamber temperatures were measured with a gas probe thermistor (manufactured by the Yellow Springs [Ohio] Instrument Company) suspended near the subject. Accuracy of the temperature readings was ±0.1°C.

The subject sat in the same relative positions for all dives; Balldin (1973) has demonstrated that the position of the body can cause a difference of up to 30% in inert gas elimination. The amount of helium at each reading was computed by multiplying the percentage of helium in the closed-circuit system by the calculated volume including the dead space and the estimated volume in the subject's lungs. The subject was instructed to inhale maximally and hold his breath during a 30-s sampling period spaced every 5 min during the 90-min measuring period. Between samples the subject breathed normally and tidal volumes were not measured. Vital capacity was measured twice during the actual course of the experiment at 40 fsw by measuring the difference in the total volume of the spirometer between maximum inhalation and exhalation. The average of these two measurements was used in calculating helium volume. It was impossible, despite careful instruction, to be sure that the subject had breathed out fully and then inhaled maximally prior to each volume measurement. Data from the mass spectrometer revealed that the helium percentage in the closed-circuit system tended to go up very smoothly. The average of the helium content of the closed system at the end of the runs was less than 1.3%.

Volumes were measured using an extremely accurate, thermally insulated potentiometer attached to the axle of the chain balance wheel on a Collins 120-liter spirometer. Changes in the resistance of the potentiometer as the bell moved were displayed on a Hewlett-Packard ohmmeter with a 4½-digit digital readout. Changes in bell volume of the order of 1 part in 5000 could be reliably detected. Bell temperatures of the spirometer were measured with a

TABLE 1

Total helium elimination with regard to weight, height, and age of subjects

	Subject data		Total helium eliminated		
	Age (yr)	Height (cm)	Weight (kg)	Oxygen (ml)	Air (ml)
C.Z.	23	188	104.1	972	930
L.M.	35	177	79.3	604	633
N.T.	21	166	66.7	*570	*629
T.J.	26	180	78.2	732	795
C.R.	21	167	56.5	620	565

*Average of two dives.

Yellow Springs Instrument Company gas probe thermistor in the bell. Accuracy of temperature readings was ±0.1°C.

Respiratory rate was measured using a thermistor probe inserted into the mouthpiece opposite the breathing opening. When the subject exhaled, a thermistor signal (increased heat) was recorded on a Sanborn strip chart recorder enabling a subsequent count of respirations per minute.

RESULTS

Figures 2 through 6 present data on the total helium eliminated at each sampling period for the individual subjects. The irregularities of the curves are caused by inaccuracies in estimating the volume of a subject's lungs (as noted previously).

Difficulties were encountered in the first trials as shown in Fig. 2. It was discovered that the helium-oxygen mask had to be applied very carefully and in the same way for each dive so that the same amount of helium was absorbed at depth each time. The low amount of helium eliminated for one of the oxygen decompression dives (Fig. 2) was caused by nitrogen leaking from around the mask of the subject while at 120 fsw. The subject eliminated over twice as much nitrogen during the *low helium-elimination* run.

Table 1 shows total helium elimination with regard to weight, height, and age. Figure 3 shows that the largest subject, weighing 104 kg and standing 188 cm, eliminated the most gas during decompression. Figure 4 shows data from the smallest subject, who weighed only 56 kg and eliminated the least helium during decompression. Figures 5 and 6 show results on two subjects of approximately the same height and weight (with differences of 3 cm and 1.1 kg, respectively). One subject eliminated 120 ml more helium breathing oxygen and 162 ml more helium breathing air than the other.

Figure 7 shows the averages of helium eliminated breathing oxygen or air for all dives. The total amount of helium eliminated while breathing air was 19 ml greater than while breathing oxygen. This amount is 2.8% of the total amount eliminated breathing oxygen and 2.7% of the total amount eliminated breathing air.

The number of breaths per minute taken by the subjects showed a difference in the average of 0.79 breaths per minute between breathing oxygen and air (Table 2).

TABLE 2
Number of breaths per minute

Subject	Air	Oxygen
C.Z.	8.71	10
L.M.	10.86	10.61
N.T.	14.06	14.96
T.J.	6.42	5.67
N.T.	13.73	14.73
C.R.	12.16	14.71
Avg.*	10.99	11.78

*NS difference.

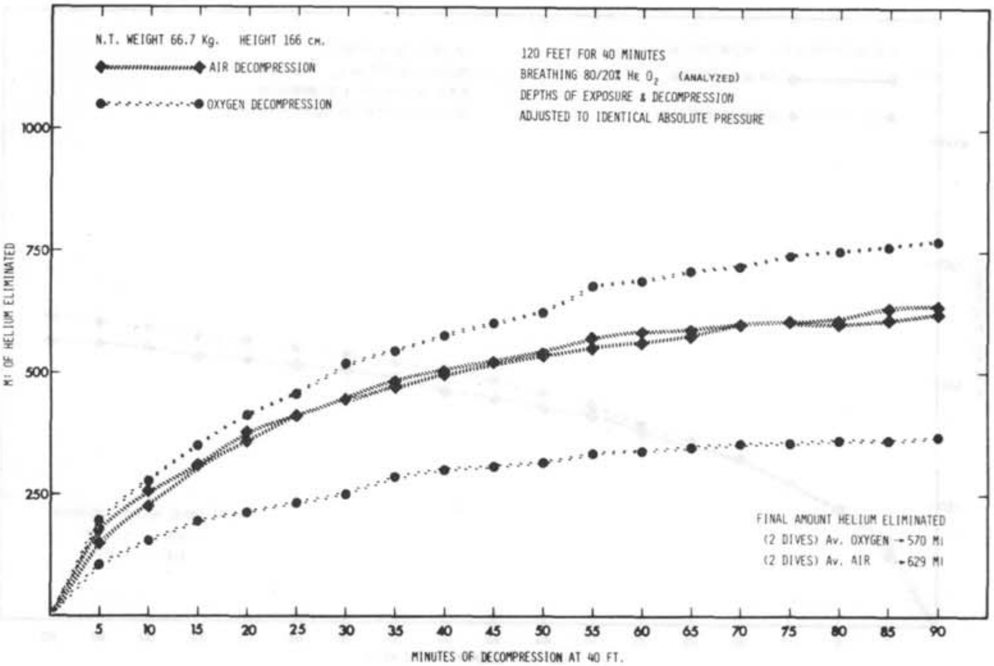

Fig. 2. Total helium eliminated at each sampling period for Subject N.T.

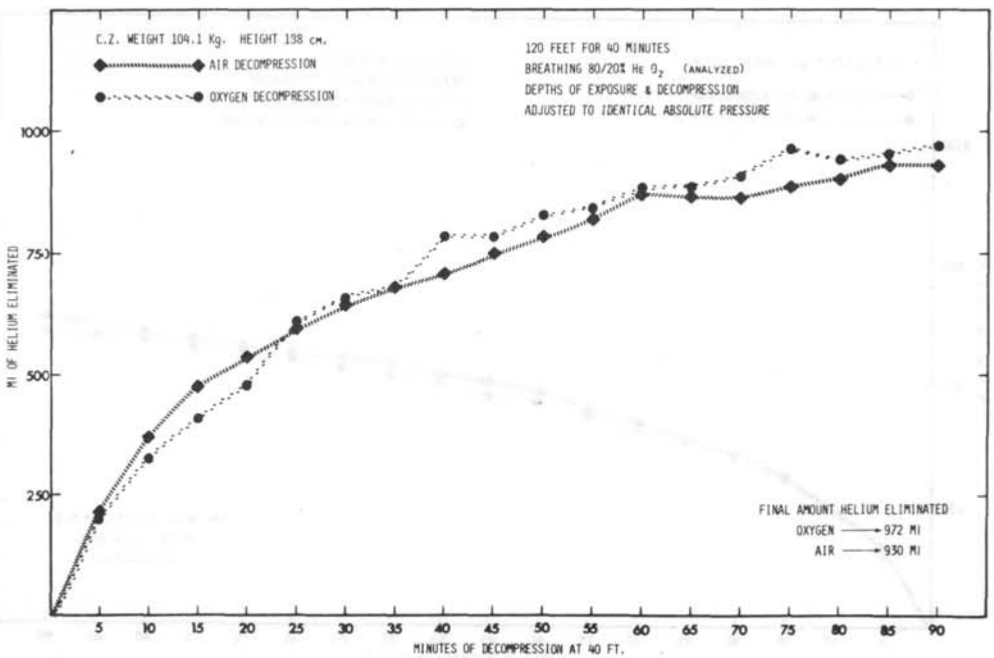

Fig. 3. Total helium eliminated at each sampling period for Subject C.Z.

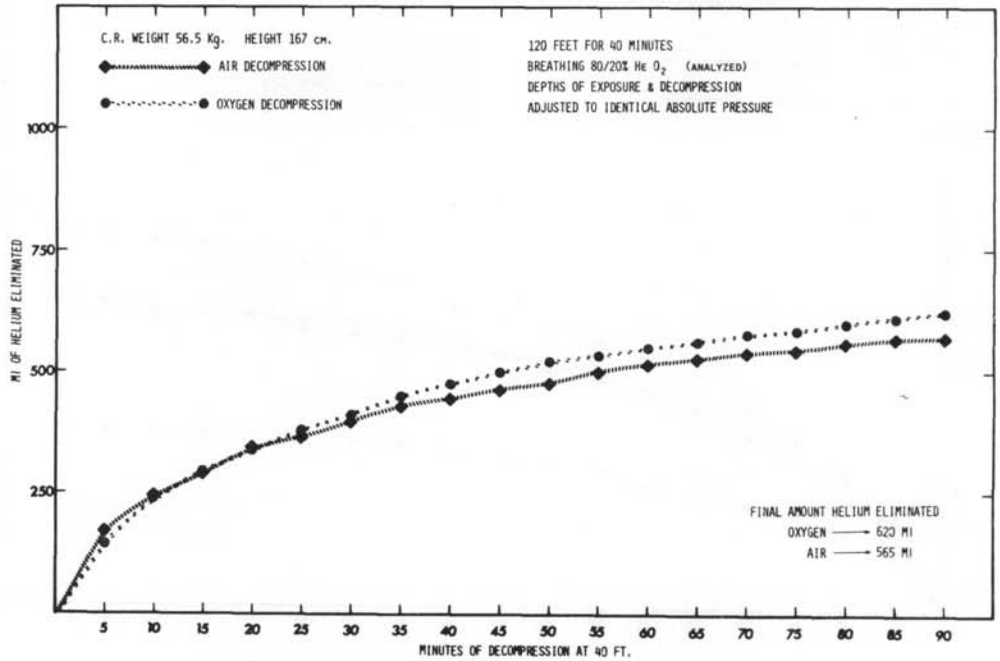

Fig. 4. Total helium eliminated at each sampling period for Subject C.R.

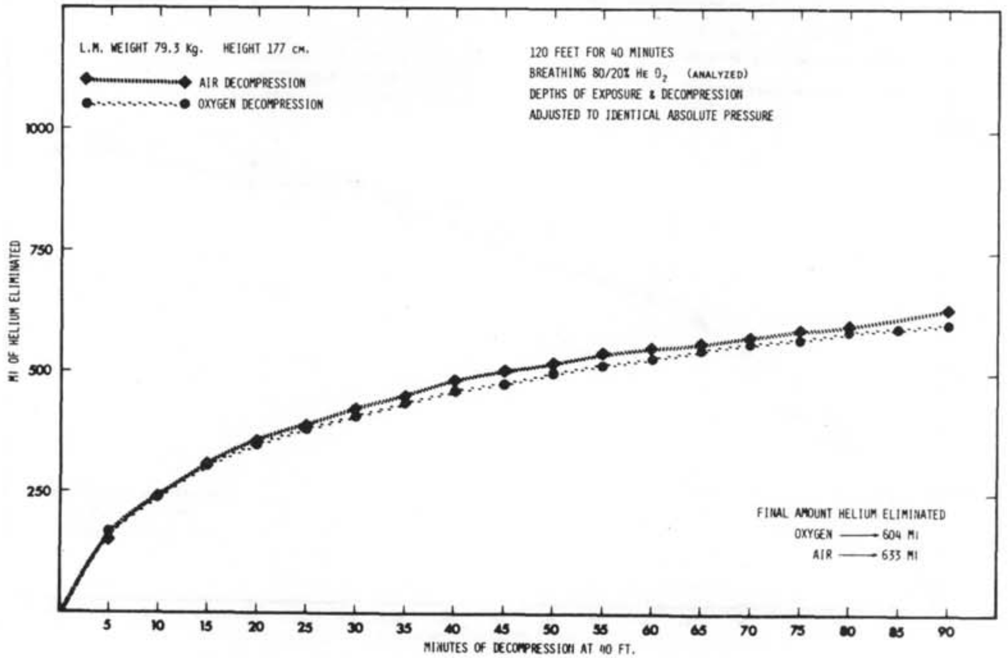

Fig. 5. Total helium eliminated at each sampling period for Subject L.M.

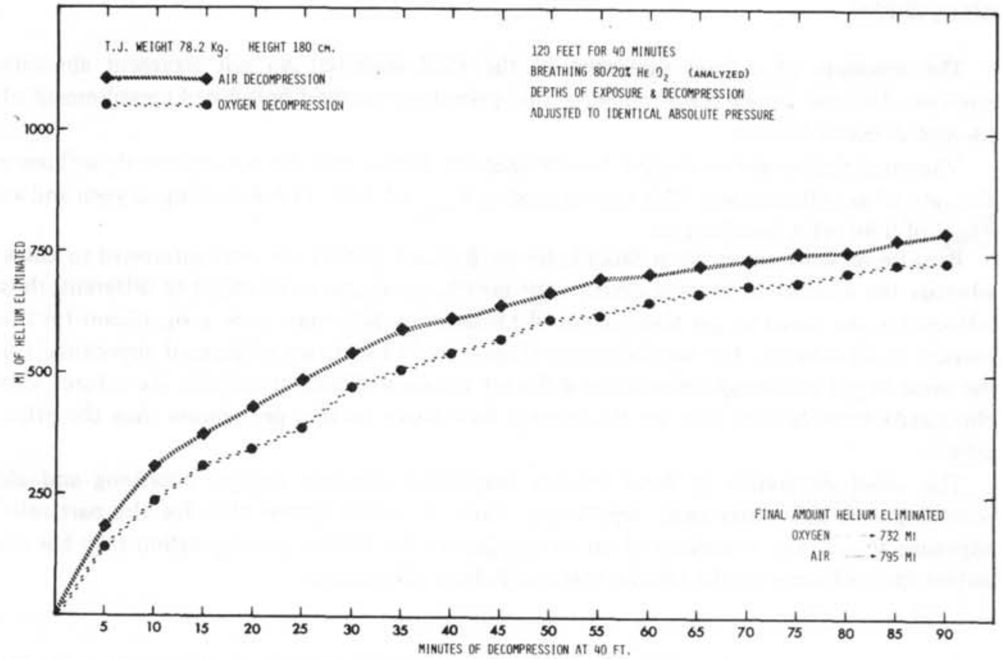

Fig. 6. Total helium eliminated at each sampling period for Subject T.J.

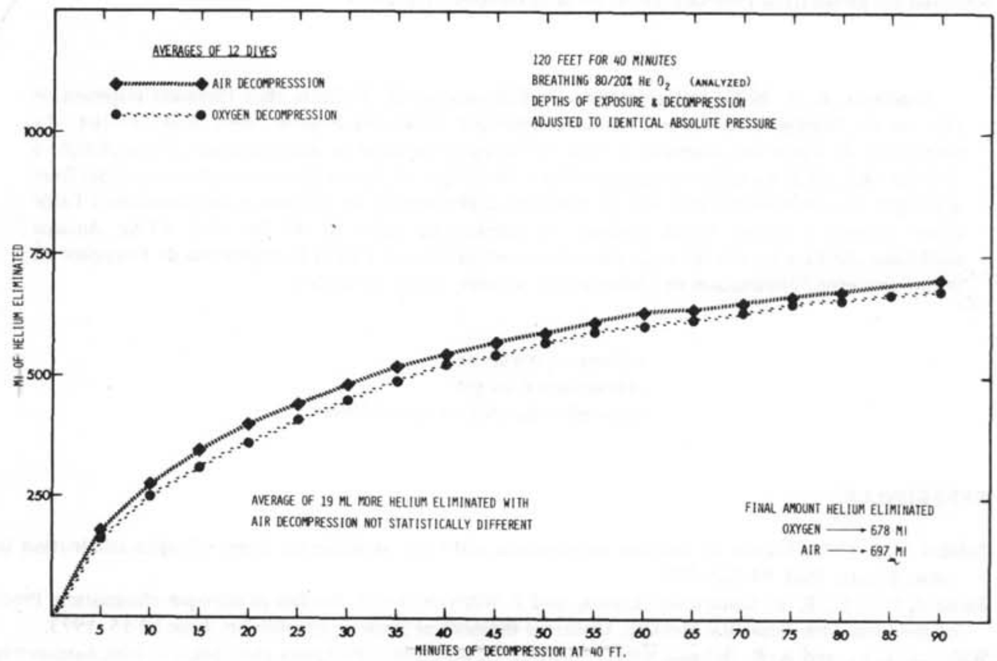

Fig. 7. Average total amounts of helium eliminated breathing oxygen or air for all dives.

DISCUSSION

The amounts of helium measured in the final wash-out do not represent absolute amounts, because during the 3-min lung rinse period our method prohibited measurement of the initial loss of helium.

Vasoconstriction due to oxygen breathing at the 40-fsw stop did not apparently influence the rate of gas elimination. This represented an $F_{I_{O_2}}$ of 2.21 ATA breathing oxygen and an $F_{I_{O_2}}$ of 0.46 ATA breathing air.

Because of work reported in Stockholm by Barnard (1973), we were interested to know whether the number of breaths taken while breathing oxygen or air might be different, thus influencing the speed of gas elimination. We found this difference to be insignificant for the average of all subjects, but we did notice (Figs. 5 and 6) that two subjects of approximately the same height and weight eliminated different amounts of helium and that the subject who eliminated *more* helium took on the average 44% *fewer* breaths per minute than the other subject.

The small difference in total helium eliminated between oxygen breathing and air breathing was not statistically significant. Thus, it would appear that for the particular exposure tested, the breathing of air or oxygen at the 40-fsw decompression stop has no differential influence on the relative speed of helium elimination.

This work was supported by Office of Naval Research Contract #N00014-73-A0139-0001 and by the Bureau of Medicine and Survey, U.S. Department of the Navy. Grateful acknowledgment is hereby given to Mask, Fins, and Snorkel, Inc., of Milwaukee, Wisconsin, for providing the necessary diving subjects for this experiment; to the Dacor Corporation for providing equipment; and to the staff members of St. Luke's Hospital Hyperbaric Medicine Unit for their assistance in performing these experiments.

Received for publication February 1975; revision received July 1975.

Kindwall, E. P. 1975. Détermination de l'élimination de l'hélium chez l'homme respirant de l'air ou de l'oxygène au cours de la décompression. Undersea Biomed. Res. 2(4):277-284.–La respiration de l'air a été comparée à celle de l'oxygène pendant la décompression d'une plongée à 120 fsw (4.6 ATA) en hélium-oxygène (80 p.c. He: 20 p.c. O_2) pour déterminer chez lequel des deux avait lieu une élimination plus vite de l'hélium. L'élimination de l'hélium a été measurée à l'aide d'une système à circuit fermé pendant 90 minutes au palier de 40 fsw (2.2 ATA). Aucune différence significative n'a été constatée entre la respiration de l'air et la respiration de l'oxygène en ce qui concerne l'élimination de l'hélium chez les cinq sujets examinés.

mélange respiratoire
elimination d'un gaz
appareil respiratorie à circuit fermé

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