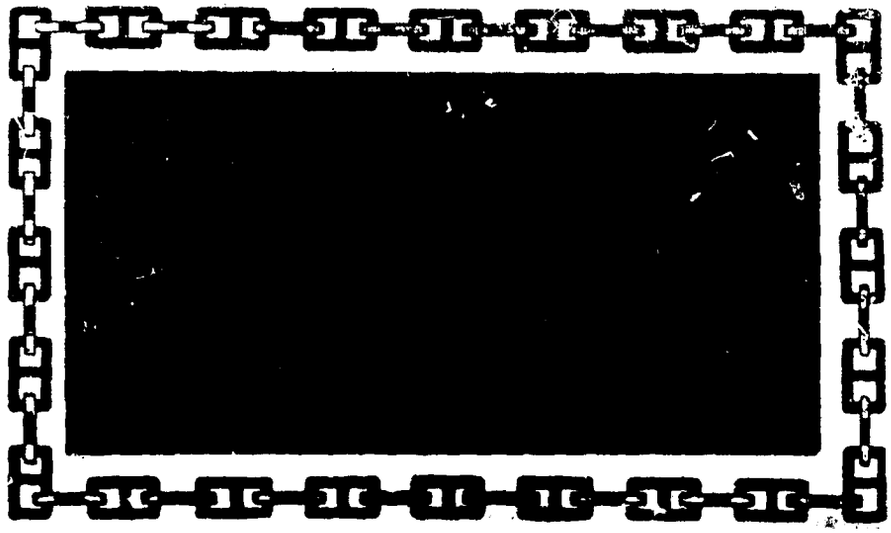
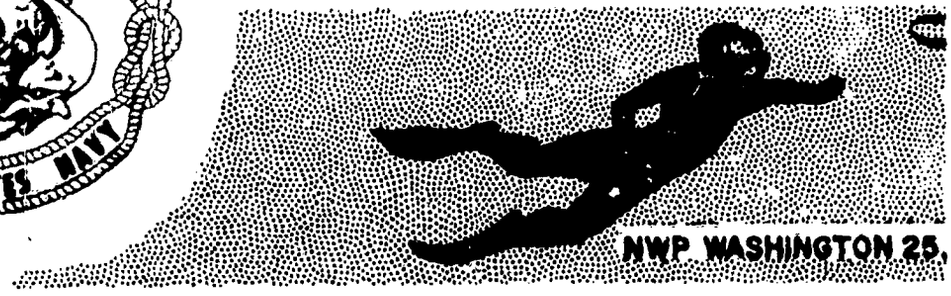


U. S. Navy
Experimental Diving Unit



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RESEARCH REPORT 4-64

DECOMPRESSION SICKNESS AMONG U.S. NAVY OPERATIONAL DIVERS: AN ESTIMATE OF INCIDENCE USING AIR DECOMPRESSION TABLES

PROJECT SF-011--06-01 TASK 3361 SUB TASK 9

by
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15 February 1965

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ABSTRACT

A "liberal" estimate of the incidence of decompression sickness in U. S. Navy operational diving was computed for years 1958, 1960, and 1961. A comparison was made between the incidence using the old U. S. Navy air decompression tables (1958) and the revised U. S. Navy air decompression tables (1960, 1961). Incidences were also computed for dives equal to or greater than 100 feet and less than 100 feet. Findings revealed that for the three years a total of 7625 dives were made resulting in 62 reported cases of decompression sickness for an incidence of 0.81 percent. Incidence for the old tables was 1.10 percent versus 0.69 percent for the revised tables. Comparatively few dives of less than 100 feet required decompression, however, a somewhat higher incidence was found for these dives using the revised tables. The author gives a possible explanation for this apparent paradox. As a by-product of this study an incidence of 0.83 percent was noted when the U. S. Navy helium decompression tables were required.

SUMMARY

PROBLEM:

To obtain an estimate of the incidence of decompression sickness among U. S. Navy operational divers and to make a comparison between the relative efficiency of the old air decompression tables and the revised air decompression tables.

PROCEDURE:

Incidence was obtained for three years (1958, 1960, 1961) using two sources of data: decompression sickness reports on file at the Experimental Diving Unit, and Diving Log Books, NAVSHIPS 1000 (Rev 11-57). Only dives made in the open sea requiring decompression were considered. Computed incidences were considered to be slightly inflated because a strong possibility existed that all the Diving Log Books were not made available to the author, and some cases of decompression sickness occurred from dives not requiring decompression.

FINDINGS:

(1) For the three years a total of 7625 dives were made of which 62 resulted in decompression sickness for an incidence of 0.81 percent.

(2) The incidence using the old tables (1958) was 1.10 percent while the incidence for the revised tables (1960, 1961) was 0.69 percent.

(3) Relatively few dives of less than 100 feet were of sufficient duration to require decompression. However, a slightly higher incidence was found for dives of this category using the revised tables. Further investigation revealed that a disproportionate number of bends cases in this category (i.e. less than 100 feet) received insufficient decompression due to the administration of the wrong decompression tables. This, plus the unreliability of such small numbers, could easily account for what is seemingly a paradox.

(4) As a by-product of this study it was noted that for the 3 years of 1958, 1960, 1961 there were 721 dives performed requiring decompression on the U. S. Navy standard helium decompression tables resulting in 6 cases of reported decompression sickness for an incidence of 0.83 percent.

CONCLUSIONS AND RECOMMENDATIONS:

(1) Since the incidence of 0.69 percent for the revised tables must be considered to be somewhat inflated it would seem safe to conclude that the incidence of decompression sickness in U. S. Navy operational diving using present procedures is substantially less than 1.00 percent. The computed incidence of 1.10 percent for the old tables does not allow for such a conclusion. However, if the "true" incidence for the old tables was not less than 1.00 percent it was extremely close.

(2) Without knowing the extent of inflation for each of the computed incidences it is difficult to make a definitive comparison between the old air decompression tables and the revised air decompression tables. However, the obtainable estimate indicate a superiority of performance favoring the revised tables.

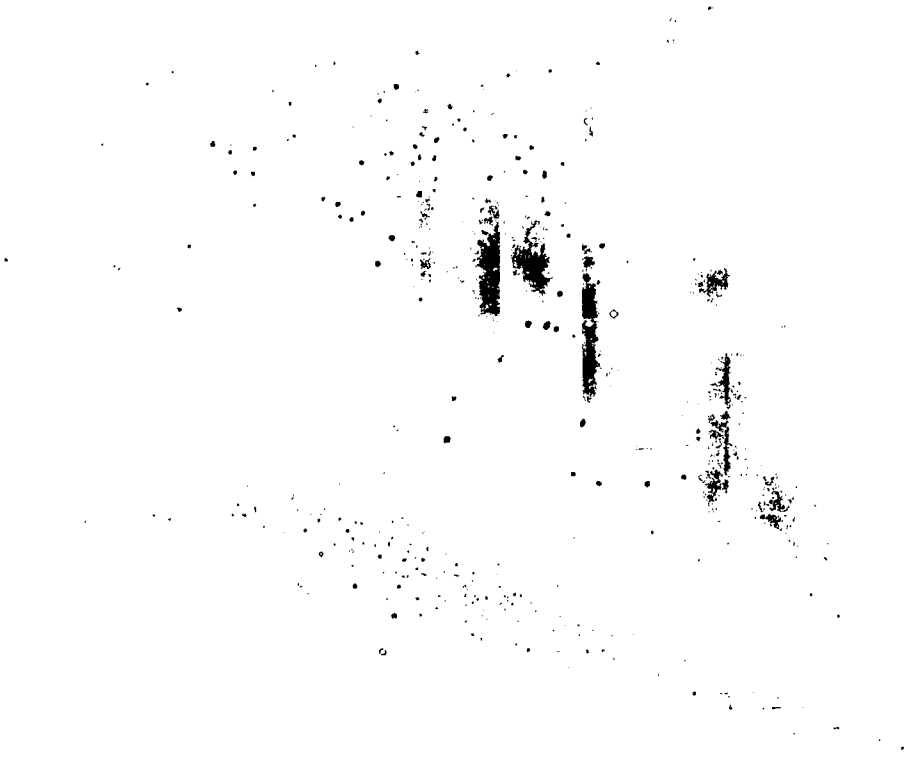
(3) It is recommended that a study of this nature be done on a periodic basis under more controlled conditions. Pertinent data for each case of decompression sickness and for each decompression dive should be put on ADP Cards allowing for continuous comprehensive examination of the problem of decompression sickness incidence.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Ships, Navy Department Research Project SF-011-0601 Task 3361 Sub Task 9. Data abstraction from Diving Log Books, NAVSHIPS 1000 (Rev 11-57) and Diving Casualty Data Cards was begun 1 November 1963 and completed 1 September 1964. Statistical analysis of the abstracted data was initiated 15 September 1964 and completed 1 November 1964. The final manuscript was completed on 15 February 1965.

ACKNOWLEDGEMENT

The author wishes to express his gratitude to Captain R. D. Workman who provided a significant amount of guidance in writing the manuscript.



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I. INTRODUCTION

1.1 Background

1.1.1 To date there has never been an empirically derived estimate of the incidence of decompression sickness in U. S. Navy operational diving. Such an estimate is desirable in that it allows for an appreciation of the true efficiency of systems and procedures that are developed in a laboratory setting. It would not be safe to assume a one-to-one relationship between results obtained in the laboratory and those obtained in the operational situation.

1.1.2 In 1958 a revision of the air decompression tables was developed. This revision did not become operational, however, until 1959. The purpose of this study was to obtain an estimate of incidence of decompression sickness in U. S. Navy operational diving with these revised air decompression tables. It was also felt that by including an estimate of incidence during a period when the old tables were operational an interesting comparison could be obtained.

1.1.3 Several estimates of incidence of decompression sickness or "bends rate" among caisson workers have been reported. An incidence of 4.00 percent during construction of a caisson was reported by Lewis and Paton (4). Construction of the Tyne Tunnel resulted in a "bends rate" of 0.87 percent as reported by Paton and Walder (6). Golding, et al (3) report an incidence of 0.56 percent during construction of the Dartford Tunnel. Finally at the Clyde Tunnel a rate of 0.31 per [illegible] is reported by Davidson (1). However, the vast differences between the situations of the caisson workers and the divers of the U. S. Navy preclude any direct comparison of results. The caisson workers are exposed to a relatively small amount of pressure of less than 30 P.S.I. or the equivalent of about 70 feet of depth in water. At the same time, they are exposed to these pressures for extremely long periods of time, usually about 8 hours. Navy diving, on the other hand, includes an extremely wide variety of depths, bottom times and types of equipment.

2. PROCEDURE

2.1 Casualty Reports

2.1.1 A complete file of past diving casualty reports is maintained at the U. S. Navy Experimental Diving Unit, Washington, D. C. The earliest reports accumulated and still available began in 1933. These reports were submitted in compliance with the Bureau of Construction and Repair Letter Directive of 1933, later by the Bureau of Medicine and Surgery directives, and finally by the Manual of the Medical Department (5), and U. S. Diving Manual (8).

2.2 Diving Log Books

2.2.1 It has been the policy of the diving activities in the U. S. Navy to return to the U. S. Navy Experimental Diving Unit after four years retention all completed Diving Log Books, NAVSHIPS 1000 (Rev. 11-57). Just prior to the undertaking of this study an additional request was made of all diving activities to return all completed log books.

2.3 Liberal Estimate

2.3.1 Using these two sources of data a "liberal" estimate of the incidence of reported decompression sickness was obtained. It was considered a liberal estimate in the sense that the completeness of the records of reported decompression sickness was more assured than that of the diving logs. Since a four year lag often occurred between the completion of a diving log and its being forwarded to the Experimental Diving Unit it would not be surprising if some logs were lost, and thus not recorded in this study. Such a circumstance would cause the estimate of incidence reported in this study to be higher than had they been included. A second factor exists which would tend to bias the estimate towards inflation. Since only dives that required decompression were included for an estimate of "bends rate", any reported case of decompression sickness resulting from dives not requiring decompression would bias the computed incidence toward inflation. An examination of the description of the decompression sickness cases (Appendix) reveals that 4 such cases occurred under these circumstances. This problem could not be avoided since there were literally thousands of dives made during this period requiring no decompression. If these dives were included it would have given unfair estimate of incidence. At the same time it was felt that these 4 cases of decompression sickness should not be excluded since they must be considered as a shortcoming of the diving procedures in use at the time.

2.4 Dives to be Included

2.4.1 For a dive to be included in this survey it had to (1) require decompression on the air decompression tables and (2) be in the open sea. No dives or case reports were considered from the Experimental Diving Unit or the U. S. Navy Deep Sea Diving School. These two complexes were excluded because their dives are made for the most part in recompression chambers or wet tanks. Also, dives made at the Experimental Diving Unit are often of an experimental nature not subject to the usual Navy diving procedures.

2.4.2 The years included in this study were 1958, 1960, 1961. Although the decompression tables were revised in 1958 it could not be assumed that they were universally applied throughout the U. S. Navy until 1960. Since both the old and the revised tables were being used during 1959 it was felt that this year should be excluded. Inclusion of the year 1958 allows for a comparison between the relative efficiency of the old and revised air decompression tables.

2.5 Case Reports

2.5.1 All reports were considered to be bonafide cases of decompression sickness by a pooling of judgements of several submarine medical officers attached to the Experimental Diving Unit and Deep Sea Diving School.

2.6 Analysis

2.6.1 A total of 7,625 dives and 62 reported cases of decompression sickness were recorded for the 3 years of 1958, 1960, 1961. The analysis consisted of computing an incidence of decompression sickness for: (1) each of the 3 years, (2) total of the 3 years, (3) dives of 100 feet and deeper, and dives of less than 100 feet for each of the 3 years and total 3 years, and (4) old air decompression tables (1960, 1961).

2.6.2 Incidences are in percentages derived simply by dividing the number of dives into the number of decompression sickness cases.

3. RESULTS AND DISCUSSION

3.1 General Considerations

3.1.1 It must be emphasized that in interpreting these results one should keep in mind that these percentages of bends incidence are somewhat inflated for the previously mentioned reasons. On the other hand, this is a survey of the incidence of reported decompression sickness. It would be presumptious to think that there were no valid cases of decompression sickness which were not reported by the diver and which resolved themselves without treatment.

3.2 Tables

3.2.1 Examination of Table 1 reveals a definite tendency towards a lower incidence in those years (1960, 1961) when the revised tables were universally applied. It would seem safe to conclude that the revised air decompression tables result in an incidence of decompression sickness of substantially less than 1.0 percent. The incidence of 0.68 percent for 1960 and 0.70 percent for 1961 demonstrates good reliability for this statement. On the other hand, it would be difficult to conclude that the old tables had a "bends rate" of less than 1.00 percent. However, the 1.10 percent incidence found for 1958 shows that if the incidence was not actually less than 1.00 percent it was very close. Although it is statistically[1] impossible to test for the significance of the differences between these incidences it seems that a definite difference in bends rate does exist.

[1]No statistical test is available to valiuly test for significance of differences when one category (viz. dives resulting in decompression sickness) represents such a small proportion of the total number (viz. total number of dives made).

TABLE 1

TOTAL INCIDENCE FOR EACH YEAR

YEAR	DIVES	CASES	INCIDENCE
1958	2172	24	1.10%
1960	2768	19	0.68%
1961	2685	19	0.70%
TOTAL	7625	62	0.81%

3.2.2 In Table 2 the incidence is broken down into two categories of depth for each year: 100 feet or greater and less than 100 feet. It can be readily seen that there are relatively few dives of less than 100 feet requiring decompression. This is due obviously to the long bottom time required before it is necessary to decompress. One would hypothesize that dives of this category would result in a lower "bends rate" than the deeper dives. Such a hypothesis would be based upon two facts. The relatively shallow dives require a greater exposure time to increase the inert gas concentration in the body tissues a finite amount. Secondly, the body tissues which equilibrate more rapidly would contain a greater concentration of inert gas following an equivalent exposure period at deeper depths. This hypothesis was confirmed for 1958. However, this was not true for the revised air decompression tables in which a higher incidence exists for dives of less than 100 feet. In an attempt to find some possible explanation for this it was discovered that a disproportionate number of bends cases resulting from these shallower dives were given insufficient decompression due to the administration of the wrong decompression table.

3.2.3 Examination of the case descriptions for 1960, 1961 in the Appendix shows that, of the 6 cases of bends occurring from dives of less than 100 feet, 3 or 50 percent has been decompressed on the wrong table. Whereas of the 32 cases occurring from dives of 100 feet or deeper only 3 or 9 percent were exposed to such faulty procedures. Statistically this difference is significant at .05 level of confidence.[3] This, plus the unreliability of such small numbers, could easily account for what is seemingly a paradox.

TABLE 2

INCIDENCE OF DECOMPRESSION SICKNESS FOR DIVES ≥100 FEET AND <100 FEET FOR EACH YEAR

	≥100 FEET			<100 FEET		
YEAR	DIVES	CASES	INCIDENCE	DIVES	CASES	INCIDENCE
1958	1887	22	1.16%	285	2	0.70%
1960	2307	16	0.69%	461	3	0.65%
1961	2433	16	0.65%	252	3	1.19%
TOTAL	6627	54	0.81%	998	8	0.80%

[3]Chi square test using Yate's correction for continuity. The correction is recommended when numbers of less than 5 fall into any category (2).

3.2.4 Table 3 directly compares the old air tables and the revised air tables. As was evident in Table 1, a substantial decrease in "bends rate" with the revised tables exists.

TABLE 3

OLD TABLES (1958) VS REVISED TABLES (1960, 1961)

	OLD TABLES			REVISED TABLES		
DEPTH	DIVES	CASES	INCIDENCE	DIVES	CASES	INCIDENCE
≥100	1887	22	1.16%	4740	32	0.67%
<100	285	2	.70%	713	6	0.84%
TOTAL	2172	24	1.10%	5453	38	0.69%

3.3 Helium Decompression Tables

3.3.1 As a by-product of this study and one certainly worthy of note were the 721 dives made using a helium-oxygen gas mixture for the three years of 1958, 1960, and 1961. These dives, all requiring decompression on the U. S. Navy standard helium decompression tables developed in 1950, resulted in 6 reported cases of decompression sickness for an incidence of 0.83 percent. Due to the small number of helium dives and bends cases resulting from these dives it is difficult to make any conclusions, but from the evidence available so far there seems to be very little difference in the incidence using the revised air tables and the helium tables.

3.4 Appendix

3.4.1 The case reports of decompression sickness for 1958, 1960, and 1961 reflected in the Appendix are only a small part of the case reports used by Rivera (7) in his analysis of decompression sickness. In light of this, no analysis was made of the data in the Appendix other than that already mentioned.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 The estimates of decompression sickness incidence reported in this study must be considered liberal. The computed incidence of 0.69 percent for the revised tables therefore allows one to conclude that the true incidence using these tables is substantially less than 1.00 percent. On the other hand, the computed incidence of 1.10 percent for the old tables does not allow for such a conclusion. It does seem apparent, however, that if the "true" incidence for the old tables was not less than 1.00 percent it was extremely close.

4.2 Without knowing the extent of inflation for each of the computed incidences, it is difficult to make a definitive comparison between the relative efficiencies of the old air decompression tables and that of the revised tables. However, the obtainable estimates indicate a superiority favoring the revised tables.

4.3 The higher incidence for dives of less than 100 feet using the revised tables could be explained by the disproportionate number of bends cases in this category whigh received insufficient decompression due to the use of the wrong decompression table. It is tempting for one to speculate that perhaps there exists a tendency to "slacken off" somewhat on safety procedures during relatively shallow dives.

4.4 As a by-product of this study it was noted that an incidence of 0.83 percent resulted from use of the helium decompression tables. Although based on small numbers (viz. 721 dives and 6 reported cases of bends) there seems to be little difference in the "bends rate" of the revised air decompression tables and helium decompression tables. However, investigation of the latter should be the subject of a study in its own right.

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APPENDIX: DESCRIPTION OF DECOMPRESSION SICKNESS CASES CODE

AGE

Under 20 years	1
21 to 25 years	2
26 to 30 years	3
31 to 35 years	4
36 to 40 years	5
Over 40 years	6

BUILD

Slender	S
Medium	M
Heavy	H
Obese	O

EQUIPMENT

Deep Sea	DS
Light Weight	LW
Scuba	S

WORK

None	N
Mild	Mi
Moderate	Mo
Heavy	H

APPENDIX

* No decompression required

** Less than proper decompression due to error

	YEAR	DEPTH	BOTTOM TIME	AGE	BUILD	EQUIPMENT	WORK	REPETITIVE DIVE
1)	58	190	22	4	M	S	Mi	No
2)	58	163	20	3	M	DS	Mi	No
3)	58*	110	9	2	M	S	H	No
4)	58	141	12	4	S	DS	H	No
5)	58	124	51	3	S	DS	H	No
6)	58	144	19	1	M	DS	Mo	No
7)	58	122	30	5	H	DS	H	No
8)	58	143	16	1	H	DS	Mo	No
9)	58	140	27	4	M	DS	Mo	No
10)	58	161	11	2	M	DS	N	No
11)	58	141	35	3	H	DS	H	No
12)	58**	135	12	5	M	S	Mi	Yes
13)	58	112	8	5	H	S	H	Yes
14)	58	237	14	6	M	DS	Mi	No
15)	58	159	19	3	S	DS	Mi	No
16)	58	140	41	4	M	DS	Mo	No
17)	58	148	17	2	S	DS	H	No
18)	58	110	9	3	M	S	H	Yes
19)	58	190	25	5	M	S	Mi	Yes
20)	58	110	20	5	M	S	Mo	No
21)	58	110	16	4	S	DS	H	No
22)	58	46	120	2	H	LW	H	No
23)	58*	50	48	1	S	LW	Mi	No
24)	58	141	35	3	H	DS	H	No
25)	60	120	47	3	M	DS	N	No
26)	60	215	31	4	S	DS	H	No
27)	60**	90	18	4	S	S	Mo	Yes
28)	60**	160	13	3	H	S	Mo	No
29)	60**	115	9	4	M	S	H	Yes
30)	60	215	42	4	S	DS	H	No
31)	60**	200	22	4	H	DS	Mo	No
32)	60	170	25	3	M	DS	H	No
33)	60	170	29	3	M	DS	M	No
34)	60	145	37	4	S	DS	H	No
35)	60	142	29	4	M	DS	M	No
36)	60**	93	18	1	M	S	M	Yes
37)	60	191	19	4	S	DS	M	No
38)	60	246	20	4	M	DS	H	No
39)	60	231	10	2	H	DS	H	No
40)	60	120	47	2	O	DS	N	No
41)	60*	65	13	4	H	S	Mi	Yes
42)	60	215	25	4	H	DS	H	No
43)	61	60	40	4	M	DS	Mi	Yes

APPENDIX

	YEAR	DEPTH	BOTTOM TIME	AGE	BUILD	EQUIPMENT	WORK	REPETITIVE DIVE
44)	61	168	6	3	M	S	Mo	Yes
45)	61	166	14	3	M	DS	Mi	No
46)	61*	65	46	5	H	DS	Mo	No
47)	61	247	14	6	M	DS	Mo	No
48)	61	237	19	3	H	DS	Mo	No
49)	61	247	14	6	H	DS	Mo	No
50)	61	126	3	3	M	S	H	No
51)	61	200	43	5	M	DS	H	No
52)	61	187	15	4	S	DS	H	No
53)	61	185	24	6	M	DS	H	No
54)	61	257	13	4	M	DS	M	No
55)	61	112	24	5	M	DS	H	No
56)	61	148	13	3	H	DS	M	No
57)	61	127	19	4	H	DS	H	No
58)	61	107	33	3	H	DS	M	No
59)	61	170	5	3	M	DS	Mi	No
60)	61	128	13	3	M	S	Mo	No
61)	61	180	8	4	M	S	H	No
62)	61**	50	20	3	M	LW	Mi	Yes