NEW NO-DECOMPRESSION TABLES BASED ON NO-DECOMPRESSION LIMITS DETERMINED BY DOPPLER ULTRASONIC BUBBLE DETECTION

by

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ABSTRACT

Studies done by Spencer in 1976 produced new no-decompression limits designed to eliminate venous bubbles. This paper has used those limits as the basis for a full set of no-decompression tables. The resulting tables are more conservative than the Navy tables but have more potential for multi-level diving.

DISCLAIMER

These tables have been developed mathematically and have not been subjected to testing to validate them. They are more conservative than the Navy's tables and if used in the same manner as the Navy's tables will give less allowed bottom time.

The use of these tables, or any others, for multi-level diving should be discouraged until testing has validated an acceptable technique.

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INTRODUCTION

Recently there has been growing concern in the diving community that the Navy no-decompression tables may not be as safe for the sport diver as they should be. Studies have shown that there is bubble formation in divers who have been exposed to dives within the Navy's limits (Spencer 1976). Using these findings new no-decompression limits were calculated to prevent the formation of bubbles. This paper carries this development one step further by developing a set of no-decompression tables based on these new limits.

BACKGROUND

The concern over the Navy tables exsists even though the incidence of decompression sickness experienced by Navy divers using the tables is less than 0.04% (Bassett 1979). The problem with this statistic is that its sample is made up of Navy divers, not sport divers. Most of the Navy's no-decompression dives are conducted in depths shallower than 60 feet, and the tables are not pushed to their limits. Sport divers, on the other hand, quite frequently push the tables to their limits and dive to depths in excess of 100 feet. Another problem that occurred recently, in using the Navy tables, is that divers developed multi-level methods to extend their bottom time by reading the tables sideways. In theory some of these multi-level methods are feasible (Graver 1976), but the Navy tables were not developed for such manipulations. Calculations have shown that tissue pressures produced by this type of diving are pushed to and sometimes over the limits set by the Navy (Huggins 1980). The worst problem in the sport diving community is that reporting of decompression sickness tends to be neglected in all but the most serious cases.

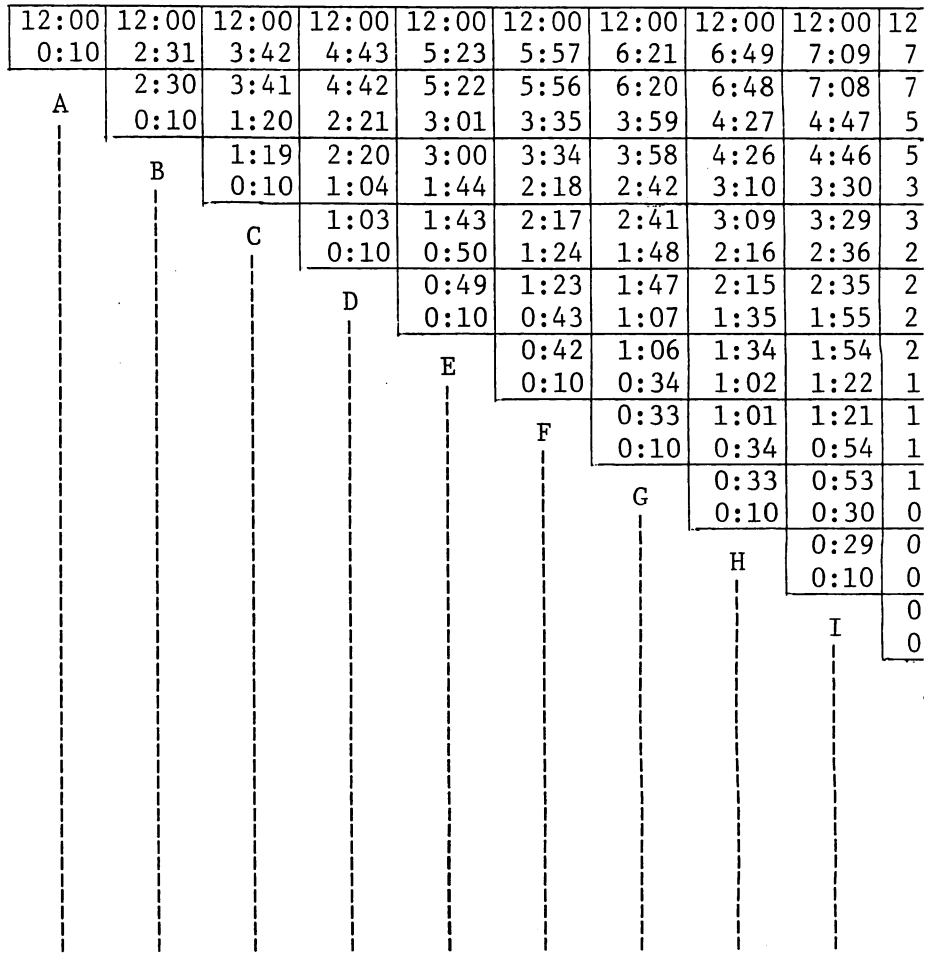
In a study (Spencer 1976) using a Doppler ultrasonic bubble detector, it was shown that venous gas bubbles were produced after exposing subjects to dives within the Navy's no-decompression limits. Although there is some controversy on the effects that these bubbles may have on the body, it seems a good idea to try to prevent their formation. As a result of this study, new no-decompression limits were developed for the prevention of bubble formation (Table 1).

TABLE 1.

NO-DECOMPRESSION LIMITS

Depth	Navy's	Spencer's	Depth	Navy's	Spencer's
30'	none	225 min	80'	40 min	30 min
35'	310 min	165 min	90'	30 min	25 min
40'	200 min	135 min	100'	25 min	20 min
50'	100 min	75 min	110'	20 min	15 min
60'	60 min	50 min	120'	15 min	10 min
70'	50 min	40 min	130'	10 min	5 min

The objective of this project was to develop a set of no-decompression tables that would be based on these new limits and could theoretically be used safely for multi-level diving.



DEPTH (FT.)	NO DECOM. LIMITS	BOTTOM TIME AND REPETITIVE GROUP CO									
		A	B	C	D	E	F	G	H	I	
20	–	10	25	40	60	85	110	135	170	215	2
30	225	5	15	25	40	50	65	75	95	110	1
35	165	5	15	20	30	40	50	60	70	85	1
40	135	5	10	20	25	35	40	45	55	60	
50	75	–	10	15	20	25	30	35	37	40	
60	50	–	5	10	15	20	23	25	27	30	
70	40	–	5	10	13	15	17	20	23	25	
80	30	–	5	7	→	10	13	15	17	20	
90	25	–	–	5	7	→	10	→	13	15	
100	20	–	–	–	5	7	→	→	10	→	
110	15	–	–	–	–	5	→	7	→	→	
120	10	–	–	–	–	–	5	→	→	7	
130	5	–	–	–	–	–	5				

12:00 8:01	12:00 8:18	12:00 8:27	A	12	8	7	6	5	4	4	3	3	3	3	2	2
8:00 5:39	8:17 5:56	8:26 6:05	B	28	18	16	14	11	9	8	7	6	6	5	5	4
5:38 4:22	5:55 4:39	6:04 4:48	C	45	29	25	21	17	14	12	9	8	6	6	5	5
4:21 3:28	4:38 3:45	4:47 3:54	D	65	41	34	30	23	19	15	10	8	7	6	5	5
3:27 2:47	3:44 3:04	3:53 3:13	E	86	53	44	37	28	22	17	12	9	8	7	6	5
2:46 2:14	3:03 2:31	3:12 2:40	F	111	66	53	43	32	24	19	14	11	9	7	6	6
2:13 1:46	2:30 2:03	2:39 2:12	G	140	80	62	49	36	27	22	17	12	10	8	7	6
1:45 1:22	2:02 1:39	2:11 1:48	H	175	96	73	57	40	30	24	19	14	11	9	8	7
1:21 1:01	1:38 1:17	1:47 1:26	I	219	113	86	65	45	34	26	21	16	12	10	8	7
1:00 0:42	1:16 0:58	1:25 1:07	J	279	132	103	75	51	38	29	23	18	13	11	9	8
0:41 0:24	0:57 0:40	1:06 0:49	K	369	154	122	88	57	43	32	26	20	15	12	10	8
0:23 0:10	0:39 0:24	0:48 0:33	L	-	178	139	103	64	47	35	28	22	18	13	11	9
L	0:23 0:10	0:32 0:18	M	-	207	158	124	71	52	40	30	25	20	15	12	10
	M	0:17 0:10	N	-	225	165	135	75	53	41	31	26	21	16	13	11
		N		20	30	35	40	50	60	70	80	90	100	110	120	130

DEPTH

L	M	N
175	205	225
135	155	165
100	120	135
60	70	75
45	47	50
33	35	40
27	→	30
20	23	25
15	17	20
→	13	15
10		

NEW

NO-DECOMPRESSION TABLES

PROCEDURES & CALCULATION

The basic problem was to develop the three tables that make up the no-decompression tables: the Repetitive Group table, the Surface Interval table, and the Residual Nitrogen Time table. Programs were developed for a Hewlett Packard HP-67 calculator that would produce these tables given:

a. limits for the depths; 20, 30, 35, 40, 50, 60, 70, 80, 90, 100, 110, 120, and 130 feet;

b. M_o values for six tissue groups;

c. what percent of M_o corresponded to Group A on the tables;

d. the increments between the groups, in percentage of M_o

The limits for the respective depths are already given by the new limits listed in Table 1.

The M_o values were a little more difficult to obtain. The M_o value for a tissue group is the pressure of nitrogen that the group can withstand at the surface. The six tissue groups used for these tables are the same that are used in the Navy's model. They are the 5 min., 10 min., 20 min., 40 min., 80 min., and 120 min. tissue groups. The new M_o values were found by calculating the tissue pressures produced by exposures to the new limits using the formula:

$$Pt = Po + (Pa - Po)\,(1 - e^{-.693t/T.5})$$

where:

Pt = Total pressure of nitrogen in the tissue group
Po = Initial pressure of nitrogen in the tissue group
Pa = Ambient partial pressure of nitrogen in the breathing medium
t = Time exposed to pressure Pa
T.5 = Tissue group, half-time

The calculated tissue pressures are shown in Table 2 with the greatest pressure achieved by a single group underlined.

TABLE 2.

TISSUE PRESSURE PRODUCED BY THE NEW LIMITS

Limit	TISSUE PRESSURES (fswp) 5 min.	10 min.	20 min.	40 min.	80 min.	120 min.
30' for 225 min.	49.77	49.77	49.76	49.29	46.40	43.31
35' for 165 min.	53.72	53.72	53.63	52.41	47.10	43.06
40' for 135 min.	57.67	57.67	57.38	54.62	47.86	43.18
50' for 75 min.	65.57	65.35	62.63	54.80	44.95	39.96
60' for 50 min.	73.42	71.99	65.09	53.54	42.73	39.96
70' for 40 min.	81.15	77.91	67.55	53.72	42.27	37.48
80' for 30 min.	88.28	81.37	66.93	51.69	40.54	36.13
90' for 25 min.	94.95	84.60	67.28	51.07	39.92	35.63
100' for 20 min.	100.13	85.32	65.57	49.21	38.64	34.69
110' for 15 min.	102.11	82.25	61.30	45.96	36.66	33.28
120' for 10 min.	97.17	73.47	53.84	41.15	33.94	31.39
130' for 5 min.	77.42	56.15	42.41	34.59	30.42	28.99

By rounding these values down to the nearest 0.5fswp we get the new M_o values. These new values are shown in Table 3 along with the Navy M_o values for comparison.

TABLE 3.

COMPARISON OF NEW M_o VALUES TO NAVY'S

Tissue Group	Navy	New	% of Navy's
5 min.	104	102	98%
10 min.	88	85	97%
20 min.	72	67.5	94%
40 min.	58	54.5	94%
80 min.	52	47.5	91%
120 min.	51	43	84%

As it can be seen the new M_o values are more conservative than the Navy's. These M_o values were then used in the calculations for the new tables.

The only other value that is needed to be found is the percent of saturation corresponding to Group A on the tables. This value was found by determining what percent surface nitrogen partial pressure was of the M_o values for each tissue group. It was found that the highest percent occured in the 120 minute tissues where the value was 60.63%. This meant a percent greater than 60.63% was needed for the value of Group A. The value that was chosen was 63%.

The percent increment between the groups was chosen to be 3%. This means that group B represents 66% of the M_o pressure in the tissue groups, Group M_o represents 99%, and N is 100% of the M_o pressure.

With these values the no-decompression tables (Pages 2 & 3)were produced. They are read in the same manner as the Navy no-decompression tables.

DISCUSSION

These new tables achieve the goals that were set to produce a set of no-decompression tables based on Spencer's no bubble, no-decompression limits and which are safe for multi-level diving. In preliminary examination calculations show that the M_t values are not exceeded when multi-level diving is performed using these tables. It must be remembered that the mathematical confirmation of the multi-level diving technique does not mean that the tables should be used in this manner. Testing is required before any type of confirmation can be made on the safety of any multi-level diving technique.

Even though the tables produced are quite a bit more conservative than the Navy tables, they do give the diver a reasonable amount of bottom time before the limits are reached. I believe that if these tables are used by the sport diving community, the chances of divers developing any type of decompression sickness (reported or unreported) will greatly diminish.

REFERENCES

Bassett, Bruce E., "Results of Validation Testing of Flying After Diving Schedules," in Boone, C. (ed.) PROCEEDINGS OF THE ELEVENTH INTERNATIONAL CONFERENCE ON UNDERWATER EDUCATION, National Association of Underwater Instructors, Colton, Ca, 1979.

Graver, Dennis, "A Decompression Table Procedure for Multi-Level Diving," in Fead, 1. (ed.), PROCEEDINGS OF THE EIGHT INTERNATIONAL CONFERENCE ON UNDERWATER EDUCATION, National Association of Underwater Instructors, Colton, Ca, 1976.

Huggins, Karl E., MATHEMATICAL EVALUATION OF MULTI-LEVEL DIVING, University of Michigan, 1980 (unpublished).

Spencer, M., "Decompression Limits for Compressed Air Determined by Ultrasonically Detected Blood Bubbles," JOURNAL OF APPLIED PHYSIOLOGY, 40 (2) : 229-235, 1976.