Comparing dive computers

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Key words
Computers, multi-level diving, repetitive diving, simulation

Abstract

(Lippmann L, Wellard M. Comparing dive computers. *SPUMS J*. 2004; 34: 124-9.)
Introduction: There are few comparative data on dive computers. This study aimed to observe differences in allowed dive profiles for five models of computer.
Methods: Computers were subjected to pressure–time exposures in a small, water-filled compression chamber to compare their decompression requirements with the Canadian Forces (DCIEM) decompression model and its derivative tables, for which extensive data are available. Pressure exposures were similar to actual depth–time diving profiles occurring in the field. Profiles consisted of: Profile 1. a two, rectangular dive series with reducing depths
Profile 2. a three, rectangular dive series with increasing depths
Profile 3. a multi-level dive with reducing depths
Profile 4. a multi-level dive with increasing depths and
Profile 5. a series of deep, repetitive, 'bounce' dives.
All dives were chosen so they could be compared easily with the DCIEM tables. All computers were set in their standard mode with no 'safety' or altitude time reductions implemented.
Results: The decompression requirements varied greatly between dive computers and with respect to the tables. The decompression times (in minutes) indicated at the end of the final dive for each series were: profile 1 – range (min) 0 – 13; profile 2 – range 0 – 25; profile 3 – no-stop time at final depth 23 – 61; profile 4 – no-stop time at final depth 0 – 11; profile 5 – range 0 – 28.
Conclusions: Some dive computers gave more conservative decompression profiles than others on most, but not all, exposures. Occasional idiosyncratic differences emerged. Some computers were consistently less conservative than DCIEM recommendations. The more conservative computers behaved similarly to DCIEM profiles on many exposures.

Introduction

Electronic dive computers utilise a depth (pressure) sensor, timer, microprocessor, display and may also possess various other features. Although the microprocessors in some devices were encoded with decompression tables, most dive computers are now encoded with a decompression algorithm: a set of mathematical equations designed to simulate the uptake and release of inert gas within a diver's body.

Early models assumed that both gas uptake and elimination were symmetrical and both were exponential. However, many current models are programmed to delay the predicted gas elimination rate to allow for the effects of bubble formation, vasoconstriction and various other factors that can affect gas kinetics. Unfortunately there are few data from which to construct appropriate gas kinetic equations.

By reading the depth and recalculating every few seconds, dive computers enable dive times to be extended well beyond those permitted by tables on most dives, especially on multi-level dive profiles. Many of the current dive computers have been re-programmed to become more conservative over the past few years, reducing no-stop times and increasing decompression requirements, even to the extent that external parameters such as temperature and gas consumption are integrated into the determination. Despite many refinements, there remains concern about the efficacy of these devices in determining dive profiles that minimise the incidence of decompression sickness (DCS).

DAN America data indicate that in 2002, 72% of the divers who were treated for DCS had been using a dive computer,[1] similar to the 2000 figure of 73%.[2] 1997 DAN America data indicate that a very high proportion (93.7%) of such cases reported diving 'within the limits' of their devices.[3] DAN SEAP dive injury records also indicate that the great majority of members who were treated for DCS had been using a dive computer and had reported diving within the limits indicated by the computer (Lippmann JL, unpublished data). However, the high proportion of divers presenting with DCS who had been using dive computers does not indicate that the devices are inherently unsafe. The trend is likely to largely reflect the increase in dive computer usage.

Current dive computers vary greatly in the times they allow and the decompression obligations indicated, and it is important that divers appreciate these differences so that they are more able to select the level of risk that they are willing to take. However, there are few useful comparative data available by which to compare dive computers. This study aimed to observe the differences in allowed dive profiles for a small selection of common dive computers over several dive series.

Methods

One each of a group of dive computers commonly used in the diving industry was selected and subjected to several series of pressure exposures in a small, perspex compression chamber, filled with fresh water. These pressure exposures were designed to simulate as closely as possible actual depth–time diving profiles that occur in the field, despite some being somewhat undesirable.

The five dive computers tested were:
- Suunto 'Solution'
- Suunto 'Vytec'
- Uwatec 'Aladin Pro'
- Uwatec 'Aladin Smart'
- Oceanic 'Versa'

The Suunto Solution preceded the Suunto Vytec, and the Uwatec Aladin Pro preceded the Aladin Smart. The earlier models were tested as they are still very commonly used by divers; and to determine what differences in dive times and/or decompression requirements were generated by updated decompression algorithms incorporated in the newer models. All computers were set in the standard mode with no 'safety' or altitude time reductions implemented.

The series of profiles tested were (times shown are bottom times):

1. Repetitive series with reducing depth
   36m / 10 minutes
   Surface interval 60 minutes
   30m / 18 minutes

2. Repetitive series with increasing depth
   27m / 18 minutes
   Surface interval 32 minutes
   30m / 16 minutes
   Surface interval 32 minutes
   36m / 10 minutes

3. Multi-level dive with reducing depth
   30m / 5 minutes
   20m / 10 minutes
   15m / as indicated by dive computers

4. Multi-level dive with increasing depth
   15m / 15 minutes
   21m / 10 minutes
   27m / as indicated by dive computers

5. Cyclic repetitive dive series*
   45m / 5 minutes
   Surface interval 60 minutes
   45m / 5 minutes
   Surface interval 60 minutes
   45m / 5 minutes

   * The cyclic repetitive dive series (5) was chosen as it had been shown during in-water trials by the Royal Navy to be unsafe due to an unacceptable incidence of DCS.[4]

Computers were allowed sufficient time to reset between each series of profiles.

The no-stop times allowed and the decompression requirements indicated by the computers were then compared with those generated by the Canadian Forces (DCIEM) tables.[5] These tables were chosen for comparison as they are widely considered to be a benchmark for determining decompression risk.

Table 1
Repetitive dive series with reducing depth (* - see text for explanation)

		Solution	Vytec	Aladin Pro	Aladin Smart	Versa	DCIEM tables*
Dive 1	Depth = 36 msw						
	Bottom time = 10 min						
	No-stop time allowed (min)	10	10	11	11	13	10 (10)
	Ascent time = 3.5 min						
Surface interval = 60 min							
Dive 2	Depth = 30 msw						
	Bottom time = 18 min						
	No-stop time allowed (min)	17	10	16	15	16	10 (11)
	Decompression 6 msw	0	0	0	0	0	3 (0)
	Decompression 3 msw	1	13	1	1	0	9 (11)

Table 2
Repetitive dive series with increasing depth (* - see text for explanation)

		Solution	Vytec	Aladin Pro	Aladin Smart	Versa	DCIEM tables*
Dive 1	Depth = 27 msw						
	Bottom time = 18 min						
	No-stop time allowed (min)	22	22	20	19	25	20 (20)
	Ascent time = 3min						
Surface interval = 32 min							
Dive 2	Depth = 30 msw						
	Bottom time = 16 min						
	No-stop time allowed (min)	12	10	10	12	11	9 (9)
	Decompression 6 msw	0	0	0	0	0	3 (0)
	Decompression 3 msw	9	20	8	8	9	9 (11)
Surface interval = 32 min							
Dive 3	Depth = 36 msw						
	Bottom time = 10 min						
	No-stop time allowed (min)	6	5	6	7	9	5 (6)
	Decompression 6 msw						5 (0)
	Decompression 3 msw	18	25	7	6	0	10 (12)

Table 3
Multi-level dive with reducing depth (* - see text for explanation)

		Solution	Vytec	Aladin Pro	Aladin Smart	Versa	DCIEM tables*
Dive 1	**Level 1** Depth = 30 msw						
	Time at level 1 = 5 min						
	No-stop time allowed (min)	18	16	16	16	20	15
	Ascent to level 2 = 1 min						
	Level 2 Depth = 20 msw						
	Time at level 2 = 10 min						
	No-stop time allowed (min)	32	29	27	14	39	23
	Ascent to level 3 = 0.5 min						
	Level 3 Depth = 15 msw						
	No-stop time allowed (min)	44	40	37	23	61	35 (29)

Table 4
Multi-level dive with increasing depth (* - see text for explanation)

		Solution	Vytec	Aladin Pro	Aladin Smart	Versa	DCIEM tables*
Dive 1	**Level 1** Depth = 15 msw						
	Time at level 1 = 15 min						
	No-stop time allowed (min)	72	69	65	56	87	75
	Descent to level 2 = 0.5 min						
	Level 2 Depth = 21 msw						
	Time at level 2 = 10 min						
	No-stop time allowed (min)	27	24	25	13	31	23 (15)
	Descent to level 3 = 0.5 min						
	Level 3 Depth = 27 msw						
	No-stop time allowed (min)	10	7	6	0	11	0 (0)

Table 5
Cyclic repetitive dive series (* - see text for explanation)

	Solution	Vytec	Aladin Pro	Aladin Smart	Versa	DCIEM Tables*
Dive 1 Depth = 45 msw						
Bottom time = 5 min						
No-stop time allowed (min)	6	6	6	4	7	6 (6)
Ascent time = 4.5 min						
No-decompression limit						
Surface interval = 60 min						
Dive 2 Depth = 45 msw						
Bottom time = 5 min						
No-stop time allowed (min)	6	4	6	4	5	5 (6)
Decompression 6 msw	0	0	0	0	1	0 (0)
Decompression 3 msw	0	3	0	1	10	0 (0)
Surface interval = 60 min						
Dive 3 Depth = 45 msw						
Bottom time = 5 min						
No-stop time allowed (min)	5	4	6	5	0	5 (6)
Decompression 6 msw					3	0 (0)
Decompression 3 msw	0	2	0	1	25	5 (0)

Results

The results are shown in Tables 1 to 5. The first number in the DCIEM column is the time given by the DCIEM tables.[5] The number in brackets is the time given by the actual DCIEM model (provided courtesy of Ron Nishi, DCIEM).

The Vytec yielded times similar to the DCIEM tables and model more consistently than the other computers tested on these profiles. The Vytec was consistently more conservative than its predecessor, the Solution.

The Aladin Pro and Aladin Smart generated similar no-stop times and decompression times on the rectangular profiles tested. However, the Aladin Smart was considerably more conservative on the multi-level profiles than the Aladin Pro and all the other units tested.

The Oceanic Versa was consistently less conservative than the other dive computers and the DCIEM tables except on the series of deep, repetitive 'bounce' dives. In this case it required decompression times well in excess of the DCIEM tables and model and the other dive computers. The decompression times indicated in these cases appear to be excessive, when compared with other decompression tables.

Discussion

All computers examined generally yielded longer no-stop times than the DCIEM tables and model. The Versa was less conservative than the others over most of the profiles tested. With the cyclic bounce dives of known high risk (Table 5), the computers required a decompression stop earlier, suggesting that the models used in the computers are incorporating some additional off-gassing factors compared with the base DCIEM model.

Decompression models include a series of mathematical equations that are designed to simulate inert gas kinetics within the body. These models are mainly based on Haldanian theory, utilising a set of tissue compartments with varying half-times that act independently, 'in parallel', of each other. By contrast, the DCIEM decompression model uses a set of four tissue compartments 'in series', rather than independently of each other.

Many of the algorithms incorporated in dive computers are derived from the work of the late AA Buehlmann.[6] Incarnations of this Haldanian model are incorporated in the Uwatec series of computers, as well as many other brands. The basic equations used in a Buehlmann model are shown below. The other major dive computers on the market use similar concepts and basic equations, with unique modifications.

1. CALCULATING THE PARTIAL PRESSURE OF NITROGEN IN THE INSPIRED GAS

$$pN_2insp = (p_{amb} - 0.063 \text{ bar}) \times 0.79$$

where pN_2insp = inspired nitrogen pressure
p_{amb} = ambient pressure
0.063 = the constant water-vapour pressure in the lungs

2. CALCULATING SATURATION / DESATURATION

$$pN_2 = pN_2^0 + (pN_2insp - pN_2^0) \times (1 - 2^{-\Delta t/T})$$

where pN_2 = partial pressure of nitrogen
pN_2^0 = initial partial pressure of nitrogen
T = tissue compartment half-time
t = time of exposure

Saturation is generally assumed to occur exponentially. In earlier models, desaturation was also assumed to occur exponentially, and at the same rate. However, desaturation is now usually treated as a modified exponential, with factors such as presumed or estimated bubble formation affecting and slowing down the rate of desaturation. One method to incorporate this concept is to include multiplicative factors or coefficients in this equation.

3. CALCULATING THE TOLERATED NITROGEN PRESSURE / AMBIENT PRESSURE

For each tissue compartment, it is assumed that there is a maximum nitrogen pressure that can be tolerated at a particular ambient pressure before bubble formation and/or decompression sickness occurs. Tissue compartments with shorter half-times, presumed to represent body tissues with high blood supply such as blood and brain, are set to be able to tolerate higher nitrogen pressures at a given depth (ambient pressure) than the 'slower' tissue compartments,

$$Pamb_{tol} = (pN_2 - a) \times b$$

where $Pamb_{tol}$ = minimum ambient pressure to which ascent can be made, and a and b are constants, verified through experimentation by Buehlmann.

Buehlmann conducted a variety of experiments including chamber trials with human volunteers. During these trials, certain mild symptoms of decompression sickness were deemed acceptable and adjustments were not always done to try to eliminate these (Buehlmann AA, personal communication). However, with this model, alterations to the no-decompression limits (NDLs) and decompression requirements are easily made by adjusting the values of the constants a and/or b and this has been done by various dive computer programmers. In addition, user-selected 'added safety' adjustments can readily be made by alterations to the constants.

Most dive computers display similar NDLs for an initial, rectangular profile dive. This is because the decompression models on which they are based generally perform similarly on the initial pressure exposure. The initial NDLs for the computers tested, and for the DCIEM tables are shown in Table 6.

Greater differences in decompression advice emerge with repetitive pressure exposures. In addition, further divergence may occur with situations such as a rapid ascent, increased breathing rate, cold water exposure and increasing depth of dive or repetitive dives. The so-called 'adaptive' dive computers are programmed to try to account for events that may increase inert gas load and/or bubble formation during the dive. However, although such events should reduce allowed no-stop dive time or increase decompression obligations and so inherently increase safety, there are unfortunately still relatively few data on which to base accurate computations.

Bubble formation has been handled by entering data into a separate set of equations or conversion fractions (e.g., the reduced gradient bubble model used in the Suunto Vytec[7]) designed to determine the amount and effect of bubble formation, or by adding multiplication factors to existing saturation–desaturation equations, and others.

In addition to altering the constants, increasing the number and range of tissue compartments can also affect the decompression times, as well as the recommended interval to flying after diving. The longer half-times may come into play for multi-day, repetitive diving, as they allow for a presumed nitrogen load to be tracked for an extended period.

Table 6
Initial no-decompression limits (min) for depths from 9 to 42 msw

Depth (m)	Solution	Vytec	Aladin Pro	Aladin Smart	Versa	DCIEM
9	222	204	334	324	283	300
12	127	124	121	124	184	150
15	72	72	70	70	85	75
18	52	52	50	50	59	50
21	37	37	30	36	41	35
24	29	29	28	27	32	25
27	23	23	22	21	25	20
30	18	18	16	16	20	15
33	13	13	14	13	17	12
36	11	11	12	11	14	10
39	9	9	10	10	11	8
42	7	7	9	9	9	7

Table 7
Dive computer tissue compartments and half-times

Computer	Tissues	Half-times (min)
Solution	9	2.5,5,10,20,40,80,120,240,480
Vytec	9	2.5,5,10,20,40,80,120,240,480
Aladin Pro	6	6,14,34,64,124,320
Aladin Sm	8	5,10,20,40,80,160,320,640
Versa	12	5,10,20,40,80,120,160,200,320, 400,480

In practice, the range and number of half-times (Table 7) alone and the published initial dive NDLs (Table 6) may well paint a misleading picture of how a particular dive computer will perform in the field on real dives. As seen in this experiment, the decompression advice displayed by different computers can and often does vary greatly, especially with repetitive dives. The decompression times indicated result from the interplay of a variety of factors, including the particular base decompression used; the amount and type of real dive data, if any, used to adjust the sensitivity of the base model; and if or how adjustments are made to attempt to cater for bubble formation and other variants.

Conclusions

On occasions, the five models of dive computer tested in this study indicated quite different decompression advice with up to 25 minutes' variation on decompression stop time and up to 38 minutes of allowable no-stop time on some profiles. Certain computers were consistently less conservative than the DCIEM tables and the DCIEM model when assessed with a set of essentially rectangular pressure exposures. In these exposures, only the relatively conservative dive computers yielded decompression advice similar to that of the DCIEM tables and the model. The performance of the different computers diverged for dive profiles that were less than optimal.

To minimise the risk of decompression sickness, divers who plan to use a dive computer are advised to choose one that is relatively conservative on the types of dive profile that they are planning to conduct.

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References

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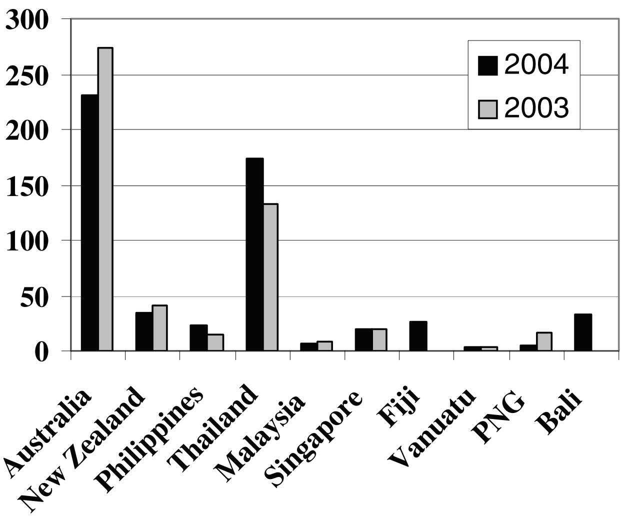
South-East Asia and Pacific
Incidence of decompression illness 2003/2004
(provisional; courtesy of DAN SEAP)



South-East Asia and Pacific
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