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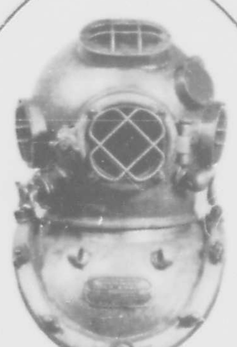

U. S. Navy
Experimental Diving Unit

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U. S. NAVAL WEAPONS PLANT
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RESEARCH REPORT 1-61

AN EVALUATION OF THE EQUIVALENT AIR DEPTH THEORY

PROJECT NS 185-005 SUBTASK 5 TEST 1

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ABSTRACT

U. S. Navy divers performed working dives on air and on nitrogen-oxygen mixtures other than air with equivalent partial pressures of nitrogen. Results of these dives were then scored in three manners. The first method used was "bends-no bends", which depends upon the development of decompression sickness after a dive. The second method was that of Snyder which utilizes a weighted scale of minor and major decompression symptoms. Third was the method of Kiessling and Duffner which depends upon the development of symptoms of decompression sickness at an ambient pressure equivalent to one-half atmosphere which scores in terms of mean endpoint measured in time at altitude. Inspection of the data revealed a difference in the scores, the dives on the nitrogen-oxygen mixtures appearing to produce higher scores than those on air. Statistical analysis, however, failed to demonstrate any significant differences between the scores of the various comparable dives. It was concluded that the mixed gas decompression system now in use is adequate for decompression.

This experiment supports the view that oxygen does have some effect on the decompression problem, however, it is slight and statistical significance could not be demonstrated.

SUMMARY

PROBLEM:

To re-evaluate the adequacy of the present decompression system for mixed gas diving as outlined in the U.S. Navy Diving Manual and to determine if, in the system as now used, oxygen has any marked effect on the decompression problem.

PROCEDURE:

Divers made working dives of equivalent nitrogen pressures on air and on nitrogen-oxygen mixtures other than air. Dives were then scored and evaluated according to three established methods.

FINDINGS:

Inspection of the data indicated some effect of oxygen on the decompression. The effect observed was not great and it was determined that the present system remains adequate.

RECOMMENDATIONS:

1. No change is necessary in the present system of decompression from dives on nitrogen-oxygen mixtures other than air. No further time is to be spent on this project.

2. Further study at a more propitious time to determine the quantitative effect of oxygen in human decompression is indicated.

ADMINISTRATIVE INFORMATION

Project NS 185-005 Subtask 5 Test 1 was established by BuShips letter 9940/1 Serial 638C-238 of 24 February 1960 following a series of conferences at the Experimental Diving Unit in which it became apparent that the influence of oxygen on decompression in man required further evaluation.

The manpower requirements were as follows:

DESCRIPTION	MANHOURS
Planning	200
Testing	680
Data Reduction and Analysis	100
Preparation of Report	120
Drafting	40
Typing and Duplication	100
TOTAL	1240

Actual experimental dives under this project commenced on 1 February 1960 and completed on 11 April 1960. Additional dives were used in calculation from previous studies.

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1. INTRODUCTION

1.1 Background

1.1.1 Since the earliest works on decompression sickness, a generally accepted theory proposed to explain this pathological condition has been that the condition is due to the release of bubbles into the blood and tissues as a result of inadequate decompression following exposures to increased pressures. Further, it has been believed that this is due solely to the amount of inert gas in excess of that which the body can hold and that the amount of excess nitrogen dissolved in the body is a direct result of the ambient partial pressure of nitrogen to which a diver is exposed and the duration of that exposure. The Equivalent Air Depth theory (1) is based on these assumptions and states that in a mixture of nitrogen and oxygen other than air, the decompression can be related to the air decompression tables simply by relating the ambient partial pressure of nitrogen in the mixture to the depth at which the same partial pressure of nitrogen would be attained breathing air. With this in mind one set of decompression tables would be adequate for all nitrogen-oxygen mixtures as long as these mixtures can be related to the basic 80-20 mixture (air).

1.1.2 Donald (2, 3), however, demonstrated the possibility of producing "bends" in goats breathing oxygen mixtures at increased pressures, though these pressures were held within the no decompression range with relation to nitrogen tensions and duration of dive. While his experiments were based on rather long exposures and very rapid rates of ascent they are not without application to scuba swimmers. These findings present the possibility that oxygen may act in some degree in the same manner as nitrogen.

1.1.3 Rashbass (4), working with small animals determined that oxygen could be a factor in the development of decompression sickness. He found that it must be accounted for in gas mixtures considering it as an inert gas present in 25-30% of its actual content in the mixture. If this is true, then the equivalent air depth theory as stated above exhibits some deficiencies.

1.1.4 These reports indicated the necessity of considering oxygen in the calculation of equivalent depth and were in opposition to the view expressed in the U.S. Navy Diving Manual which takes into account only the nitrogen in the mixture in determining the equivalent air depth.

1.2 Objective

1.2.1 With these considerations in mind, this project was established to determine whether there was any increased hazard of decompression sickness in utilizing gas mixtures according to the method described in the Diving Manual (1). That is, in utilizing the equivalent air depth equation as stated below in conjunction with the new U.S. Navy Standard Air Decompression Table, is decompression adequate or is a revision necessary to account for oxygen present acting as an inert gas? In addition, this study, involving decompression, provided an opportunity to put into practice some features of the test of decompression adequacy proposed by Kiessling and Duffner (5).

2. EXPERIMENTAL DESIGN

2.1 General Considerations

2.1.1 The design of this experiment was based on two features, first, the necessity of knowing whether for a given decompression schedule there is any difference between an air dive and an equivalent dive with relation to the partial pressure of nitrogen, on another gas mixture, and second, the practical aspect of the limitations of scuba with regard to depth and possible decompression time. One hundred twenty-six dives were included in this study. In the interest of time-saving, data from previous dives with the same subjects were used when available. Every attempt was made to utilize decompression schedules about which other data was available for comparison.

2.1.2 With regard to the difference between an air dive and its equivalent on another nitrogen-oxygen mixture it was assumed that the equivalent air depth of a dive could be determined by the formula:

$$E = \left[\frac{(1.00 - b)}{0.79} (D + 33)\right] - 33$$

where:

E = equivalent air depth

b = percentage decimal of oxygen in the inspired gas

0.79 = percentage decimal of nitrogen in air

D = gauge depth

D + 33 = absolute pressure in feet of sea water

It will be noted, as mentioned above, that this formula does not take into consideration oxygen acting in the manner of an inert gas.

2.1.3 With regard to the limitations of scuba it was necessary to consider the relative oxygen depth in order to keep the absolute oxygen tension less than two atmospheres. The supply percentage of oxygen was used in determining the relative oxygen depth as this is the maximum percentage of oxygen which could possibly be attained in the semi-closed apparatus in use. It was also believed necessary to limit the total time of dive, i.e., bottom time plus total decompression time less than three hours to keep within the limits of a charge of non caustic baralyme. In addition, in the interest of keeping the study of practical importance, the depth limitation described by the U.S. Navy Diving Manual was exceeded somewhat in order to allow for future developments. ALTHOUGH "bag levels" AND "baralyme duration" ARE BASIC CONSIDERATIONS, THE ACTUAL DIVES WERE MADE WITH OPEN-CIRCUIT DEMAND TYPE EQUIPMENT USING O_2 PERCENTAGES CALCULATED FROM SEMI-CLOSED MIXED GAS TECHNIQUES.

2.1.4 Percentages of oxygen in the mixtures was determined by the formula:

$$b = \frac{MS - C}{M - C}$$

where:

b = bag level of oxygen as percentage decimal

M = constant mass flow setting

S = percentage decimal of oxygen in supply mixture

C = the anticipated oxygen consumption, i.e., in a swimming vs. a non-swimming dive

Percentage of nitrogen in the mixture was then determined simply by subtracting the oxygen percentage from unity (6).

2.1.5 It was also believed that it was not advisable in this study to exceed the depth-time relationships to be found in the standard air decompression tables. A sample graph for one supply mixture and one flow setting-consumption rate combination is found in Figure 1. The extreme exposure limit described is the same as the maximum exposures on the standard air table. The "baralyme duration" curve covers the range of depth and bottom time attainable while keeping the total time of dive within the three hour limitation mentioned above. A difference between the oxygen supply limit and the limit as determined by the bag level can be observed.

2.2 Scoring

2.2.1 Scoring of the dives was done according to three methods. These were the time honored "bends-no bends" method, a modification of the Snyder (7) method, and the recently described method of Kiessling and Duffner (5).

2.2.2 The bends-no bends method of evaluation consists of a twenty four hour period of observation following the dive for the development of decompression sickness. Scoring consists of examination of the raw "bends-no bends" data.

2.2.3 The Snyder method of scoring (7) consists of weighting of various minor symptoms of decompression sickness as well as giving a number score to treated cases of bends in order of increasing severity. In the original method scoring was done by a board of five medical officers independently. Correlations were then made of the various scorings and the degree of agreement determined. For an individual dive score, the numbers assigned by these medical officers were averaged. In the present modification of the method scoring was done by two medical officers and a medical service corps officer on a previously agreed upon schedule. The schedule agreed upon was:

No Symptoms	1
Itch	2
Rash	2

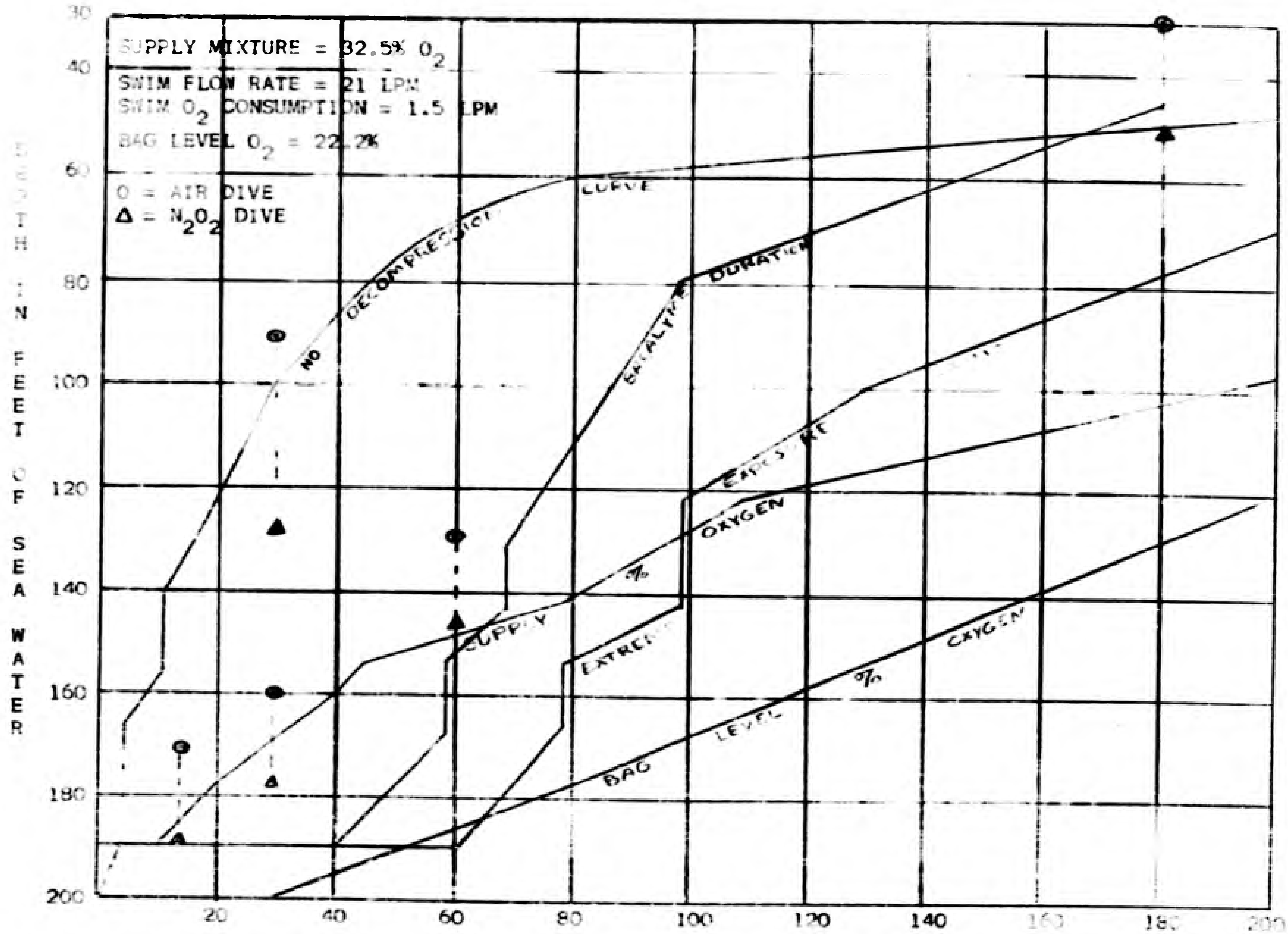

FIGURE 1 LIMITING FACTORS IN SCUBA RANGE SELECTED FOR STUDY

Fatigue	3
Dull Ache	4
Sharp Pain	5
treatment Table I	6
treatment Table II	7
treatment Table III	8
treatment Table IV	9

Any combination of symptoms were then scored on the basis of the largest score of any individual symptom. Correlations were then performed to determine the degree of agreement in scoring among the three individuals. The average correlation was found to be 0.97.

2.2.4 The method of Kiessling and Dufffner (5) was recently described in a research report from this activity. It consists of three periods after surfacing from a dive. These are: first, a fifteen minute rest period, second, a thirty minute exercise period during which five deep knee-bends and five push-ups are performed at five minute intervals, and third, a period at an altitude of 18,000 feet (one-half atmosphere) up to sixty minutes duration during which ten deep knee bends were done every five minutes. End point is described as the occurrence of a valid symptom of decompression sickness. Scoring is in terms of mean occurrence of endpoint measured in time at altitude. Scoring of such minor symptoms as a rash, itch, or fatigue occurring at altitude consists of dropping five minutes from the sixty-minute score when attained. Dives are designated as safe or hazardous according to a color code system. A safe or "green" dive has a mean of 47.5 with a standard deviation of 14.6, an intermediate or "yellow" dive a mean of 21.4 and a standard deviation of 12.1, a hazardous or "red" dive a mean of 7.2 and a standard deviation of 8.6. These figures are minutes at altitude.

2.2.5 The Snyder and Altitude score were handled according to the "t" Technique of small sample statistics.

2.3 Controls

2.3.1 Gas mixtures were assured to deliver constant oxygen percentage by previous mixing and delivery from banks to a demand regulator. Water temperature was closely regulated to $93 \pm 2^{\circ}$ Fahrenheit. Depth measurements were controlled with a standard pneumofathometer. Times were kept in the usual manner, by stopwatch. The sample taken was a purposive sample, as determined by the subjects previous performance on the Kiessling-Duffner study.

3. PROCEDURE

3.1 General

3.1.1 All dives in the group were working dives performed in the wet pressure tank. Two subjects dived together, one being designated the altitude subject, the other designated the tender who served as a control for the altitude subject and also supplied "bends-no bends" data and data for the Snyder scoring method. Breathing media were supplied via demand regulator both in order to conserve gas and to simulate as closely as possible scuba conditions.

3.1.2 Respirable media were prepared by pumping 99.5% oxygen into cylinders of 99.5% nitrogen then mixing on a machine constructed for this purpose. Calculations demonstrated that the bag level of oxygen anticipated for swim flow-rate, swim dive and non-swim flow rate, non-swim dive for the 40% and 32.5% supply mixtures ranged from 24.6 to 32.7% oxygen. It was believed that this range was narrow enough from the standpoint of this study, to be covered by one mixture. The mixture selected was 28 ± 0.4%. The same calculations performed on the 60% supply mixture showed a bag level of 31.4 and 40.7% oxygen. In this case the 40% mixture was chosen for testing and again the variation permitted was ± 0.4%. All air dives were performed "to the foot and to the minute" as indicated in the U.S. Navy Standard Air Decompression Tables. All Nitrogen-Oxygen mixture dives were as close as calculations would permit to maintaining the same partial pressure of nitrogen as the equivalent air dive. For instance, one dive selected was the one hundred thirty foot-sixty minute table (130/60). The air dive was performed at one hundred thirty feet for exactly sixty minutes bottom time. The equivalent dive on the 28% oxygen mixture was calculated as 146 feet for an equivalent air depth of 129.9 feet.

3.2 Dive Schedules

3.2.1 Five sets of dives were performed, each set consisting of two dives, one on a nitrogen-oxygen mixture and the other its equivalent on air. These pairs were:

N_2O_2 Mixture	Compressed Air
179/30 - 28%	160/30
146/60 - 28%	130/60
190/15 - 28%	170/15
127/30 - 40%	90/30
50/180- 40%	30/180

Of each dive ten tests were made, one half of the subjects then exercising and being taken to altitude according to the method of Kiessling and Duffner, one half of the subjects remaining at the surface, resuming normal, routine duties in order to obtain "bends-no bends" and Snyder score data. In comparing the mixed gas dive with its air equivalent every attempt was made, within the limitations of available time and other scheduling exigencies to retain the same altitude subject and same tender for each of the dives in a set. This was done to utilize each subject as his own control in comparison of dives.

3.2.2 As mentioned above, all dives were working dives, the work consisting of swimming on the swim ergometer against an eight pound weight which Lanphier (8) demonstrated was equivalent to swimming eight-tenths of a knot, and lifting a seventy-pound weight. Subject and tender alternated on these jobs according to the following schedule which varied only slightly on some of the shorter dives because of time limitations. The subject was required to swim ten minutes (by stopwatch) while the tender lifted the seventy-pound weight ten times per minute a height of two feet, over a period of ten minutes. The subject and tender then rested five minutes while changing positions. This routine was maintained until the start of the decompression period. During decompression the divers rested until surfacing.

3.3 Description of Subjects

3.3.1 Divers were first and second class divers with varying degrees of diving experience. Most were familiar with the altitude technique having been previously involved in the Kiessling-Duffner Study. With knowledge gained of the divers susceptibility in this previous study, control was exercised to make certain that in each set of dives the more as well as the less susceptible were included.

4. RESULTS

4.1 General

4.1.1 In all cases, gross observation of the data seemed to indicate some increase in the hazard of the mixed gas dive as compared to the air dive which was its equivalent. However, statistical analysis utilizing small sample statistics did not bear out this view.

4.2 Scoring Systems

4.2.1 According to the bends-no bends method it will be observed that in the first two sets of dives in the series (Table I) there were two cases of bends on each of the mixed gas dives while the air equivalents produced only one in each case. In both of these instances on the mixed gas dives an unknown very likely susceptible subject was involved. In all other sets of dives no cases of frank decompression sickness were recorded.

TABLE I

"BENDS-NO BENDS" DATA

	N2O2 190/15	Air 170/15	N2O2 179/30	Air 160/30	N2O2 146/60	Air 130/60	N2O2 127/30	Air 90/30	N2O2 50/180	Air 30/180
No. Dives	7	24	5	5	5	5	5	18	5	5
Bends	0	0	2	1	2	1	0	0	0	0
No Bends	7	24	3	4	3	4	5	18	5	5

4.2.2 Utilizing the modified Snyder technique, symptoms occuring after a dive were weighted and the scores compared and averaged as described above. No statistically significant difference could be demonstrated between the air dives and the equivalent dive on the gas mixtures (Table II, III).

4.2.3 With the technique of Kiessling and Duffner, the scores are in terms of mean endpoint measured in terms of time at altitude. Using this method it again will be observed that in all cases the mixed gas dives appear by inspection of the data to be more hazardous than the air dive equivalent. However, it was again impossible to demonstrate any statistically significant difference between the two scores (Table IV, V).

TABLE II

STATISTICAL DATA OF SNYDER SCORES*

	N202 190/15	Air 170/15	N202 179/30	Air 160/30	N202 146/60	Air 130/60	N202 127/30	Air 90/30	N202 50/180	Air 30/180
N	7	11	5	5	5	5	5	18	5	5
M	1.29	1.00	4.20	2.40	5.20	3.40	1.00	1.00	1	1
S.D.	±.59	0	±3.54	±2.80	±1.94	±2.48	0	0	0	0
S.E.M.	.246	0	1.77	1.40	0.97	1.24	0	0	0	0

* Key - N = Number of Subjects
M = Mean
S.D. = One Standard Deviation
S.E.M. = Standard Error of Mean

TABLE III

t TEST OF SNYDER SCORES*

	N202 Dives 190/15	179/30	146/60	127/30	50/180
170/15	1.179				
160/30		.798			
130/60			1.144		
90/30				.00	
30/180					.00

* No dive was statistically significant.

TABLE IV

STATISTICAL DATA OF ALTITUDE SCORES

	N202 190/15	Air 170/15	N202 179/30	Air 160/30	N202 146/60	Air 130/60	N202 127/30	Air 90/30	N202 50/180	Air 30/180
N	7	10	5	5	5	5	5	18	5	5
M	43.0	43.8	2.2	17.0	0.6	9.2	37.2	47.5	51.2	51.6
S.D.	18.1	21.7	13.1	21.7	7.9	5.3	18.7	14.6	8.9	8.5
S.E.M.	7.43	7.23	6.55	10.83	3.97	2.65	9.35	3.54	4.45	4.25
Color Code	GREEN	GREEN	RED	RED - YELLOW	RED - RED	RED	GREEN	GREEN	GREEN	GREEN

TABLE V

t TEST OF ALTITUDE SCORES*

	N202 Dives				
	190/15	179/30	146/60	127/30	50/180
170/15	0.772				
160/30		1.168			
130/60			1.802		
90/30				1.030	
30/180					.065

* No dive was statistically significant

4.2.4 It will also be observed from the tables that in the case of dives which are borderline or hazardous on air there is a greater difference in scores between the air dive and the nitrogen-oxygen equivalent than in the pairs in which the air dive has the color code "Green". The color code used in the table is a slight modification of the red-yellow-green color code of Kiessling and Duffner.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Examination of the data in this study would seem to support the view of Donald (2,3) and Rashbass (4) that oxygen does have some action in bubble formation and so must be taken into consideration in calculating decompression. The statistical analysis of the data does not bear this out but the statistics suffer from the paucity of data.

5.1.2 Since the differences demonstrated between nitrogen-oxygen dives and air dives using the present system is slight and statistical significance of these differences could not be demonstrated it would appear that the present system for mixed gas diving using nitrogen-oxygen mixtures is adequate from the standpoint of decompression. It should be remembered in this regard that the present standard air decompression tables were calculated by regarding air as 100% nitrogen (9), which logically should produce a built-in safety factor.

5.2 Recommendations

5.2.1 From the data presented here it would appear that no change is necessary in the present system of decompression from dives using nitrogen-oxygen mixtures other than air. It would appear that no further work is necessary on this phase of the project.

5.2.2 It would be interesting from the standpoint of further study of decompression problems to study other depth-time relationships and other gas mixtures by the Kiessling-Duffner method in order to more accurately determine the effect of oxygen on decompression in man.

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