Decompression Tables for Tolerable Oversaturatin 0.4 bar

No-Bubbles – Decompression Tables

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Introduction

The bubbles appear, as we know from doppler monitoring of divers, even after uneventful dives following the usual decompression tables. The number of bubbles is proportional to the decompression stress at the end of the dive. This means that even after no-decompression dives a large number of bubbles may appear while after a longer dive needing a decompression stop bubbles can be almost absent when the ascent was very slow and exceeding decompression stops have been performed. There is a consensus among specialists that the most dangerous symptoms of decompression sickness, namely the cerebral symptoms arise from embolic bubbles. These embolic bubbles may get into arteries through different pathways, one of which is possibly the one through an open foramen ovale.

The way of bubble development, growth and transport has been studied by many research teams. During the UHMS workshop on the physiological basis of decompression (ed R.D. Vann, 1989) there was a quasi-consensus that threshold over-saturation for bubble release to the circulation would be about 1.4 which means 40% over-saturation (thermodynamically speaking). So we wanted to test whether diving tables specially calculated on the basis of a reduced threshold will still be useful for sports diving.

Rationale:

On the basis of three highly debated hypotheses we decided to calculate a set of tables which should on a theoretical basis permit the divers to dive without producing circulating bubbles during and after decompression.

1. The patent foramen ovale is a haemodynamically possible way of bubble shunting from the right to the left side of the heart thus by passing the lung filter. The importance of this frequently found anatomic variation (30%) is not yet clear, however it remains a possible way to explain neurological decompression sickness after correctly performed dives. If we have diving tables which would guarantee that there are no circulating bubbles after decompression or during the decompression phase the presence of a PFO would not be an argument any more to declare a diver unfit to dive.

2. The presence of a gas phase within the circulation in form micro-bubbles does influence the gas washout of the body after a compression phase. This is a main criticism against the value of the perfusion limited decompression model used by Haldane, Workman, Dwyer and Bühlmann for the calculation of diving tables. If we calculate the tables in a way that there are not even silent bubbles in the circulation, the algorithm would be much closer to reality and thus more credible.

3. The fact that the majority of decompression disorders are seen in divers that have performed an uneventful dive following the accepted tables, means that the susceptibility is very difficult to determine from known values (see probabilistic approach). The main factor inducing an unforeseeable variable in the physiology of the diver is probably the presence distribution and migration of micro-bubbles. Avoiding the presence of micro-bubbles in the circulation the remaining susceptibility of diving individuals would be much more homogeneous.

The tables:

The following tables are calculated using a software for implementation of the 16 tissue model of Bühlmann 1986. The parameters are modified corresponding to a tolerable over-saturation of 0.4 bar. The calculations are done on the assumptions of

- altitude 0 m, breathing gas: air, respiratory minute volume 20 l/min, ascent velocity 10 m/min.

Decompression Table for Tolerable Oversaturation 0.4 bar

Depth (m)	Bottom time (min)	Decompression stops (min) (m)									Asc. Time (min)	Air-Cons. (m^3)
		27	24	21	18	15	12	9	6	3		
9.0												
	25.0										0.90	0.98
	50.0									1	1.90	1.96
	75.0									1	1.90	2.92
	100.0									2	2.90	3.90
12.0												
	18.0									3	4.20	0.91
	36.0									5	6.20	1.76
	54.0									8	9.20	2.63
	72.0									11	12.20	3.51
	90.0									14	15.20	4.38
15.0												
	16.0									5	6.50	0.98
	32.0								3	8	12.50	1.96
	48.0								4	12	17.50	2.90
	64.0								6	16	23.50	3.87
	80.0								7	21	29.50	4.84
18.0												
	10.0									4	5.80	0.72
	20.0								4	7	12.80	1.50
	30.0							1	6	10	18.80	2.24
	40.0							2	7	14	24.80	2.98
	50.0							2	9	17	29.80	3.68
	60.0							3	11	20	35.80	4.43
	70.0							4	12	24	41.80	5.17
	80.0							4	14	27	46.80	5.87
21.0												
	6.0									3	5.10	0.52
	12.0								4	5	11.10	1.08
	18.0							2	4	8	16.10	1.61
	24.0							3	6	10	21.10	2.14
	30.0							4	7	13	26.10	2.66
	36.0						1	4	9	15	31.10	3.20
	42.0						1	5	10	18	36.10	3.72
	48.0						1	6	12	20	41.10	4.25
	54.0						1	7	13	23	46.10	4.77
	60.0						1	8	14	25	50.10	5.27
24.0												
	5.0									3	5.40	0.51
	10.0								4	5	11.40	1.03
	15.0							3	5	7	17.40	1.57
	20.0						1	4	6	10	23.40	2.11
	25.0						2	5	7	13	29.40	2.64
	30.0						3	5	9	15	34.40	3.15
	35.0						3	6	11	18	40.40	3.67
	40.0						4	7	12	21	46.40	4.20
	45.0						5	8	13	24	52.40	4.74
	50.0						5	9	15	25	56.40	5.21
	55.0						6	9	17	28	62.40	5.74

Decompression Tables for Tolerable Oversaturatin 0.4 bar

27.0												
	5.0									5	7.70	0.61
	10.0							2	4	6	14.70	1.21
	15.0						2	4	5	9	22.70	1.86
	20.0						3	5	7	12	29.70	2.46
	25.0					1	4	5	9	15	36.70	3.07
	30.0					2	4	7	10	19	44.70	3.70
	35.0					2	5	8	12	22	51.70	4.30
	40.0					3	5	9	14	25	58.70	4.90
	45.0					3	6	10	16	28	65.70	5.50
	50.0					3	7	11	18	31	72.70	6.10
30.0												
	6.0								4	4	11.00	0.84
	10.0						1	3	4	7	18.00	1.40
	14.0						3	4	6	10	26.00	1.99
	18.0					2	3	5	7	13	33.00	2.56
	22.0					3	4	5	10	16	41.00	3.15
	26.0				1	3	4	7	11	19	48.00	3.72
	30.0				1	3	5	8	13	22	55.00	4.27
	33.0				1	4	5	9	14	24	60.00	4.68
	36.0				1	4	6	10	15	26	65.00	5.09
	39.0				1	5	6	10	17	28	70.00	5.50
	42.0				2	4	7	12	17	31	76.00	5.94
33.0												
	6.0							1	4	5	13.30	0.96
	10.0						2	4	5	8	22.30	1.62
	14.0					2	3	4	7	12	31.30	2.28
	18.0				1	3	4	5	9	15	40.30	2.96
	21.0				2	3	4	7	10	18	47.30	3.46
	24.0				2	3	5	8	11	20	52.30	3.89
	27.0				3	3	6	8	13	23	59.30	4.39
	30.0				3	4	6	10	14	25	65.30	4.86
	33.0				3	5	7	10	16	28	72.30	5.36
	36.0			1	3	5	7	12	17	31	79.30	5.87
36.0												
	6.0							3	4	5	15.60	1.10
	10.0					1	3	4	5	10	26.60	1.85
	14.0				1	3	3	5	8	13	36.60	2.59
	18.0				3	3	4	6	11	17	47.60	3.36
	21.0			1	3	3	5	8	12	20	55.60	3.93
	24.0			1	3	4	6	8	14	23	62.60	4.44
	27.0			2	3	4	7	10	15	26	70.60	5.02
	30.0			2	3	5	7	11	17	29	77.60	5.52
	33.0			2	4	5	8	12	18	32	84.60	6.05
39.0												
	6.0						1	3	4	6	17.90	1.23
	10.0					2	4	4	6	11	30.90	2.09
	14.0				2	3	4	6	8	15	41.90	2.89
	18.0			2	2	4	5	7	12	19	54.90	3.78
	21.0			2	3	4	6	8	14	23	63.90	4.38
	24.0		1	2	3	5	7	9	16	26	72.90	5.02
	26.0		1	3	3	5	7	11	17	29	79.90	5.47
	28.0		1	3	4	5	8	12	18	31	85.90	5.89

Decompression Table for Tolerable Oversaturation 0.4 bar

42.0											
	6.0						2	4	4	7	21.20	1.40
	9.0					3	3	4	6	11	31.20	2.08
	12.0				3	3	3	6	8	15	42.20	2.81
	15.0			2	3	3	5	7	10	19	53.20	3.54
	18.0		1	2	3	4	5	9	13	22	63.20	4.22
	20.0		1	3	3	4	7	9	14	25	70.20	4.69
	22.0		2	2	4	5	7	10	16	27	77.20	5.17
	24.0		2	3	4	5	7	12	17	30	84.20	5.63
45.0												
	6.0						3	4	4	8	23.50	1.53
	8.0					3	3	4	6	11	31.50	2.05
	10.0				2	3	4	5	8	14	40.50	2.61
	12.0			2	2	3	4	6	10	16	47.50	3.11
	14.0			3	3	3	5	7	11	20	56.50	3.67
	16.0		1	3	3	4	5	9	13	22	64.50	4.20
	18.0		2	3	3	4	7	9	14	25	71.50	4.69
	20.0	1	2	3	3	5	7	10	17	28	80.50	5.25
	22.0	1	2	3	4	5	8	12	17	31	87.50	5.72
48.0												
	6.0					2	3	3	6	9	27.80	1.75
	8.0				2	3	3	4	7	12	35.80	2.30
	10.0			1	3	3	4	5	9	15	44.80	2.87
	12.0			3	3	3	5	7	10	19	54.80	3.49
	14.0		2	2	3	4	5	8	13	21	62.80	4.03
	16.0	1	2	3	3	4	7	9	14	25	72.80	4.66
	18.0	1	3	2	4	5	7	10	17	27	80.80	5.20
	20.0	2	2	3	4	6	8	11	18	31	89.80	5.77

Figure 1 to 3 give examples of dives, that can be performed realistically using a 15 liters compressed air cylinder (2 + 3) or a double 10 liter tank (fig 1). One should avoid to speak of no-decompression time in these tables, because a staged decompression is the most important element of avoiding the bubbles in the circulation, which should be combined with a very slow ascent rate. The tables printed here are calculations on the basis of theoretical considerations. They have not undergone any validation with test-dives and should not be used by divers as such.

If we try to further reduce the threshold value to 1.0 which means that we allow the tissue N_2 concentration not to be more than 100 % saturation, the calculated diving profile is not realistic any more (fig 4).

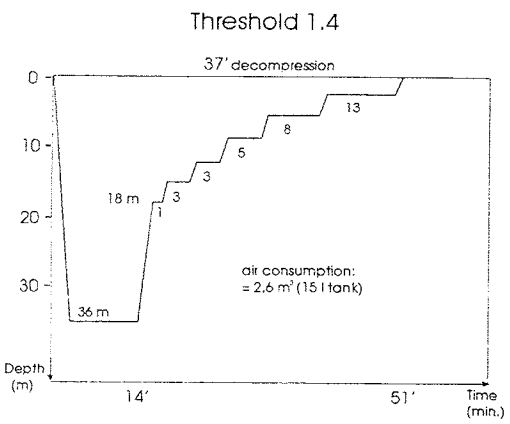


Fig. 1

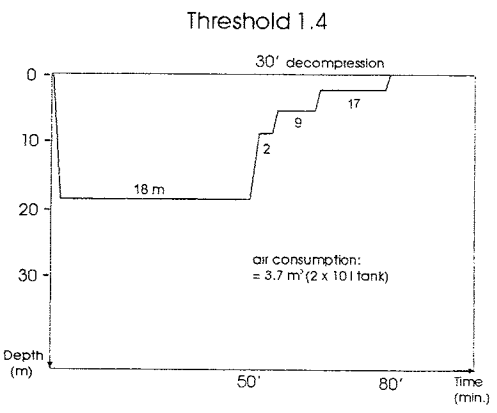


Fig 2

Decompression Tables for Tolerable Oversaturatin 0.4 bar

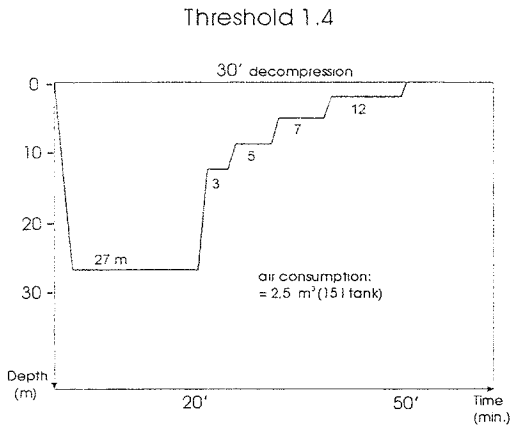


Fig. 3

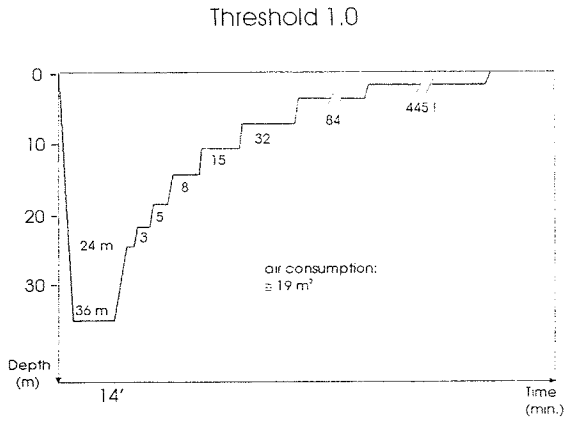


Fig. 4 Theoretical dive profile for threshold 1.0

Discussion

- Tables produced for a threshold of 1.4 clearly show that recreational diving is still possible within the usual depth range and overall diving time.

- The profiles however become a more V-shaped form compared to the classical rectangular dive profile which is normally used.

- The dives become constringently decompression-dives. For many divers this might be a problem because of incompatibility with the dogma that only no-decompression-dives are safe. Of course it is reasonable not to enter into the deco-zone of the tables in sports diving as this avoids problems like getting short in air and being hit by inert gas narcosis doing deep dives. It is however wrong to believe that zero stop dives are particularly safe as to the DCI risk. Sometimes the opposite is true. The deco stress during the ascent and after the dive is reduced by a very slow ascent rate and doing deeper deco stops than normally.

- We propose therefore that research is done to study the bubble development or hopefully absence in dives performed following the 1.4 threshold table. It is possible that the threshold will have to be further reduced to avoid bubble formation, but if validated the modified tables could be a solution for safe diving in divers with individually higher risk for DCI.

References

1. BÜHLMANN A.A., Tauchmedizin 1995 3rd ed., Springer-Verlag, Berlin, 1993 ISBN 3-540-58970-8

2. UHMS Symposium 1989, The Physiological Basis of Decompression. Ed. VANN R.D., Publication Number 75(Phys)6/1/89