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RESEARCH REPORT 5-65
MINIMAL-RECOMPRESSION, OXYGEN-BREATHING APPROACH TO TREATMENT OF DECOMPRESSION SICKNESS IN DIVERS AND AVIATORS

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by
LCDR M. W. GOODMAN (MC) USN
and
CAPT R. D. WORKMAN (MC) USN

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SUBMITTED:

M. W. Goodman

M. W. GOODMAN
LCDR (MC) USN
ASS'T SUBMEDRESEARCH

APPROVED:

R. D. Workman

R. D. WORKMAN
CAPT (MC) USN
SUBMEDRESEARCH

APPROVED:

C. H. Hedgepeth

C. H. HEDGEPETH
CDR, USN
OFFICER IN CHARGE

ABSTRACT

With growing awareness of the incremental frequency with which difficulties are encountered in recompression treatment of severely injured patients, and the grossly inadequate decompressions now characterizing the civilian diver casualty population applying to USN recompression facilities, evaluation and clinical trials of therapeutic procedures, alternative to USN treatment tables, were undertaken. These techniques are particularly suitable for recompression management of aviators' dysbarism when descent to sea level has not provided complete palliation. The proportion of good results obtained with initial recompression trials with these procedures has significantly exceeded that obtained in recent years, with the Diving Manual tables, although the current series of 79 cases surpassed comparable casualty groups in average case severity. Hypothetical and practical aspects of the treatment concept and technique are presented, and contraindications noted. There were no adverse responses to the 2.8 atmospheres absolute PO_2, and nine normal volunteer subjects showed no impairment of timed vital capacity following test exposures.

SUMMARY

PROBLEM

During the two-year period, 1963-1964, the Experimental Diving Unit received reports of 133 cases of decompression sickness in which U.S. Navy recompression treatment tables were applied. In 32 instances the initial recompression trial terminated in a clinically unsatisfactory manner: the patient did not obtain full relief of symptoms, or there was a reappearance of symptoms. Treatment tables 3 and 4 accounted for 62 of the initial therapeutic exposures and all but three of the failures, a 46.8% incidence of failure of the first recompression trial. There were no instances of clinical failure with tables 3 and 4, however, when antecedent exposures of Navy divers were conducted in accordance with procedures promulgated in the U.S. Navy Diving Manual.

FINDINGS

(1) Current U.S. Navy recompression procedures are, generally, reliable therapeutic schedules for divers who have reported "pain-only" bends subsequent to exposures conducted in accordance with procedures promulgated by the U.S. Navy Diving Manual.

(2) Current U.S. Navy recompression procedures are, generally, inadequate in the management of severe decompression sickness following grossly inadequate decompressions from compressed-air dives.

(3) The recompression treatment procedures herein reported have afforded complete, firm relief to divers stricken with severe decompression sickness. Efficacy has also been demonstrated in fourteen cases which followed "saturation" dives, and in three cases of altitude dysbarism.

(4) Fifty-six percent of 79 reported cases fulfilled the standard criteria for manditory application of USN treatment tables 3 or 4. The incidence of unsatisfactory first-recompression results was 3.6% for the group managed within the limits of a "minimally-adequate" routine. Overall, there was an 8.9% failure incidence, and, for the adequately-managed cases, 2.0% failure of the initial recompression trials.

RECOMMENDATIONS

(1) Steps should be now initiated, and approval sought, for promulgation of these treatment procedures in the next edition of the Diving Manual.

(2) The current USN treatment tables should be retained, with the oxygen recompression procedures alternatively available, particularly for use with severely-stricken divers who have had grossly inadequate decompression.

ADMINISTRATIVE INFORMATION

Project Authorization. BUSHIPS (Code 636) authorized this project work in response to request of Senior Medical Officer, NAVXDIVINGU, upon citation of paragraph 3a(7), Section I of the Manual of the U. S. Navy Experimental Diving Unit, which assigns the "study, compilation, and revision of decompression and treatment tables" as specific responsibilities of the activity.

Project Chronology. The 79 cases of decompression sickness managed according to the concepts now reported occurred between 28 October 1963 and 21 October 1965.

Approval of Cognizant Authority. Appropriate correspondence, here cited, conveys notices of permission for exposures of normal volunteer subjects and for clinical application of these procedures, as granted by, respectively, BUMED and SECNAV to NAVXDIVINGU, NAVSUBMEDCEN and SUBASE Pearl Harbor.

(1) NAVXDIVINGU ltr EDU:RDW:fw, 3900 ser 183 of 12 Aug 1964 to BUMED (Code 7).

(2) BUMED ltr BUMED-75:JHS:dms, 3900 R/S 51, ser 511 of 31 Aug 1964 to NAVXDIVINGU.

(3) BUPERS ltr PERS-A212-mh of 28 Sep 1964 to BUMED.

(4) BUMED ltr BUMED-7111, 3900 ser 624 of 20 Oct 1964 to NAVXDIVINGU.

(5) NAVXDIVINGU ltr EDU:RDW:hr, 6000 ser 262 of 29 Oct 1964 to COMSUBPAC (Force Medical Officer) and NAVSUBMEDCEN.

Manpower Expenditures. Test exposures of nine normal volunteer subjects required approximately 120 manhours of input: subjects, tenders, chamber operators, etc. No further estimates of the manhour cost of this work can be at all realistic. However, the following estimations of manpower which has been conserved indicate that promulgation of these new treatment procedures will facilitate Naval diving activities in fulfilling their missions and responsibilities.

The duration of treatment according to USN Tables is about 18 hours with Table 3 and 38 hours with Table 4. In all likelihood at least 5 personnel will compose the treatment table duty section in attendance. If it is assumed that, on the average, the duration of treatment for divers committed to the long tables is about 28 hours, than,

(1) For the 17 reported Experimental Diving Unit cases in which Table 3 or 4 would have been required:

PRESUMPTIVE MANPOWER NEEDS: 2380 MANHOURS
ACTUAL EXPENDITURE OF MANPOWER: 570 MANHOURS

(2) For the series total of 44 instances in which Table 3 or 4 would have been required:

PRESUMPTIVE MANPOWER NEEDS: 6160 MANHOURS
ACTUAL EXPENDITURE OF MANPOWER: 925 MANHOURS

(3) By application of the 1964 incidence of Table 3 and 4 therapeutic failure to the above, an anticipated re-treatment load of 20 cases (45%) is derived. All re-recompressions are assumed to be in accordance with Table 4:

PRESUMPTIVE TOTAL MANPOWER NEEDS: 9960 MANHOURS
ACTUAL EXPENDITURE OF MANPOWER: 950 MANHOURS
MANPOWER CONSERVATION ESTIMATE: 9000 MANHOURS (91%)

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1. INTRODUCTION

1.1 Background

1.1.1 General. As the hypothetically-reasonable foundation for clinical management of divers and caisson workers stricken with decompression sickness, recompression antedates the first "medical lock" installation, in 1894, at the New York North River Tunnel site (3). Re-application of pressure, per se, is distinguished by its universal acceptance, while the methods and techniques for its practical exploitation have been diverse and often discordent (Appendix 4). The current U. S. Navy recompression treatment tables (29) were developed at the Experimental Diving Unit and the Naval Medical Research Institute by Van Der Aue and his associates, and underwent initial clinical trials in 1945 (31). The outcome was satisfactory in 62 of the original series of 65 recompressions, and this record represented a nine-fold improvement of results over those obtained earlier in that year with seventeen recompressions by a Haldanian air saturation procedure (11)(30). In recent times the U. S. Navy treatment tables have been integrated into the practices of commercial and military diving organizations throughout the world.

1.1.2 Specific. The cumulative experiences with these tables have been reviewed by Rivera (24), for the period 1946 - 1961. Slark (25) has presented, also in review, the results obtained by the Royal Navy during the ten year period 1952 - 1962 with similiar treatment procedures. Table 1 is an expansion and analysis of treatment report data from these and other sources. In this table, and throughout this entire report as well, attention has been focused upon the clinical efficacy of initial recompression trials, while the ultimate disposition of cases has largely been ignored. A dual motivation governed the choice of this convention: (a) the requirement for a simple and clear criterion for case analysis, together with the imposition of a stringent standard of therapeutic satisfaction, and (b) the intrinsic desirability of an emphasis on first-trial success. Upon this background, the summated experiences (Table 1) clearly indicate the areas of inadequacy. MacKay (21), taking notice of an unwarranted confidence in the dogmatic application of recompression tables, remarked that,

> "the discomfort of decompression sickness, the confinement in a small metal cylinder, the noise of frequent air changes to prevent carbon dioxide accumulation--and also prevent restful sleep, the loss of taste of food, the lack of comfort in toilet arrangements or bedding, and the resistance to breathing from increased density of air or from auxillary breathing equipment, makes the whole process very exhausting .... This might be justified if one could promise success, but the prospect of spending up to 40 hours more after an initial six to ten hours can be demoralizing for patient and attendants .... The treatment of decompression sickness needs revision."

1.2 Objective. It is the purpose of this paper to report and discuss, and to reccommend for authorization as an alternative to the U.S. Navy Treatment Tables, a low-pressure, minimal-recompression, oxygen-exposure therapeutic approach. This treatment concept has, in clinical trials, provided complete and firm relief for divers stricken with severe manifestations of decompression sickness.

1.3 Scope

1.3.1 Determination of the factors affecting and influencing efficacy of the promulgated U.S. Navy recompression treatment tables was undertaken.

1.3.2 From the cumulative experiences with U.S. Navy Treatment Tables, standard values were established for several parameters and utilized in judgements of case severity and therapeutic adequacy of the experimental series (Appendix 2).

1.3.3 The scope of this effort consists, in essence, of clinical applications of experimental therapy during a two-year period beginning in October 1963. A parallel group of nine exposures with normal volunteer subjects was undertaken to estimate potential hyperoxic hazards to pulmonary and central nervous system tissues and to test the predictions of decompression adequacy for compressed-air breathing attendants.

2. PROCEDURES

2.1 Data Acquisition. Fifty two cases (67 percent of the total reported caseload) were contributed by nine reporting activities while twenty-seven recompressions were conducted by the NAVXDIVINGU - NAVSCHOOL DEEP SEA DIVERS Staff. The institutional origin of each case can be determined from Appendix 1. Twelve recompressions, all successful, have been deleted from the series because of insufficient information. NAVMED Form 816, Report of Decompression Sickness and All Diving Accidents, served as the standard vehicle for data reporting. Supplimentary documentation was submitted in most instances.

2.2 Exposures of Normal Subjects

2.2.1 Respiratory Functions. Timed vital capacity and maximal mid-expiratory flow rate were determined before and after each 285 minute exposure (240 minutes oxygen breathing according to the schedule described in paragraph 2.4.5.2). A carefully-balanced, chain-compensated 13.5 liter spirometer (Warren E. Collins Co.) equipped with a large-bore directional breathing valve and 1.5 inch I.D. smooth-bore hoses was used for these tests.

2.2.2 Miscellaneous Tests and Precautions

(a) Preliminary clinical and roentgenographic examinations of the lungs and thorax confirmed the suitability of each subject. It was further ascertained that current, general medical status was unremarkable, and that freedom from coryzal-type symptomatology was manifested.

(b) Each subject was advised to inhale maximally, randomly at intervals, several times during the procedure, and to be conscious of

any sensation necessitating ear and sinus squeeze (barotrauma) precautionary maneuvers. Postural attitudes of sitting erect or lying supine were assigned.

(c) Visual fields were examined by confrontation.

(d) Apical pulse rate and respiratory frequency were monitored, respectively, with precordial leads from a Sanborn model 350-3200 EKG preamplifier and a Statham PR 23-1D-300 temperature-compensated 5cm Hg differential pressure transducer which detected pressure changes within the face mask. Amplification was by a Sanborn 350-1100 carrier preamplifier, and recording was accomplished with a Sanborn model 964 hot-stylus oscillographic recorder.

(e) Mixed, ambient recompression chamber atmospheric gas, and aliquots drawn from within face masks (M.S.A. Aviation Type, part no. 72534), were intermittently sampled, delivered via a regulating- valve system to exterior sea-level pressure, and analyzed with a Beckman Model F3 paramagnetic oxygen analyzer. Readout of the analysis data was performed with an Esterline-Angus Model AW recording DC milliammeter. Analysis of mixed-expired gas, and of end-expired gas, sampled with an automatic, intermittent breath-by-breath technique, was performed with three subjects only.

(f) Simulated depth (pressure) was determined with accurate Wallace and Tiernan Model FA 234 bourdon-tube depth gauges equipped with custom-calibrated dials graduated in one-foot (sea water, S.G. 1.025, 25°C) increments.

(g) Adequacy and safety of the air decompression exposures of the tenders was predicted by modified Haldane computational procedures as described by Dwyer (12) and Workman (34).

2.3 Statistical Appraisal (See Appendix 3).

2.4 Treatment Schedule Development

2.4.1 First Provisional Format. The original trial schedule was drawn as a line chart and was characterized by provisions for two trials of relief and by prominently-marked indications for abandonment of the profile, in favor of standard recompression procedures.

(a) Breathing oxygen, the patient was recompressed to 33 feet. If relief was complete within 10 minutes, this depth was maintained for an additional 30 minutes.

(b) Decompression was by continuous ascent at the uniform rate of one foot per minute.

(c) Total treatment time, therefore, could vary from 64-74 minutes.

(d) If relief was not complete at 33 feet, however, the patient was recompressed to 60 feet, where similiar provisions were stipulated for relief time and treatment time (10 minutes and 30 minutes).

(e) Decompression, again, was by continuous ascent at the uniform rate of one foot per minute, requiring, therefore, 60 minutes.

(f) Total treatment time for this option could vary between about 103 and 112 minutes, oxygen breathing throughout.

(g) Incomplete relief at 60 feet, with a need for additional treatment according to a standard table, was never encountered.

2.4.2 Interrupted Ascent. In a small number of cases the uniform speed of ascent from 60 feet was altered in the following manner:

(a) 60 feet-30 feet at 1 foot per minute: 30 minutes
(b) Oxygen-breathing time at 30 feet: 30 minutes
(c) 30 feet-surface, at 1 foot per minute: 30 minutes

2.4.3 Maximal Recompression Depth. Largely by reason of the results obtained by statistical comparisons of all cases treated and the treatment failure groups, with the parameters under study (Table 3) being recomputed with each case report received, the following changes were generated:

(a) The routine reminder of potential need to recompress with a standard table was discontinued.

(b) Recompression directly to 60 feet was established as a requirement of the method. The 33-foot trial of relief was eliminated.

(c) Total treatment time could vary from about 100-130 minutes, depending upon rapidity of relief and the need for an interrupted ascent.

2.4.4 "Adequate" Treatment. By retrospective statistical study, noted above, it became apparent that the full treatment depth and the oxygen breathing time at that depth were significantly related to treatment adequacy. The following parameters describe the minimal requirements for adequacy: treatment depth 60 feet; 30 minutes oxygen breathing at full treatment depth; 90 minutes oxygen-breathing total treatment time.

2.4.5 Breathing Media Alternation and Relief Time. Schedules of duration approximating one and one-half times, and three times, the duration specified as least adequate were empirically evolved. Breathing media alternation was introduced, and the relief-time parameter emphasized in a decisive functional position.

2.4.5.1 Relief Complete Within 10 Minutes at 60 feet

DEPTH (FEET)	TIME (MINUTES)	BREATHING MEDIA	TOTAL O_2 TIME (MINUTES)	TOTAL TREATMENT TIME (MIN)
60	40	O_2	40	40
60-30	30	O_2	70	70
30	30	O_2	100	100
30-0	30	O_2	130	130

2.4.5.2 Relief Not Complete Within 10 Minutes at 60 Feet

DEPTH (FEET)	TIME (MINUTES)	BREATHING MEDIA	TOTAL O_2 TIME (MINUTES)	TOTAL TREATMENT TIME (MIN)
60	30	O_2	30	30
60	15	AIR	30	45
60	30	O_2	60	75
60-30	30	O_2	90	105
30	15	AIR	90	120
30	60	O_2	150	180
30	15	AIR	150	195
30	60	O_2	210	255
30-0	30	O_2	240	285

2.4.6 Final Format. These schedules (above) have been efficacious. Additional refinements have been directed toward the hopeful achievement of minimal risk of acute oxygen intolerance without sacrifice of decompression adequacy and treatment efficiency. The final procedural format schedules have been tested clinically and hypothetically, i.e., by calculating adequacy using inputs derived from grossly-insufficient decompression exposures, and from casualty dives which were not satisfactorily responsive to U.S.N. Tables 3 and 4. (Figures 1 and 2).

2.4.6.1 Relief Complete Within 10 Minutes at 60 Feet

DEPTH (FEET)	TIME (MINUTES)	BREATHING MEDIA	TOTAL O_2 TIME (MINUTES)	TOTAL TREATMENT TIME (MIN)
60	20	O_2	20	20
60	5	AIR	20	25
60	20	O_2	40	45
60-30	30	O_2	70	75
30	5	AIR	70	80
30	20	O_2	90	100
30	5	AIR	90	105
30-0	30	O_2	120	135

2.4.6.2 Relief Not Complete Within 10 Minutes at 60 Feet

DEPTH (FEET)	TIME (MINUTES)	BREATHING MEDIA	TOTAL O_2 TIME (MINUTES)	TOTAL TREATMENT TIME (MIN)
60	20	O_2	20	20
60	5	AIR	20	25
60	20	O_2	40	45
60	5	AIR	40	50
60	20	O_2	60	70
60	5	AIR	60	75
60-30	30	O_2	90	105
30	15	AIR	90	120
30	60	O_2	150	180
30	15	AIR	150	195
30	60	O_2	210	255
30-0	30	O_2	240	285

3. RESULTS

3.1 Data Tables. Table 1, compiled from hitherto unpublished data and from reliable sources of diving casualty information (6)(18)(22)(24)(25), offers an overview of recompression treatment efficiency, relates subsequent therapeutic inadequacy to antecedent exposures, and provides the statistical foundation for a conclusion of urgent need regarding alternatives to the Diving Manual treatment tables. The results obtained with reoxygenation-recompression techniques are summarized in the Table 2. Table 3 presents the statistical significance of selected mean differences between therapeutic failures and the total casualty population. Appendix 1 summarizes each documented recompression, and Appendix 2 considers the nature of the diving casualty population.

3.2 Adequacy of Diving Manual Treatment Tables-Summary. With a presumption of accuracy and reliability of the Table 1 information sources, it is evident that the 1964 initial recompression failure rate was eight and one-half times greater than the 1946 rate. The cumulative casualty management experience for the 19 year period is seen to be:

TOTAL CASES REPORTED: 1185
INITIAL RECOMPRESSIONS: 1088
RELIEVED, FIRST RECOMPRESSION: 933
UNRELIEVED AND RECURRED: 155
FAILURE INCIDENCE: 14.3%

TOTAL "SERIOUS" CASES REPORTED: 321
INITIAL TABLES 3 AND 4: 302(27.7%)
RELIEVED, FIRST TABLE 3 OR 4: 214
UNRELIEVED AND RECURRED: 88
FAILURE INCIDENCE: 29.1%

3.3 Adequacy of Diving Manual Treatment Tables and Case Severity. We have assumed that some of the influences affecting casualty incidence and treatment efficiency will remain essentially constant as time passes: professional competance levels of diving officers and medical department representatives, the recompression procedure formats, etc. The influence of case severity was tested in the following manner: any exposure not conducted in accordance with procedures promulgated in the U.S. Navy Diving Manual and taught by the U.S. Naval School, Deep Sea Divers was classed as a "non-standard" dive. A Spearman Rank Correlation Coefficient (Appendix 3) was computed between

percent of cases arising after non-standard dives and percent failure of initial recompression. This was determined to equal 0.86, and with 5 degrees of freedom, $P<0.02$. This correlation, therefore, appears to be highly significant and important.

3.4 Results of Initial Recompression - Current Series. As related in Table 2, 79 cases of decompression illness have been handled. The criteria of therapeutic schedule adequacy were met in 50 instances. Summarized, below, are incidence rates of failure for all recompression trials, for the adequate procedures only, and for the residual cases ("OTHER"). Comparative results are for USN treatment tables.

FAILURE INCIDENCE FOR INITIAL RECOMPRESSIONS

EXPERIMENTAL THERAPY			USN DIVING MANUAL TABLES		
ALL	ADEQUATE	OTHER	1946-1964	1963	1964
8.9%	2.0%	20.6%	14.3%	21.9%	26.7%

FAILURE INCIDENCE FOR "SERIOUS", TABLE 3 - 4 CASES

EXPERIMENTAL THERAPY			USN TREATMENT TABLES 3 AND 4		
ALL	ADEQUATE	OTHER	1946-1964	1963	1964
11.4%	3.6%	24.8%	29.7%	46.4%	47.1%

3.5 Characteristics of the Current Series of Cases. From Appendix 2 it is evident that, in comparison to the 935 cases reported by Rivera, the experimental caseload is composed of older divers who have been exposed for longer bottom time durations and at greater depths. The incidence of "serious" cases exceeds that of the comparative group and, likewise, the record of successful initial recompression trials is significantly improved.

3.6 Exposures of Normal Subjects. There were no subjective manifestations of oxygen toxicity. The prolonged periods of continuous face-mask application did not provoke reportable discomforts. No symptoms related to pulmonary irritation followed these exposures, nor was any objective evidence of compromised function apparent (Table 4). Lung fields remained normal as determined by clinical auscultation; post-exposure roentgenography was not obtained. Average gas-analysis results obtained during steady-state exposures at 60 feet were the following:

SAMPLE SOURCE	F_{O_2}(%)	P_{O_2}(mmHg)
Within Face Mask	98	2085
Collected mixed-expired gas	95	2020
End-expired gas	89	1852

3.7 Exposures of Treated Patients: Miscellany

3.7.1 Post-Exposure Chest Films. Shortly after completion of the prolonged treatment exposure, described below (paragraph 3.7.3), a PA chest roentgenogram was obtained. This study was interpreted as a normal film. In all, nine patients were radiographically examined not later than two hours post-therapy. None of the results were outside of normal limits. One patient became febrile six days after his treatment, and was found to have a right lower lobar pneumonia with consolidation. Treatment was based upon specific chemotherapy and standard adjuvant measures, and resolution was achieved. It is not considered that this particular clinical entity was in any manner precipitated by or related to the antecedent oxygen exposure.

3.7.2 During the final minute of his second thirty-minute oxygen period at 60 feet a patient became "dizzy" (Case No. E18, second recompression). Oxygen inhalation was discontinued and ascent to 30 feet was postponed for five minutes. Oxygen breathing was resumed during the third minute of the standard one foot-per-minute decompression. No symptoms were manifested thereafter. This is not believed to represent a true instance of oxygen intolerance.

3.7.3 In Case K1 intermittent oxygen and air breathing was continued for 1553 minutes (about 26 hours) at 30 feet. No changes from normal were detected by repeated clinical examinations of the chest, and total vital capacity (serially observed during the exposure) remained constant at 3.2-3.5 liters. Substernal distress was noted as the elapsed exposure time neared 825 minutes, including 661 minutes oxygen inhalation (80% of the total treatment time). The proportionate distribution of air-oxygen inhalation time was altered thereafter: 728 minutes additional treatment duration, 358 minutes oxygen exposure (50% of the remaining time at 30 feet).

4. DISCUSSION

4.1 Theory of the Minimal Pressure-Oxygen Approach to Recompression

4.1.1 Bubble Dynamics.

(a) Wyman, et.al. (35) derived the following expression for the relationship of rate change of bubble radius and time at various pressures from the general gas law and Fick's first law of diffusion:

$$\frac{dr}{dt} = RT \frac{\Delta a}{d} \frac{(P-P_o)}{P}$$

in which R = the gas constant
T = temperature (°K)
Δ = diffusion constant of the gas in water
a = solubility of the gas in water
d = diffusion shell thickness
P = pressure in the bubble
Po = partial pressure of the gas in the water outside the shell

The fundamental basis for the result is that pressure within a bubble depends upon its volume, whereas the quantity of gas escaping by diffusion depends upon the bubble surface area. For any value of P, corresponding to any stipulated depth, bubble radius should decrease in a uniform manner with time. Pressure effects upon bubble resolution rate are predicted, and minor surface tension pressure effects are ignored. (Surface tension pressure is expressed by $\Delta P = 2y/r$. Surface tension, y, of water is 73 dynes/cm at 20°C, $\Delta P = 0.03$ atm., or 23 mmHg. for a bubble of 0.1 mm diameter). Pressure due to surface tension is a dominant factor when bubble diameter does not exceed 0.09mm.

(b) It is apparent that the ratio dr/dt is but little affected at depths greater than 66 feet (3 atm. abs. pressure). As ambient depth is increased, however, uptake of inert gas in solution in body tissues surrounding a bubble increases at a rate proportional to the greater exchange gradient (P - Po), with the result that the rate of inert gas diffusion from the bubble into the surrounding fluid is more rapidly diminished. Thus, at 6 atm. abs. (165 feet) the ratio of $\frac{(P - Po)}{P}$ is decreased from 5/6 to 2.5/6 in the same time period that it changes from 4/6 to 2/6 at 3 atm. abs. (66 feet).

(c) Compression to a depth exceeding 66 feet would provide little advantage in rate of bubble resolution except for the additional reduction of the relative diameter of the bubble (0.693 at 66 feet to 0.550 at 165 feet.). This, however, is at the additional obligation of inert gas uptake in tissue fluids surrounding the bubble while air is breathed, with resultant nitrogen supersaturation upon subsequent reduction of ambient pressure. Under these conditions, persistant bubbles must grow in size to maintain both osmotic and dynamic equilibrium.

4.1.2 Gas Exchange and Tissue Oxygenation. Considerable advantage can be gained in bubble resolution processes by maintainence of the gas exchange gradient from the bubble to the circumjacent fluids ($P-P_O$). This advantage occurs during oxygen breathing and can be exploited at depths where oxygen can be used with safety. The time-course of this gas elimination gradient is maintained optimally throughout the entire oxygen-breathing period and, therefore, reductions of ambient pressure are unlikely to permit or facilitate bubble growth through attainment of osmotic equilibrium with supersaturated tissue-fluid inert gases. When air is breathed during therapeutic recompression, bubble growth by such mechanism is feasible.

Of equal or surpassing importance, however, is the tissue oxygenation which occurs and which aides in functional restoration of tissues rendered hypoxic by the ischemic actions of bubble emboli. Collateral channels can supply hyperoxgenated blood to tissue sites affected by emboli impacted within cognate arteriolar vessels. If reflexogenic vasoconstrictive effects of bubble emboli are diminished by re-oxygenation, the tissue perfusion thereby enhanced will favor bubble resolution. Hyperoxia-induced reductions of peripheral blood flow (13) do not significantly influence therapeutic progression, as compared to diving-decompression theory which requires that

inert-gas balances be computed or integrated through a spectrum of perfusion-determined hypothetical tissue reservoirs. With reoxgenation of hypoxic tissues, and the patient respiring inert-free gas, rapidity of bubble resolution seems not likely to be of decisive concern.

4.1.3 Sequellae of Impaired Perfusion and Tissue Injuries. Perfusion alterations may result whenever tissues are morphologically distorted by expanding extravascular gas pockets or harmed by vascular occlusions. Regardless of mechanism, however, the elimination of inert gas from within bubbles will be compromised because of stagnation of the contactant blood. Perhaps the most important pathophysiological consideration in this regard is the unpredictable manner of elimination of dissolved inert gases from injured or convalescent tissues. During the descent and bottom-time stages of compressed-air recompression exposures, inert gas is taken up in solution in tissues. Should supersaturation sufficient for bubble formation occur during the subsequent decompression, and clinical symptoms be thereby generated, the likely (and erroneous) clinical classification is "recurrance." It is important, therefore, to limit uptake of inert gas during recompression treatment in order to avoid both growth of unresolved bubbles and formation of new bubbles within or circumperipheral to areas of disturbed and injured tissues.

4.2 Application of Minimal-Pressure, Oxygen Recompression.

4.2.1 General.

(a) These procedures have proven to be practical for field use, and are considered as being entirely compatible with respect to capabilities both of deployed recompression facilities and the personnel responsible for their supervision.

(b) In decompression sickness the specific therapeutic fundamental has been, and remains, prompt recompression. We wish to emphasize the following: whenever acute, massive bubble formation is presumed or possible, e.g., explosive decompression of a diver blowing up to the surface, or the traumatic cerebral air embolism syndromes of buoyant-assisted ascents, recompression to at least six atmospheres absolute pressure-165 feet-is manditory in order to insure rapid, maximal reduction in bubble size.

4.2.2 Descent and Ascent Phases

(a) Descent time is normally one or two minutes, and is not counted as time spent at full treatment depth. Oxygen inhalation, however, should be started prior to recompression.

(b) Decompression from 60 to 30 feet, and from 30 feet to sea-level, is continuous (as opposed to "stage" ascent) at the uniform rate of one foot per minute. If this speed is inadvertently exceeded there should be a suitable compensatory adjustment. On the other hand, corresponding accelerative adjustments for slowing of the rate are not used. Depth gauge accuracy and precision are,of course, important, and gauges with dial graduations to one foot (sea water) increments are desirable.

(c) The continuous-bleed technique provides a safe schema for pressure changing during oxygen breathing and ensures maintenance of an optimal whole-body inert gas elimination gradient. Avoidance of the sudden, substantial pressure reductions of staged ascent may act to minimize the undesirable effects of mechanical stimuli upon persisting micro-bubbles.

4.2.3 Symptom Relief and Treatment Duration

4.2.3.1 Duration of U.S. Navy Treatment Tables. Recompression treatment according to Table 4 necessitates about a ninefold greater time obligation than the 285 minute duration schedule here proposed. Neither theoretical propositions, nor methodology of computational procedures, appears with the proposal report (31) in which the Navy Treatment Tables development was first related. Duration was actually determined by a series of empirical modifications of older procedures which themselves induced acute decompression sickness and is, therefore, related to decompression adequacy of the therapeutic exposure, not to the clinical condition of the stricken diver.

4.2.3.2 Duration of Reoxygenation Recompression Procedures. Treatment time depends upon the response to therapy and the limitations imposed by oxygen-exposure hazards. Relief time data is available for 45 of the reported cases, 30 of which exhibited symptoms requiring table 3 or 4 management. Correlations between time for complete relief and case severity were not significant. However, the difference in duration of oxygen-breathing time at treatment depth between all cases treated and all treatment failures was highly significant (table 3).

4.2.3.3 Relief of Symptoms. The tender must verify a report of complete relief by questioning, physical examination, and by having the patient exercise, e.g., by moving the affected limb against resistance for a few seconds. If any doubt exists concerning completeness of the remission the longer treatment schedule is selected. If symptoms recur, if fresh symptoms appear, or if the patient's condition deteriorates, he should again be recompressed to 60 feet, with treatment then in accordance with the 285 minute schedule. Treatment duration may be extended only by a medical officer qualified in diving (see Figure 1).

4.2.4 Oxygen Administration

4.2.4.1 Preparations and Precautions. Matters of daily routine, and good recompression chamber technique include, of course, optimum demand-valve functioning, snug face-mask fitting, and provisions for maximal comfort of the patient. If possible, humidify the inhaled oxygen. In order to preclude trapping and absorption of oxygen from paranasal sinuses and the middle ear cavities, the following measures are suggested: decongestant nasal solutions or sprays (e.g., tetrahydrozoline HCl,0.1%, or phenylephrine HCl,0.25-0.50%) can be applied when indicated; 80% helium-20% oxygen can be breathed in lieu of chamber air during the air intervals and for several minutes after surfacing, and the patient urged to remain awake subsequent to completion of treatment.

4.2.4.2 Oxygen Tolerance and Reactions

(a) Intermittent administration of oxygen and air (i.e., a low-oxygen gas) at 2.8 atmospheres absolute pressure will broaden the preclinical latency period prior to the appearance of symptomatic central nervous system hyperoxic toxicity (20)(23). Appendix 5 is a reference file of oxygen tolerance data, an abundance of which exists for exposures at 60 feet. We have not encountered any CNS oxygen reactions. In 1937 Behnke and Shaw (5) noted that oxygen could be breathed without discomfort for 3 hours with subjects at rest at three atmospheres absolute. The maximum hyperoxic time-pressure stress of these proposals, one hour in three twenty-minute segments at sixty feet, may perhaps be convulsogenic for one individual in three or four hundred.

(b) Hopefully without unduly emphasizing this small but real hazard of CNS toxicity, the following factors, well-known modifiers of oxygen tolerance, are noted in review.

FACTORS ENHANCING OXYGEN EFFECTS & LESSENING TOLERANCE	FACTORS ENHANCING OXYGEN TOLERANCE AND LESSENING TOXICITY
Emotional activity	Emotional calm
Physical activity	Physical inactivity
Breathing apparatus gasflow impedances	Breathing apparatus favorable characteristics
Increasing P_{IO_2}	Periodic calibration of depth gauges
Sympathomimetic drugs	Sedative drugs
High ambient temperature	Hypothermia

4.2.4.3 Management of Oxygen Reactions

(a) Immediate removal of the face-mask oxygen supply, halting the ascent, and holding depth are measures to be invoked as soon as oxygen intolerance is suspected or observed. Having the patient hyperventilate, for a few moments, with chamber atmospheric air may be beneficial. The general management of a convulsive reaction includes protecting the patient from injury due to violent contacts with fixtures, deckplates or the pressure hull, avoiding forceful opposition of convulsive movements, and insertion of a padded mouthbit to protect the tongue. Sedative medications are administered parenterally upon direction of the medical officer.

(b) Chamber air is breathed for an additional fifteen minutes after the reaction has subsided and prior to resumption of the treatment schedule from the point of its interruption. If a reaction occurs with the 135 minute schedule, at 60 feet, switch to the 285 minute schedule pattern at 30 feet.

4.2.5 Tender in the Chamber. The tender breathes compressed air during the entire 285 minute schedule, and at any time he may decompress directly to the surface. If the treatment recompression constitutes a repetitive diving exposure for the tender, or if the schedule is in any manner lengthened, he is obligated to breathe 100% oxygen during the final 30-minute phase

(ascent from thirty feet to the surface). If necessary, the tender may re-enter the chamber, with a patient who requires re-treatment, and can again breathe ambient chamber air during a 285 minute exposure. Direct surfacing, however, is no longer permissible, and he is committed to the full treatment duration. (Limiting situations which have been computed include: air exposure at 60 feet for 150 minutes, with resumption of the 285 minute schedule, and re-treatment exposure after one minute surface interval).

4.2.6 Miscellaneous Considerations.

(a) The discomforting and debilitating consequences of increased respirable-gas density, inert-gas narcosis, and adiabatic heat of compression are diminished or unencountered with these recompression regimes.

(b) Depth sensors or pressure gauges should be calibrated at intervals and read with care. It may be advisable for chamber operating personnel to familiarize themselves with manually-controlled, continuous-bleed decompression techniques.

(c) Active upper respiratory inflammations, severe coryza, or coexisting pneumonitis may, in some instances, constitute relative contraindications to prolonged oxygen inhalation, and decisions in this regard are, properly, a province of the diving-trained attending medical officer.

4.3 Recompression Therapy in Altitude Decompression Sickness. Fliers with symptomatic subatmospheric decompression sickness nearly always obtain prompt and complete remissions during recompression to sea-level atmospheric pressure. Certain patients not relieved by descent to the runway, however, as well as those first exhibiting symptoms during or following descent, may have stormy clinical courses. Treatment by recompression to greater than sea-level pressure has been urged, theoretical justifications have been advanced, and several cases have been reported and reviewed (7)(8)(10)(15). We are aware of no a priori rationale for the application of specific divers' recompression schedules to the management of aviators' decompression sickness, and suggest that whatever validity attends the hypotheses as set forth in paragraph 4.1.3, above, apply with equal vigor to the flier undergoing recompression. Entries numbered K1, U1 and U4 (Appendix 1) are the cases of aviators dysbarism in this series.

4.4 Case Reports and Case Discussions

4.4.1 Case No. E4. About one hour after reaching the surface a 34 year old diver suffered nausea, malaise, vertigo and generalized weakness. Onset was acute. The antecedent recompression chamber compressed-air exposure had been 240 minutes at 70 feet. When examined, one minute after onset, there was obvious dysdiadokokinesia and deteriorating finger-to-nose coordination. Within seconds the patient became unresponsive and, apparently, unconscious. He was immediately recompressed to 60 feet with oxygen breathing, and complete subjective relief occurred within four minutes. Vital signs were stable and normal and no neurological deficits could be detected. Total time of treatment was 98 minutes, after which, and throughout the ensuing evening hours, the patient felt unusually fatigued.

4.4.2 Case No. P4. The following table contains pertinent exposure data for a series of six open-circuit compressed-air SCUBA dives by a 33-year old patient:

DIVE	DEPTH(FT)	TIME(MIN)	SURFACE INTERVAL(MIN)
1	60	30	55
2	110	5	15
3	165	20	15
4	165	20	5
5	165	20	1
6	70	15	-

Nausea and shortness of breath occurred during ascent from the fourth dive and persisted and worsened thereafter. Dive number six was "for decompression" (on the advice of his topside attendant, who was partially paralyzed from a bends episode which had occurred one year previously). Upon arrival at the chamber site he was unconscious. Symptoms exhibited during the pre-treatment period included shoulder pain, generalized muscular weakness, nausea, vomiting, loss of sensation over left lower leg and lower abdomen, paralysis of the left leg and spontaneous micturition. Recovery was prompt and complete with oxygen breathing during recompression.

4.4.3 Case No. P8. A 30 year old patient made a series of five dives to 110 feet. The bottom time was reported to have been about 15 minutes for each of these dives and for an initial 40 foot dive as well. Thirty minute surface intervals intervened, and a single decompression stop, three minutes at 10 feet, occurred during ascent number six. The patient was fatigued, having obtained not over two hours sleep the previous night, and confessed to steady, "heavy" drinking during the prior two week period.

Symptoms appeared within five minutes after surfacing from the final dive: severe crampy epigastric pain, and numbness of both legs. Physical examination, three hours later, revealed uniform hypesthesia below the navel. The level of hypesthesia (to pin prick) rose to the costal margin during treatment time at 60 feet. "He was brought up to 30 feet and after one hour at this stop we were unable to elicit either knee jerk, although the achilles reflexes were active and equal bilaterally. He was unable or unwilling to move either leg, and the attending physicians were impressed by his apathy and lack of motivation as well as by his strange symmetrical signs and symptoms." Following treatment the hypesthesia level remained at T-4. Moderate weakness of arm muscles developed during the next two days, and both arm and leg deep tendon reflexes disappeared. Tonus of anal sphincter and bladder musculature was regarded as poor. Recovery of arm muscle strength was complete within about 17-18 days.

4.4.4 Case No. P12. Ten minutes after surfacing from an uneventful 172/15 deep- sea air dive this 39 year old patient noted general blurring of left-eye vision and associated loss of superior visual fields. The pupil of this eye was dilated and unresponsive. Mild pain, localized to the left buttock, developed rapidly thereafter. Clearing of both vision and pain was complete before reaching 60 feet, oxygen breathing having been initiated

just prior to recompression. Treatment course was uneventfully completed in 130 minutes.

4.4.5 Case No. U1. This patient, age 21 years, used open-circuit SCUBA while diving for golf balls in a pond. Water depth did not exceed twenty feet. Mild mid-sternal pain was experienced about fifteen minutes after he completed his dive. During the next four hours this pain exacerbated, dyspnea appeared, and the patient collapsed. Having been taken first to a local hospital, an additional period of six hours passed before he arrived at the recompression chamber. Examination at this time (10 hours, fifteen minutes after the dive) revealed a semi-comatose young male adult who reacted to painful stimuli by withdrawal, but remained unresponsive to spoken voice. Respirations were shallow at 36 per minute. Arterial blood pressure was 125/70 and the pulse rate was 88 per minute. His skin appeared dusky. Babinski reflexes could be elicited bilaterally. The recompression schedule and clinical course for this traumatic cerebral air embolism-pneumothorax patient are summarized, following:

DEPTH (FT)	TIME (MIN.)	CLINICAL NOTES
0 - 33	8	Conscious; responding
33	55	on oxygen; still some midsternal pain on deep inspiration
33	30	on air; condition satisfactory
33	30	on oxygen; condition satisfactory
33 - 0	30	condition good

4.4.6 Repetitive Diving and Omitted Decompression

(a) Computation of omitted decompression in a casualty-inducing repetitive diving series is, perhaps, highly artificial with respect to interpretation of decompression adequacy for that particular case. Both interest and value, however, are derived when these estimates are used in case comparisons, especially when casualties are characterized by differing numbers of particular dives, to several depths, by differing bottom times, and by variable-duration surface intervals.

(b) The calculations for Case Number P8 are typical and are shown here in order that the procedures may be reviewed:

DIVE (FT/MIN)	T.B.T. + R.N.T.	ASCENT SCHEDULE	ASCENT (MIN) USED	ASCENT (MIN) NEEDED	REPET. GROUP 1	REPET. GROUP 2	S.I. (MIN)	R.N.T.
40/15	-	40/200	0.7	0.7	B	B	30	6
110/15	21	110/25	1.8	4.7	H	H	30	27
110/15	42	110/50	1.8	35.5	M	L	30	42
110/15	57	110/60	1.8	55.5	N	M	30	47
110/15	62	110/70	1.8	73.3	O	N	30	51
110/15	66	110/70	4.8	73.3	-	-	-	-
		TOTAL:	12.7	243.0				
		OMITTED:	230 MIN.					

(c) Here tabulated, following, are the reported total ascent times, estimated requirements for adequate decompression, treatment-time obligations, and treatment results, for the repetitive exposures of the caseload series.

CASE NO.	NO. OF DIVES	DECOMPRESSION TIME (MIN) USED	NEEDED	OMITTED	TREATMENT TIME(MIN)	RESULT
E12	5	69	131	62	117	1
E18	2	4	40	36	73	4
P3	5	5	111	106	285	1
P4	6	11	441	430	285	1
P6	3	5	146	141	130	1
P7	2	3	16	13	285	1
P8	6	13	243	230	282	3
P9	5	3	40	37	130	1
P13	5	9	230	221	130	1
P14	4	8	305	297	285	1

4.4.7 Bends-Provocative Dives

(a) Stubbs and Kidd have reported that their trials, with a decompression computer (26), included exposures with prototype computers set with threshold data. "The value to us of using the oxygen treatment table was incalculable-in fact, it was as a result of early delight with the efficacy of the tables that we became bolder and extended the trials to provoke bends" (Kidd, D.J., personal communication).

(b) Sixteen cases of decompression sickness were thus reported among the diver subjects for the bends-provoking exposure series. Initial recompression proved to be sufficient and adequate therapy in all cases but one.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 U.S.N. recompression procedures are, generally, reliable and efficient therapeutic schedules for divers who have contracted "pain-only" bends following exposures conducted in accordance with the procedures promulgated by the U.S. Navy Diving Manual and taught by the U.S. Naval School, Deep Sea Divers. These recompression procedures are, generally, inadequate for successful management of severe decompression sickness following "non-standard" compressed-air exposures.

5.2 Many reported instances of decompression sickness recurring during and subsequent to recompression probably represent expressions of freshly-provoked pathology, often in the region affected by the original bubble embolus. It is presumed that inadequate elimination of inert gas absorbed during the treatment procedure is the responsible mechanism.

5.3 The recompression treatment procedures herein reported will provide complete and firm relief for most divers stricken with severe decompression sickness and, when properly administered, should be effective in 98 of 100 trials.

5.4 Approval should be sought for promulgation of these procedures in the next revision of the U.S. Navy Diving Manual.

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TABLE 1. DECOMPRESSION SICKNESS CASELOAD, CASE SEVERITY, RESPONSE TO RECOMPRESSION, AND CASUALTY SOURCES

YEAR(S)	INITIAL RECOMPRESSIONS			PERCENT FAILURE OF INITIAL RECOMPRESSION	INITIAL TABLES 3 & 4 ONLY			PERCENT FAILURE OF INITIAL TABLES 3 & 4	NUMBER OF CASES FOLLOWING		PERCENT OF CASES FOLLOWING "NON-STANDARD" DIVES
	TOTAL	RELIEVED	UNRELIEVED AND RECURRED		TOTAL	RELIEVED	UNRELIEVED AND RECURRED		"STANDARD" DIVES	"NON-STANDARD" DIVES *	
1946	113	107	6	5.3	18	17	1	5.6	96	17	15.0
1947-1955	343	313	30	8.7	62	52	10	16.1	303	40	11.7
1956-1959	256	204	52	26.3	78	51	27	34.6	88	167	65.2
1960-1961	176	151	25	14.2	59	44	15	25.4	124	52	30.8
1962	67	57	10	14.9	23	17	6	26.1	40	27	40.3
1963	73	57	16	21.9	28	15	13	46.4	25	48	65.7
1964	60	44	16	26.7	34	18	16	47.1	28	32	53.4
TOTALS	1088	933	155	14.3	302	214	88	29.1	705	383	35.2
	CHI SQUARE 34; $p<0.01$ CORR. CONT. COEFFICIENT 0.21				CHI SQUARE 17.9; $p<0.01$ CORR. CONT. COEFFICIENT 0.29				CHI SQUARE 254; $p<0.001$ CORR. CONT. COEFFICIENT 0.51		

* "NON-STANDARD" DIVE DEFINED AS ANY EXPOSURE IN WHICH U.S. NAVY STANDARD DECOMPRESSION SCHEDULES WERE NOT EMPLOYED OR ANY DIVE PERFORMED BY A NON-GRADUATE OF THE U.S. NAVAL SCHOOL, DEEP SEA DIVERS;

YEAR(S)	REFERENCE	INITIAL RECOMPRESSIONS			PERCENT FAILURE OF INITIAL RECOMPRESSION	TOTAL "SERIOUS" CASES	NUMBER RELIEVED WITH FIRST RECOMPRESSION	PERCENT FAILURE WITH FIRST RECOMPRESSION
		TOTAL	RELIEVED	UNRELIEVED				
1952-1962	ROYAL NAVY-SLARK, 1962	134	108	26	19.4	10	8	20.0
1909	EAST RIVER TUNNELS-KEAYS, 1909	3,680	3,167	513	13.9	402	217	46.2
1948-1950	TYNE TUNNEL-PATON, 1954	350	268	82	23.4	14	9	35.7
1957-1959	DARTFORD TUNNEL-CAMPBELL-GOLDING, 1960	689	471	218	31.6	35	35	0

TABLE 2.

RESULTS OF RECOMPRESSION THERAPY WITH MINIMAL PRESSURE, OXYGEN-BREATHING TECHNIQUES: INITIAL RECOMPRESSION TRIALS

	TOTAL NUMBER	SYMPTOMS RELIEVED	INCOMPLETE RELIEF	RECURRENCE	PERCENT FAILURE
ALL CASES DECOMPRESSION SICKNESS	79	72	3	4	8.9
"ADEQUATE" * THERAPY	50	49	1	0	2.0
"SERIOUS" ** CASES	44 (55.7%)	39	2	3	11.4
SERIOUS CASES - ADEQUATE THERAPY	28	27	1	0	3.6
ALL RECOMPRESSIONS	88	80	3	5	9.1

* ADEQUATE THERAPY: PROCEDURE WITH MINIMUM OF 30 MINUTES OXYGEN BREATHING AT 60 FEET, AND MINIMUM TREATMENT TIME OF 90 MINUTES.

** SERIOUS CASES: THOSE WITH SYMPTOMS OTHER THAN PAIN ONLY, FOR WHICH TREATMENT WITH USN TABLES 3-4 IS INDICATED.

63 CASES (79.7%) OCCURRED SUBSEQUENT TO "NON-STANDARD" EXPOSURES

OVERALL FAILURE INCIDENCE, WHEN 13 DELETED RECOMPRESSIONS ARE INCLUDED, IS 7.6%

INCIDENCE OF "BENDS" PAIN ——— 83.5%

INCIDENCE OF NEUROLOGICAL INVOLVEMENT ——— 50.6%

INCIDENCE OF CHOKES & SYNCOPE ——— 10.2%

TABLE 3.

STATISTICAL SIGNIFICANCE OF MEAN DIFFERENCES:
ALL TREATED CASES AND SEVEN FAILURES OF INITIAL RECOMPRESSION

PARAMETER	MEAN, ALL CASES	MEAN, 7 CASES	t – TEST LEVEL OF CONFIDENCE
AGE IN YEARS	32.1	36.7	$p < 0.05$
NUMBER OF DIVES	1.94	2.29	0.05
MAXIMUM DEPTH OF DIVE	205ft.	104 ft.	0.01
TOTAL BOTTOM TIME	193 min.	389 min.	0.20
TIME TO ONSET	94.1 min.	58.6 min.	0.20
ONSET TO TREATMENT	298 min.	164 min.	0.01
TIME AT MAXIMAL TREATMENT PRESSURE	47.3 min.	38.2 min.	0.01
TOTAL TREATMENT TIME	112 min.	124 min.	0.05
MAXIMUM TREATMENT PRESSURE	48.4 ft.	36.9 ft.	0.001

TABLE 4. TIMED VITAL CAPACITY, VITAL CAPACITY AND APICAL PULSE RATE IN NINE NORMAL SUBJECTS

SUBJECT	RATE	AGE	VITAL CAPACITY (LITERS) BEFORE AND AFTER OXYGEN				ONE SECOND TIMED VITAL CAPACITY (%)			APICAL PULSE RATE (PER MINUTE)		
			PREDICTED	OBSERVED 1	OBSERVED 2	DIFFERENCE	OBSERVED 1	OBSERVED 2	DIFFERENCE	OBSERVED 1	OBSERVED 2	DIFFERENCE
GAR	MRI	28	4.285	3.900	3.660	−0.240	84.5	87.5	+3.0	74	60	−14
WYA	DCI	36	4.200	3.500	4.000	+0.500	81.5	85.0	+3.5	68	64	−4
RUD	BM2	31	4.500	4.800	4.580	−0.220	84.0	90.0	+6.0	72	56	−16
HOY	PHI	36	4.155	4.700	4.850	+0.150	80.0	78.4	−1.6	94	72	−22
TAY	BMC	37	4.140	4.850	4.350	−0.500	90.7	88.5	−2.2	88	57	−31
MUL	DCI	30	4.425	5.400	5.450	+0.050	74.1	78.0	+3.9	82	64	−18
SIM	SFI	37	3.885	3.250	3.600	+0.350	73.8	84.7	+10.8	82	74	−8
BIG	BMC	34	4.425	4.450	4.900	+0.450	78.5	88.7	+10.2	86	76	−10
BRO	BMI	37	4.230	4.150	3.900	−0.150	63.9	64.1	+0.2	68	64	−4
		MEAN	4.249	4.333	4.376	+0.043	79.0	82.8	+3.8	79	65	−14
		S.D.	0.177	0.208	0.188	0.288	8.0	7.5	4.4	8.7	7.5	8.3

FIGURE 1.

MINIMAL-PRESSURE, OXYGEN RECOMPRESSION TREATMENT OF DECOMPRESSION SICKNESS

METHOD USED WHEN RELIEF OF SYMPTOMS IS COMPLETE WITHIN 10 MINUTES AT 60 FEET			
DEPTH (FEET)	TIME (MINUTES)	BREATHING MEDIA	TOTAL ELAPSED TIME (MIN.)
60	20	O_2	20
60	5	AIR	25
60	20	O_2	45
60-30	30	O_2	75
30	5	AIR	80
30	20	O_2	100
30	5	AIR	105
30-0	30	O_2	135
METHOD USED WHEN RELIEF OF SYMPTOMS IS NOT COMPLETE WITHIN 10 MINUTES AT 60 FEET			
60	20	O_2	20
60	5	AIR	25
60	20	O_2	45
60	5	AIR	50
60	20	O_2	70
60	5	AIR	75
60-30	30	O_2	105
30	15	AIR	120
30	60	O_2	180
30	15	AIR	195
30	60	O_2	255
30-0	30	O_2	285

COMMENCE O_2 BREATHING PRIOR TO DESCENT. DEPTH - TIME SCHEDULES SHOULD BE FOLLOWED WITH CARE.

COMPRESSION: RAPID DESCENT IS DESIRABLE, BUT DO NOT EXCEED RATE TOLERATED BY PATIENT. DESCENT TIME, USUALLY 1-2 MINUTES, IS NOT COUNTED AS TIME AT 60 FEET. DO NOT HALT THE DESCENT TO VERIFY A REPORT OF SYMPTOM RELIEF.

DECOMPRESSION: ASCENTS ARE CONTINUOUS AT UNIFORM 1 F.P.M. DO NOT COMPENSATE FOR SLOWING OF THE RATE BY SUBSEQUENT ACCELERATION. DO COMPENSATE IF THE RATE IS EXCEEDED. IF NECESSARY, HALT ASCENT AND HOLD DEPTH WHILE VENTILATING THE CHAMBER.

INSIDE TENDER: TENDER ROUTINELY BREATHES CHAMBER AIR. IF TREATMENT SCHEDULE IS LENGTHENED (SEE BELOW), OR IF THE TREATMENT CONSTITUTES A REPETITIVE DIVE FOR THE TENDER, HE MUST BREATHE O_2 FOR THE FINAL 30 MINUTES, FROM 30 FEET TO THE SURFACE.

RELIEF OF SYMPTOMS: IF COMPLETENESS OF RELIEF IS AT ALL DOUBTFUL AFTER 10 MINUTES O_2 BREATHING AT 60 FEET USE THE 285 MINUTE SCHEDULE.

IF SYMPTOMS RECUR, FRESH SYMPTOMS APPEAR, OR THE PATIENT'S CONDITION WORSENS, RETURN TO 60 FEET AND USE THE 285 MINUTE METHOD.

IF RELIEF IS NOT COMPLETE AT 60 FEET, PROCEED WITH THE 285 MINUTE SCHEDULE, OBSERVING CLOSELY FOR ANY CHANGES OF THE PATIENT'S CONDITION, OR LENGTHEN THE SCHEDULE (SEE BELOW), OR RECOMPRESS TO 165 FEET AND COMMIT THE PATIENT TO U.S.N. TREATMENT TABLE 2A, OR TABLE 4 IF SYMPTOMS ARE NOT RELIEVED WITHIN 30 MINUTES.

A MEDICAL OFFICER QUALIFIED IN DIVING, OR THE DIVING SUPERVISOR (DIVING OFFICER; MASTER DIVER) CAN EXTEND THE 285 MINUTE SCHEDULE WITH A FOURTH O_2 - AIR SEQUENCE (20 MINUTES O_2 - 5 MINUTES AIR) AT 60 FEET, OR A THIRD AIR - O_2 SEQUENCE (15 MINUTES AIR - 60 MINUTES O_2) AT 30 FEET, OR BOTH.

FIGURE 2.

OXYGEN ADMINISTRATION: RULES, ROUTINES, REACTIONS AND PRECAUTIONS

IF OXYGEN INTOLERANCE OCCURS OR IS ANTICIPATED:

(A) HALT ASCENT; REMOVE MASK AT ONCE; MAINTAIN DEPTH CONSTANT;

(B) PROTECT A CONVULSING PATIENT FROM INJURY DUE TO VIOLENT CONTACT WITH FIXTURES, DECKPLATES OR HULL, BUT DO NOT FORCEFULLY OPPOSE CONVULSIVE MOVEMENTS;

(C) WITH A PADDED MOUTHBIT PROTECT THE TONGUE OF A CONVULSING PATIENT;

(D) FOR NON-CONVULSIVE REACTIONS, HAVE PATIENT HYPERVENTILATE - WITH CHAMBER AIR - FOR SEVERAL BREATHS;

(E) ADMINISTER SEDATIVE DRUGS UPON DIRECTION OF A MEDICAL OFFICER;

(F) 15 MINUTES AFTER THE REACTION HAS ENTIRELY SUBSIDED RESUME THE SCHEDULE AT THE POINT OF ITS INTERRUPTION;

(G) IF THE REACTION OCCURRED AT 60 FEET, ON THE 135 MINUTE SCHEDULE: UPON ARRIVAL AT 30 FEET SWITCH TO 285 MINUTE-SCHEDULE (15 MINUTES AIR - 60 MINUTES OXYGEN, 15 MINUTES AIR - 60 MINUTES OXYGEN);

OXYGEN REACTIONS - SYMPTOMS

TWITCHING (FASCICULATIONS OR TREMORS) OF FACIAL MUSCLES AND LIPS; NAUSEA; DIZZINESS AND VERTIGO; VOMITING; CONVULSIONS; ANXIETY, CONFUSION, RESTLESSNESS AND IRRITABILITY; MALAISE; DISTURBANCES OF VISION AND NARROWING OF VISUAL FIELDS; INCOORDINATION; TREMORS OF ARMS OR LEGS; NUMBNESS OR "TINGLING" OF FINGERS OR TOES; FAINTING; SPASMOTIC BREATHING;

OXYGEN ADMINISTRATION - PREPAREDNESS	OXYGEN ADMINISTRATION - ROUTINE PRACTICES	FIRE WARNING
(A) SUFFICIENT CYLINDER SUPPLY	(A) INSURE PATIENT IS AS COMFORTABLE AS POSSIBLE	DANGER OF IGNITION AND PROPAGATION OF FIRE INCREASED UNDER PRESSURE. AS O_2 IS EXHALED INTO THE CHAMBER ATMOSPHERE THE HAZARD IS MAGNIFIED. AMPLE VENTILATION MUST BE PROVIDED. DO NOT USE ELECTRICAL APPLIANCES. KEEP COMBUSTIBLES CLEAR OF THE CHAMBER.
(B) DEMAND VALVES OPERATIVE	(B) PATIENT AT COMPLETE REST	
(C) EMERGENCY KIT STOCKED	(C) INSURE SNUG FACE-MASK FIT	
(D) TENDERS TRAINED TO MANAGE REACTIONS	(D) FOLLOW AIR - O_2 SCHEDULE CLOSELY.	
(E) O_2 HUMIDIFIED IF POSSIBLE	(E) BE ALERT FOR SIGNS OR SYMPTOMS OF REACTIONS	
(F) DEPTH GAUGES CURRENTLY IN CALIBRATION	(F) PATIENT TO TAKE A FEW DEEP BREATHS EVERY FIVE MINUTES DURING TREATMENT	

APPENDIX I. SUMMARY OF INDIVIDUAL CASUALTY AND TREATMENT DATA

GUIDE TO TABLE ENTRY CODES AND ABBREVIATIONS

CASE NUMBERS: Reporting activities are designated by a single letter:

B: Buffalo, University of
E: EDU-DSDS
K: Keyport, USN Torpedo Station
N: New London, USN SUBMEDCENTER
P: Pearl Harbor, USN Submarine Base
R: RCAF Institute of Aviation Medicine
S: School of Aerospace Medicine, USAF
T: Taylor Diving and Salvage Co.
U: University of Pennsylvania
W: Westinghouse Corporation

DIVE CATEGORY: Denotes purpose of dive, number of dives, and identifies cases other than diving decompression sickness.

A: _____ Altitude exposure
B: _____ Buoyant ascent
C: _____ Civilian diver
E: _____ Experimental dive
R: _____ Recreational dive
T: _____ Traumatic air embolism
W: _____ Working-training dive
2-6: _____ Number of dives, if more than one

PAIN:

1: Dull, aching
2: Mild
3: Moderate
4: Severe
M: Multiple sites

USN TABLE INDICATED:

S: Short table (1-2) indicated
L: Long table (3-4) indicated

NEUROLOGICAL:

1: Minimal
2: Moderate
3: Impaired function
4: Generalized
C: Convulsion
M: Motor (e.g., paralysis)
S: Sensory
SS: Special sense organ (e.g., eye)
U: Unconscious

OTHER:

A: Apprehension
C: Chokes
E: Edema
N: Nausea
R: Rash
S: Syncope
V: Vomiting

RESULT:

1: Relief complete
2: Relief substantial
3: Residual substantial
4: Recurring symptoms

NOTE: Greatest depth attained has been listed in cases with multilevel repetitive dives; Sums of individual bottom times have been listed in cases with repetitive dives; "P" in the "time to onset" column denotes onset under pressure

CASE		EXPOSURE				SYNDROME			TIME FACTORS					DEPTH FACTORS		RESULTS – REMARKS		
CASE NO.	AGE	DIVE CATEGORY	GAS MIX	MAXIMUM DEPTH	TOTAL TIME	PAIN	NEURO-LOGICAL	OTHER	TO ONSET	ONSET-THERAPY	TO RELIEF	AT MAX. DEPTH	TOTAL	SYMPTOMS RELIEVED	MAXIMUM DEPTH	RESULT	U.S.N. TABLE	REMARKS
B1	39	C–W	AIR	132	40	4–M	2–M	–	P	8	1	40	110	20	50	1	L	CNS HIT, 20 FT.
B2	30	C–W	AIR	198	25	2	2–M	E;R	2	90	30	75	240	60	60	1	L	CREPITANT KNEE
E1	28	E	MULTI	50	720	3–M	–	–	280	27	6	60	66	33	33	1	S	
E2	30	E	MULTI	400	20	3–M	–	–	0	8	6	36	70	33	33	1	S	
E3	33	W	He	231	18	–	4–S	N;V	37	16	51	80	156	33	33	1	L	SEVERE VERTIGO
E4	33	E	AIR	70	240	–	4–M–S	S	64	2	4	34	98	60	60	1	L	COLLAPSE
E5	34	E	MULTI	44	720	3–M	–	–	240	7	4	34	68	33	33	1	S	TRANSIENT VISUAL SYMPTOMS
E6	39	E	MULTI	48	720	–	2–SS	A	270	81	1	40	118	33	33	2	L	HYSTERIA?
E7	28	E	MULTI	48	720	3	–	–	420	65	9	39	110	60	60	1	S	
E8	35	E	MULTI	400	20	2	2–S	N	157	26	1	30	104	60	60	1	L	
E9	34	E	MULTI	400	20	–	2–S	E	1	47	9	39	73	33	33	1	L	
E10	29	E	MULTI	300	20	2	2–M	–	19	184	3	35	96	60	60	1	L	
E11	34	E	MULTI	82	720	2	2–SS	–	P	15	8	38	72	33	33	4	L	2 ND R_x RELIEVED
E12	37	C–W–S	AIR	99	240	4–M	1–M	–	225	525	6	45	117	60	60	1	L	OMITTED 65 MIN. DECOMP.
E13	25	W	AIR	248	10	3–M	–	R	5	28	1	30	61	33	33	1	S	
E14	35	W	AIR	198	15	–	3–SS	–	P	11	2	40	100	40	60	1	L	VISUAL LOSS, 10 FT.
E15	35	E	MULTI	200	30	–	2–S	R;S	40	50	1	30	64	33	33	1	L	
E16	34	E	MULTI	400	20	2–M	–	C;R	0	14	1	40	77	30	33	1	L	
E17	30	E	MULTI	400	20	2	2–M	–	493	98	15	45	120	60	60	1	L	
E18	44	C–R–2	AIR	125	30	3–M	–	–	60	330	10	40	73	33	33	4	S	2 ND R_x RELIEVED
E19	25	E	MULTI	400	20	1	–	–	120	29	5	36	73	33	33	1	S	
E20	38	E	MULTI	400	20	4–M	–	–	343	62	18	75	285	60	60	1	S	
E21	37	E	He	200	120	3	–	–	P	3	17	47	142	20	20	1	L	PAIN, 5 FEET
E22	24	E–2	He	150	35	3–M	–	–	70	12	12	30	90	50	50	1	S	S.I. 180 MIN.
E23	35	E	He	250	150	2	–	–	P	120	55	39	90	60	60	1	L	PAIN, 60 FT.
E24	37	E	MULTI	150	40	2–M	2–S	N	195	45	6	30	146	50	60	1	L	
E25	35	E	He	300	120	2–M	–	–	5	107	7	30	90	50	60	1	S	
E26	24	W	AIR	130	12	2	2–S–SS	R	140	25	10	40	125	60	60	1	L	
E27	21	W	AIR	200	12	2	2–S	N	70	48	2	40	130	30	60	1	L	POST-ETHANOLIC DIVER
K1	45	A	O_2	30,000	65	–	4–M–S	C;S	41	836	480	1538	1553	30	30	2	–	TO FULL DUTY + 3 DAYS
N1	18	B–T	AIR	50	2	–	4–U	–	0	1	8	34	187	(165)	60	1	L	165/27; 165-60/2
N2	27	B–T	AIR	50	10	3	4–M–SS	–	2	3	10	45	112	(165)	30	1	L	165/30; 165–30/6

CASE		EXPOSURE				SYNDROME			TIME FACTORS					DEPTH FACTORS		RESULTS — REMARKS		
CASE NO.	AGE	DIVE CATEGORY	GAS MIX	MAXIMUM DEPTH	TOTAL TIME	PAIN	NEURO-LOGICAL	OTHER	TO ONSET	ONSET-THERAPY	TO RELIEF	AT MAX. DEPTH	TOTAL	SYMPTOMS RELIEVED	MAXIMUM DEPTH	RESULT	U.S.N. TABLE	REMARKS
P1	35	C-W	AIR	180	10	4-M	2-M-S	C	P	127	8	75	285	60	60	1	L	FLOWN TO CHAMBER, PAIN INCREASED
P2	20	B-T	AIR	50	3	2-M	4-C	N;V	0	3	30	75	171	(165)	60	4	L	ASCENT CONTINUED DESPITE RECURRANCE
P3	33	C-W-S	AIR	65	170	4-M	2-M	—	P	3900	60	75	285	60	60	1	L	105 MIN. OMITTED DECOMP.
P4	33	C-W-6	AIR	165	105	3	4-M-U	N;V	P	76	30	75	285	60	60	1	L	430 MIN. DECOMPRESSION OMITTED
P5	21	B-T	AIR	50	2	—	2-M	—	0	2	24	77	311	(165)	60	1	L	165/30; 165-60/4
P6	20	C-R-3	AIR	100	80	2-M	—	—	0	240	2	40	130	40	60	1	S	
P7	32	C-R-2	AIR	70	65	3-M	3-M-S	N;V	480	255	15	75	285	60	60	1	L	EMBOLISM?
P8	30	C-W-6	AIR	110	90	4	4-M-S	—	5	190	30	72	282	60	60	3	L	POST-ETHANOLIC; 230 MIN. OMITTED DECOMPRESSION
P9	27	C-W-5	AIR	45	160	3-M	2-M-S	—	10	120	1	40	130	20	60	1	L	OMITTED 40 MIN. DECOMP.
P10	27	B-T	AIR	100	3	—	4-C	—	P	3	12	75	285	(165)	60	1	L	165/30; 165-60/4
P11	27	C-R	AIR	200	30	2	3-M-S	—	1	2002	30	40	130	60	60	1	L	POST-ETHANOLIC; OMITTED 50 MIN. DECOMPRESSION
P12	39	W	AIR	172	15	2	3-SS	—	10	11	1	40	125	45	60	1	L	
P13	28	C-R-5	AIR	150	120	4-M	2-S-SS	—	5	78	1	40	130	40	60	1	L	OMITTED 220 MIN. DECOMP.
P14	31	C-R-4	AIR	135	80	4-M	2-M-S	—	P	2268	40	75	285	60	60	1	L	ONSET DURING 3RD. DIVE OMITTED 300 MIN.
R1	26	E	AIR	250	30	1	—	—	7				34	30	30	1	S	
R2	39	E-5	AIR	250	102	—	4-S	—	P				170	60	60	1	L	ONSET, 17 FT.
R3	28	E-3	AIR	255	82	1	—	R	7				75	20	60	1	S	
R4	28	E-2	AIR	250	48	3	—	—	5				68	30	33	1	S	
R5	26	E-3	AIR	245	106	3	—	—	P				40	33	33	1	L	ONSET, 6 FT.
R6	42	E-3	AIR	180	45	—	4-M	—	P				104	60	60	1	L	ONSET, 2 FT.
R7	26	E	AIR	240	24	2	—	—	6				63	33	33	1	S	
R8	23	E-2	AIR	245	87	1	—	R	480				100	60	60	1	S	
R9	23	E	AIR	255	23	2	—	—	20				40	6	33	1	S	
R10	39	E-3	AIR	255	164	3	—	—	31				100	33	60	1	S	
R11	26	E-3	AIR	255	164	2-M	—	R	45				100	60	60	1	S	
R12	25	E-3	AIR	255	164	3	—	—	120				40	33	33	1	S	
R13	26	E-2	AIR	225	47	3	—	—	60				70	20	33	1	S	
R14	44	E-2	AIR	245	55	—	3-S-SS	—	P				100	60	60	1	L	ONSET, 10 FT.
R15	25	E-3	AIR	250	63	1	—	R	105				115	33	60	1	S	
R16	38	E-2	AIR	248	51	—	3-S	—	P				90	60	60	1	L	ONSET, 1 FT.
R17	26	E-4	AIR	248	114	3	—	—	P				62	30	33	1	L	ONSET, 5 FT.
R18	36	E	AIR	245	30	2	-	E	230				62	30	33	1	S	
R19	26	E-2	AIR	245	247	3	—	—	P				70	30	33	4	L	ONSET 10 FT. 2ND R, RELIEVED
R20	28	E-3	AIR	247	56	3	—	—	P				95	33	60	1	L	ONSET, 5 FT.
R21	40	E-2	AIR	245	250	—	4-S	—	P				138	33	33	1	L	ONSET, 10 FT.

CASE		EXPOSURE				SYNDROME			TIME FACTORS					DEPTH FACTORS		RESULTS—REMARKS		
CASE NO.	AGE	DIVE CATEGORY	GAS MIX	MAXIMUM DEPTH	TOTAL TIME	PAIN	NEURO-LOGICAL	OTHER	TO ONSET	ONSET-THERAPY	TO RELIEF	AT MAX. DEPTH	TOTAL	SYMPTOMS RELIEVED	MAXIMUM DEPTH	RESULT	U.S.N. TABLE	REMARKS
R22	25	E-3	AIR	245	298	1	—	R	150				95	60	60	1	5	
R23	39	E-3	AIR	245	290	1	—	—	60				95	60	60	1	5	
R24	29	E-T	AIR	245	21	2	2-S	—	P				94	60	60	1	L	ONSET, 19 FT.
R25	40	E-2	AIR	246	62	2	—	E	90				95	60	60	1	5	
R26	25	E-2	AIR	246	376	1-M	—	R	120				105	48	60	1	5	
R27	44	E-2	AIR	245	408	1	2-S	R	60				63	31	33	1	L	
R28	25	E	AIR	72	723	1	—	R	120				120	60	60	1	5	
R29	38	E	AIR	72	723	3	—	—	120				120	60	60	1	5	
R30	44	E	AIR	71	728	1	2-S	R	45				90	8	33	4	L	
R31	42	E-2	AIR	71	748	1	—	R	120				110	10	60	1	5	
R32	25	E	AIR	71	728	1	—	—	150				120	60	60	1	5	
S1	31	W-T	AIR	66	17	—	4-M	—	10	4	2	75	285	40	60	1	L	
T1	25	W-2	AIR	110	21	3	—	—	20	344	2	40	63	18	33	1	5	
U1	21	R-T	AIR	20	90	2	4-U	C;S	15	627	8	145	180	33	33	1	L	PNEUMOTHORAX-EMPHYSEMA
U2	34	A	O_2	27,000	23	3-M	4-M-U	C;S	22	92	9	30	179	66	66	1	—	NEUROCIRCULATORY COLLAPSE
U3	31	C-W	He	400	20	4-M	—	—	240	450	20	30	126	66	66	1	5	
U4	23	A	O_2	18,000	420	3-M	—	—	420	440	15	30	145	33	66	1	—	
U5	40	C-W-3	AIR	50	210	4-M	3-SS	N;R;V	30	200	5	1	190	40	66	3	L	
W1	34	C-W	AIR	120	27	3	—	—	20	2	8	40	73	33	33	1	5	
W2	39	C-W	MULTI	120	1920	.3-M	—	—	28	2	18	10	118	60	60	1	5	TREATMENT OF A RECURRANCE

APPENDIX 2.

THE NATURE OF THE DIVING CASUALTY POPULATION AND SEVERITY OF THE REPORTED CASES

1. SYMPTOMATOLOGY	NO. OF CASES	INCIDENCE (%)
Musculoskeletal pain, "Bends"	66	83.5
Only symptom	28	35.4
Single site	41	51.9
Multiple sites	25	31.6
Neurological symptoms	40	50.6
Sensory	25	31.6
Motor	16	20.3
Dizziness – Vertigo	9	11.4
Visual disturbances	6	7.6
Loss of consciousness	4	5.1
Paralysis – paresis	4	5.1
Disturbances of speech	3	3.8
Disordered cerebration	3	3.8
Neurological & bends pain	22	27.8
Rashes ("skin bends" and marbling)	15	19.0
Respiratory system, "chokes"	4	5.1
Cardiovascular system, syncope	4	5.1
Miscellaneous: Nausea	7	8.9
Vomiting	5	6.3
Restlessness – Malaise	5	6.3
Edema	4	5.1
Urinary	2	2.5

3. FACTORS INFLUENCING SEVERITY OF CASES & SUCCESS OF THERAPY		INCIDENCE (%) CURRENT	INCIDENCE (%) 1946-61	NUMBER OF CASES COMPARED	SIGNIFICANCE OF CHI SQUARE
AGE DISTRIBUTION	36–40	18.9	12.6	123	p<0.001
	OVER 40	11.4	3.8	45	0.001
DIVE CATEGORY	"NON-STANDARD"	79.7	31.1	353	0.001
DIVE DEPTH (FT.)	232–400	47.4	13.7	164	0.001
TOTAL BOTTOM TIME (MIN.)	OVER 120	34.1	16.9	204	0.001
SYMPTOM ONSET UNDER PRESSURE		22.8	7.9	102	0.001
ONSET-TREATMENT	OVER 360	16.3	21.4	206	0.02
CASES WITH "SERIOUS" SYMPTOMS		55.7	24.4	261	0.001
FAILURE OF INITIAL RECOMPRESSION	ALL CASES	8.9	13.0	122	0.10
	"SERIOUS"	11.4	30.9	58	0.01

2. DIVER-EXPOSURE-TREATMENT FACTORS		NO. OF CASES	INCIDENCE (%)
Age Distribution	Under 20	1	1.2
	21–30	33	41.8
	31–40	36	45.6
	Over 40	9	11.4
Purpose of Dive	Experimental	50	63.3
	Work / Training	16	20.3
	Other	13	16.4
Site of Dive	Dry chamber	41	51.9
	Open water	18	22.8
	Wet chamber	17	21.5
	Altitude chamber	2	2.5
	In-flight	1	1.2
Breathing Media	Compressed air	55	75.3
	$He-N_2-O_2$	15	19.0
	$He-O_2$	6	7.6
	O_2 (altitude)	3	3.8
Maximum Depth (ft.)	34–99	18	23.7
	100–165	12	15.7
	166–231	10	13.2
	232–297	26	34.2
	298–400	10	13.2
Total Bottom Time (minutes)	15–30	27	34.2
	31–60	9	11.4
	61–120	16	20.3
	121–180	6	7.6
	181–360	7	8.9
	361–740	13	16.4
	OVER 740	1	13.2
Appearance of Symptoms	Under pressure	18	22.8
	0-180 min.	50	63.3
	181-420 min.	9	11.4
	Over 420 min.	2	2.5
Time from Onset to Treatment (min.)	0–30	21	42.9
	31–60	4	8.1
	61–360	16	32.7
	Over 360	8	16.3
Time to Relief of Symptoms (min.)	1–3	14	32.7
	4–6	9	20.9
	7–10	8	18.7
	11–20	8	18.7
	21–30	4	9.3
	Over 30	5	11.7
Total Treatment Time (min.)	31–70	17	21.5
	71–100	22	27.8
	101–140	22	27.8
	141–190	8	10.3
	285	10	12.6

APPENDIX 3. STATISTICAL APPRAISAL - TECHNIQUES

1. Significance of the Difference Between Two Means. A Fisher t-test was used in analyzing for significance of the mean differences between all cases treated and cases with unsatisfactory outcome (Table 3). The derived level of confidence expresses the probability of obtaining a difference as large as the one obtained due the chance alone.

$$t = \frac{MEAN_{s.} - MEAN_{pop.}}{\sqrt{\sum (X - \bar{X})^2_s / N_s}}$$

2. Correlation. In Table 1 and Appendix 2 the Chi Square estimation of probability of association has been employed. The contingency coefficient, used to determine relationship when variables have been grouped into two or more classes, is derived from Chi Square.

$$\chi^2 = \sum \frac{(\text{observed frequency} - \text{expected})^2}{\text{expected frequency}}$$

$$C = \sqrt{\frac{\text{CHI SQUARE}}{N + \text{CHI SQUARE}}}$$

3. Ranking. A Spearman Rank Correlation Coefficient was computed for percent of cases arising fron non-standard dives and percent failure of the first recompression, using:

$$r = 1 - 6\Sigma D^2 / N(N^2 - 1)$$

The following ranking was examined (from Table 1):

YEAR GROUP	RANK: PERCENT NON-STD. DIVES	RANK: PERCENT THERAPY FAILURE	COLUMN 2 MINUS COLUMN 3	COLUMN 4 SQUARED
1946	6	7	1	1
1947-1955	7	6	1	1
1956-1959	2	3	1	1
1960-1961	5	5	0	0
1962	4	4	0	0
1963	1	2	1	1
1964	3	1	2	4
			TOTAL	8

$r = 1 - (6)(8)/7(49 - 1) = 0.86$

4. Variability. Standard deviations have been computed for the means listed in Table 5.

$$\sigma = \sqrt{\frac{\sum (X - \bar{X})^2}{N}}$$

(Reference: 1)

APPENDIX 4. TYPICAL RECOMPRESSION THERAPY PROCEDURES, CURRENT AND HISTORICAL, FOR TUNNEL-CAISSON WORKERS AND DIVERS

1. U. S. NAVY DIVING MANUAL, BUREAU OF CONSTRUCTION AND REPAIR, 1924

1.1 Recompress rapidly to 45 psi (101.5 ft.). If patient does not show marked improvement, increase pressure to 60 psi (135 ft.).

1.2 Decompression should be started as soon as the patient is relieved, the pressure being allowed to fall at the following rate:

WHEN PRESSURE IN CHAMBER IS	ALLOW TO FALL AT RATE NOT OVER
above 60 psi	Rapidly
between 60-45 psi	1 psi in 1 minute
between 45-30 psi	1 psi in 3 minutes
between 30-15 psi	1 psi in 5 minutes
below 15 psi	1 psi in 10 minutes

2. PRE-1937 AIR SATURATION TABLES

2.1 Recompress to depth of relief plus one atmosphere
2.2 Use decompression schedule which is next higher

DEPTH OF STOPS	100 Ft.	150 Ft.	200 Ft.	250 Ft.	300 Ft.
	(TIME OF STOPS IN MINUTES)				
140	-	-	-	-	4
130	-	-	-	-	14
120	-	-	-	-	16
110	-	-	-	13	16
100	-	-	-	18	18
90	-	-	7	19	19
80	-	-	22	22	22
70	-	-	24	24	24
60	-	22	26	26	26
50	-	30	30	30	30
40	14	35	35	35	35
30	42	42	42	42	42
20	52	52	52	52	52
10	68	68	68	68	68
TOTAL TIME:	175	249	306	351	387

3. PROCEDURES DEVISED BY BEHNKE AND SHAW, AND BEHNKE AND YARBROUGH

3.1 from NAV. MED BULL. (REF. 5, 1937)

FEET	MINUTES	GAS MIX	FEET	MINUTES	GAS MIX
165	15-120	50% O_2	165	15-120	50% O_2
165-60	45	50% O_2	165-60	45	50% O_2
60	60-120	100% O_2	60	60-180	100% O_2
60-0	30	100% O_2	60	24 hours	AIR
			60	120	100% O_2
			60-0	30	100% O_2

3.2 from J. INDUSTR. HYG. (REF. 32, 1939)

FEET	MINUTES	GAS MIX	FEET	MINUTES	GAS MIX
165	30	AIR	165	30	AIR
165-60	4	AIR	165-60	4	AIR
60	22	100% O_2	60	90	100% O_2
50	30	100% O_2	60-0	6	100% O_2
40	35	100% O_2			
40-0	5	100% O_2			

3.3 from MED. CLINICS N. AMERICA, 1213, 1942

FEET	MINUTES	GAS MIX	FEET	MINUTES	GAS MIX
165	30	AIR	100	30	AIR
165-60	45	AIR	100-60	10	AIR
60	30	100% O_2	60	30	100% O_2
45	30	100% O_2	45	30	100% O_2
30	30	100% O_2	30	30	100% O_2
30-0	5	100% O_2	30-0	5	100% O_2

4. BUSHIPS DIVING MANUAL, 1943 AND BUMED NEWS LETTER 3:5, 1944

FEET		MINUTES		
165	30	30	-	-
140	12	12	-	-
120	12	12	-	-
100	12	12	30	30
80	12	12	12	12
60	26	30(O_2)	26	30(O_2)
50	30	30(O_2)	30	30(O_2)
40	35	30(O_2)	35	30(O_2)
30	42	|	42	|
		5(O_2)		5(O_2)
20	52	↓	52	↓
10	68	↓	68	↓

(REF. 27, 28)

5. NAVXDIVINGU EXPERIMENTAL PROCEDURE, 1945

FEET	MINUTES
165	120
140	12
120	12
100	12
80	12
60	120(O_2)
60	22 HOURS
50	120
40	120
30	120
20	120
10	120

6. ROYAL NAVY DIVING MANUAL (B.R. 155/43), 1943

6.1 Recompress to depth of relief, than immediately begin ascent

6.2

When Pressure is	Maximum rate of ascent
100-90 psi	4 psi in 1 minute
90-75 psi	2 psi in 1 minute
75-60 psi	1 psi in 1 minute
60-45 psi	1 psi in 1 1/2 minutes
45-30 psi	1 psi in 3 minutes
30-15 psi	1 psi in 5 minutes
15-0 psi	1 psi in 8 minutes

6.3 Decompression time may be extended to:

45-30 psi	1 psi in 4 minutes
30-15 psi	1 psi in 6 minutes
15-0 psi	1 psi in 10 minutes

7. TYNE TUNNEL "SPECIAL PROCEDURE" (REF. 22)

7.1 Recompress to working pressure. Begin ascent 10 minutes after symptoms have been relieved

7.2

When Pressure is	Maximum rate of ascent
40-30 psi	1 psi in 3 minutes
30-15 psi	1 psi in 5 minutes
15-0 psi	1 psi in 8 minutes

7.3 For recurrances:

40-30 psi	1 psi in 4 minutes
30-15 psi	1 psi in 6 minutes
15-0 psi	1 psi in 10 minutes

8. DARTFORD TUNNEL "SPECIAL PROCEDURE" (REF. 6)

8.1 Recompress to depth of relief. Begin ascent after 30 minutes.

FEET	RATE OF ASCENT	TIME AT STOP
to 27	1 foot in 7 1/2 minutes	-
27	-	240 minutes
27-18	1 foot in 15 minutes	-
18	-	90 minutes
18-9	1 foot in 15 minutes	-
9	-	60 minutes
9-4.5	1 foot in 15 minutes	-
4.5	-	60 minutes
4.5-0	1 foot in 15 minutes	-

9. PROPOSALS FROM L'GROUPE D'ETUDES ET DE RESERCHES SOUS-MARINE G.E.R.S. REPORT 3/62, 1962

FEET	MINUTES	MINUTES	MINUTES
165	30-120	15	15
140	30	15	15
120	30	15	15
100	30	15	15
80	30	15	15
60	240 (Air)	20 (Air)	30
	120 (O_2, 15-Air, 15)	10 (O_2)	
50	180 (Air)	15 (Air)	30
	180 (O_2, 15-Air, 15)	15 (O_2)	
40	360 (O_2, 30-Air, 30)	5 (Air)	30
		25 (O_2)	
30	360 (Air)	10 (Air)	120
	360 (O_2, 30-Air, 30)	20 (O_2)	
20	10 (Air)	10 (Air)	120
	50 (O_2)	20 (O_2)	
10	10 (Air)	20 (O_2)	240
	50 (O_2)		
10-0	5 (O_2)	5 (O_2)	5 (O_2)

APPENDIX 5. OXYGEN TOLERANCE

1. SUSCEPTIBILITY OF RESTING ADULTS, RECOMPRESSION CHAMBER (DRY) EXPOSURES, OPEN-CIRCUIT DEMAND SYSTEMS

DEPTH (FEET):	60	60	66	80	100
NO. OF EXPOSURES:	20	1,388	241	20	20
EXPOSURE TIME (MIN):	120	30	21-67	60	35
NO. SUBJECTS WITH SYMPTOMS:	0	14	1	10	10
REACTION INCIDENCE (%):	0	1.01	0.40	50	50
MEAN TIME TO FIRST SYMPTOM (MIN):	0	-	40	-	-
CONVULSIONS, NUMBER:	0	5	1	0	0
CONVULSIONS, INCIDENCE (%):	0	0.30	0.40	0	0
REFERENCE:	30	*	14	33	33

(*OXYGEN TOLERANCE EXPOSURES, U. S. NAVAL SCHOOL DEEP SEA DIVERS, 1951-1961)

2. EFFECTS OF INTERMITTENT OXYGEN EXPOSURE PATTERNS ON SURVIVAL TIME AND PRE-SYMPTOMATIC LATENCY PERIODS: SMALL MAMMALS

2.1 MICE (Ref. 16)

$P_{I_{O_2}}$ (ATM. ABS.)	ALTERNATE GAS	O_2 EXPOSURE TIME (HOURS)	ALTERNATE GAS TIME (HOURS)	MEAN SURVIVAL (DAYS)
1	-	Continuous	-	5
1	AIR	22	2	8
1	AIR	20	4	10
1	AIR	16	8	27

2.2 GUINEA PIGS (Ref. 23)

$P_{I_{O_2}}$ (ATM. ABS.)	ALTERNATE GAS	O_2 EXPOSURE TIME (MIN.)	ALTERNATE GAS TIME (MINUTES)	MEAN SURVIVAL (HOURS)
4	-	Continuous	-	2.9
4	AIR(1 ATM)	30	10	9.7
4	AIR(1 ATM)	30	20	14.3

2.3 GUINEA PIGS (Ref. 17, 20)

$P_{I_{O_2}}$ (ATM, ABS.)	ALTERNATE GAS	O_2 EXPOSURE TIME (MIN.)	ALTERNATE GAS TIME (MINUTES)	TIME TO REACTION (HR)
3	-	Continuous	-	5.9
3	97% N_2-3% O_2	30	10	22.0

3. INTERMITTENT OXYGEN-AIR EXPOSURE: HUMAN SUBJECTS

3.1 SUBJECT: H. S. Spurway, 1942-1943; Exposures at 90 feet.

TIME (MIN) TO ENDPOINT	TOXICITY SYMPTOMS	INTERMITTENT EXPOSURE PATTERN
13	Convulsion	100% O_2 - 15 Min.
33	Vomiting	AIR - 5
35	Convulsion	O_2 - 15
41	Convulsion	AIR - 5
42	Convulsion	O_2 - 15
43	Convulsion	AIR - 5
50	Visual disturbances	O_2 - 20
		(No symptoms, 65 Min. O_2 breathing)

3.2 SUBJECT: J. B. S. Haldane, 1942; Exposures at 75 feet

TIME (MIN) TO ENDPOINT	TOXICITY SYMPTOMS	INTERMITTENT EXPOSURE PATTERN
32	Spasms of diaphragm	Same as above; no symptoms
49	Twitching of facial muscles	

4. GROUP VARIABILITY IN OXYGEN TOLERANCE: 30 SUBJECTS AT 90 FEET, DRY CHAMBER EXPOSURE

EXPOSURE TIME (MINUTES)	CUMULATIVE PERCENT WITH SYMPTOMS	EXPOSURE TIME (MINUTES)	CUMULATIVE PERCENT WITH SYMPTOMS
6	5.6	23	56.0
7	8.4	24.5	58.8
7.5	11.2	25.5	61.6
9	16.8	26.5	64.4
12.5	19.6	30	67.2
14	22.4	32	72.8
15	25.2	33	75.6
15.5	28.0	34.5	78.4
16	30.8	50.5	84.0
16.5	33.6	51	86.8
17	42.0	54.5	89.6
18	47.6	62	95.2
19.5	50.4	67	97.0
20.5	53.2	96	100.0

(Reference: 9)

5. INDIVIDUAL VARIABILITY IN OXYGEN TOLERANCE: 1 SUBJECT AT 70 FEET, WET CHAMBER, 20 EXPOSURES - 90 DAYS

EXPOSURE TIME (MINUTES)	DAY IN SERIES	EXPOSURE TIME (MINUTES)	DAY IN SERIES
7	1	31.5	48
12.5	7	67.5	56
86	9	62.5	70
27	15	43	70
23	17	41.5	76
21	20	82	78
28	30	29.5	80
61	34	125	83
148	37	78	90
37.5	42		
96	44		

(Reference: 9)

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With growing awareness of the incremental frequency with which difficulties are encountered in recompression treatment of severely injured patients, and the grossly inadequate decompressions now characterizing the civilian diver casualty population applying to USN recompression facilities, evaluation and clinical trials of therapeutic procedures, alternative to USN treatment tables, were undertaken. These techniques are particularly suitable for recompression management of aviators' dysbarism when descent to sea level has not provided complete palliation. The proportion of good results obtained with initial recompression trials with these procedures has significantly exceeded that obtained in recent years, with the Diving Manual tables, although the current series of 79 cases surpassed comparable casualty groups in average case severity. Hypothetical and practical aspects of the treatment concept and technique are presented, and contraindications noted. There were no adverse responses to the 2.8 atmospheres absolute PO_2, and nine normal volunteer subjects showed no impairment of timed vital capacity following test exposures.

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