PERFORMANCE OF DIVE COMPUTERS EXPOSED TO PROFILES WITH KNOWN HUMAN SUBJECT RESULTS

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ABSTRACT

Most dive computer comparisons address responses to fixed decompression table schedules or fabricated dive profiles. This study tests the potential for evaluating dive computer algorithms by exposing them to profiles that have known human subject results. Fifteen dive computers were exposed to profiles with either "high," "moderate," or "low" risk ratings, based on occurrence of decompression sickness and Doppler score outcomes from human subject dives. Profiles fell within, and slightly outside, the standard operational range of recreational divers. The profiles included a multi-day, multi-level repetitive dive series of "low risk" profiles (<130 fsw [500 kPa]), two "moderate risk" multi-level single dives (130 fsw & 60 fsw [286 kPa] maximum depths), a "moderate risk" short 165 fsw (609 kPa) decompression dive, and a "high risk" long 36 msw (466 kPa) decompression dive. Remaining no-decompression time (NDT), or required total decompression time (TDT), was recorded from each computer prior to departure from each depth in the profile. The results from the multi-day multi-level "low risk" profiles ranged from three computers requiring decompression following the first dive of the first day to five computers completing all nine dives within their no-decompression limits. The "moderate risk" single multi-level dive results ranged from 20 minutes NDT to 19 minutes TDT at the end of one of the dives. None of the computers permitted the "high risk" decompression profile. However, all cleared before the end of the first 30-fsw decompression stop of the "moderate risk" 165-fsw decompression profile. Response to the 165-fsw dive indicates that more conservative dive computer algorithms would be appropriate for short deep decompression dives. Since dive computer manufacturers do not validate their algorithms with human subject tests, running the algorithms against a battery of previously tested dive profiles provides some rudimentary level of validation.

BACKGROUND

In the 20 years since the introduction of commercially viable dive computers their popularity has grown to a point where the vast majority of recreational divers utilize them to determine their decompression status. In 1983, there were only two models of microprocessor based dive computers available. In 2003, the number of dive computer models on the market exceeded 75, based on approximately 15 different decompression algorithms.

This growth of the dive computer market did not generate concomitant studies to evaluate the efficacy of the decompression models programmed into the devices. Only a few studies evaluated dive computer algorithms using human subjects.

Most dive computer algorithm evaluations have been comparisons to fixed decompression table schedules or results of running the computers through generic recreational dive profiles with no human subject outcome data.

This study tests the potential for evaluating dive computer algorithms by exposing them to profiles that have known human subject results. This technique has been utilized in the past, most notably by Edmonds who compared dive computer responses to a series of bounce dives to 140 fsw and 147 fsw (532 kPa to 554 kPa).

METHODS

The fifteen dive computers that were tested and their decompression algorithms are listed in Table 1. Of these, twelve were 2003 models that had been evaluated by Scuba Diving Magazine at the Catalina Hyperbaric Chamber and retained for this study. The remaining three were older dive computer models (shaded area in Table 1).

Dive Computer	Decompression Algorithm	Algorithm Category	Number of Compartments	Half-Time Range (min.)
Aeris Atmos 1	DSAT Rogers/Powell	Modified Haldanian	12	5 - 480
Aeris Atmos 2				
Aeris Atmos ai				
Oceanic Pro Plus 2				
Oceanic Versa				
Oceanic Versa Pro				
Dacor Darwin	Rogers/Powell	Modified Haldanian	11	2.5 - 480
Mares M1				
Uwatec Smart Com	Bühlmann ZH-L8 ADT	Modified Haldanian w/ microbubble levels	8	5 - 640
Uwatec Smart Pro				
CressiSub Archimede	Bühlmann ZH-L16	Haldanian	16	5 – 640
Suunto Vytec	Wienke/Suunto RGBM	Modified Haldanian & Two Phase	9	2.5 – 480
Cochran Nemesis II	Cochran	Modified Haldanian	12	5 – 480
Suunto Solution	Nikkola SME	Haldanian	9	2.5 – 480
Orca EDGE	Huggins / Spencer	Haldanian	12	5 - 480

Table 1: Dive computers and their decompression algorithms.

The fifteen dive computers were exposed to profiles categorized with either "high," "moderate," or "low" risk ratings, based on occurrence of decompression sickness (DCS) and Doppler bubble score (VGE) outcomes from human subject dives. Decompression requirements calculated by the dive computers were compared to the tested decompression schedule and conclusions about the decompression algorithm were based on the dive computer's response to the profile (Table 2).

Dive Computer Decompression Requirements	Profile Risk Rating		
	"High" Risk DCS High VGE	"Moderate" Risk No DCS Low to Moderate VGE	"Low" Risk No DCS No VGE
Less than tested profile	Algorithm too Liberal High Risk	Algorithm too Liberal Moderate Risk	no conclusions
Greater than tested profile	no conclusions	no conclusions	Algorithm Conservative

Table 2: Risk rating vs. dive computer response to profile.

Profiles fell within, and slightly outside, the standard operational range of recreational divers. The profiles included:

- A multi-day, multi-level repetitive dive series of "low risk" profiles (<130 fsw [500 kPa]) from the Orca EDGE tests
- Two "moderate risk" multi-level single dives (130 fsw & 60 fsw [286 kPa] maximum depths) from the PADI/DSAT RDP test series (MLD 1 & MLD 2)
- A "moderate risk" short 165 fsw (609 kPa) decompression dive from the Catalina Hyperbaric Chamber historical exposures (DECO 2)
- A "high risk" long 36 msw (466 kPa) decompression dive from a DCIEM Air Decompression study (DECO 1)

The dive computers were immersed in water inside the chamber (Figure 4). The depth of the chamber was determined by a 3-D Instruments 70 msw (711 kPa) gauge calibrated to ¼% full-scale accuracy. The dive computers were monitored with the chamber's inside camera and videotaped to allow post-dive review. Remaining no-decompression times (NDT), or required total decompression times (TDT), were recorded from each computer one minute prior to departure from each depth in the profile.

RESULTS

The Uwatec Smart Com computer went into service mode after testing the "high" stress decompression profile and one of the "moderate" risk profiles.

Results from the multi-day multi-level "low risk" profiles (Figure 1) ranged from three computers requiring decompression following the first dive of the first day to five computers completing all nine dives within their no-decompression limits (Table 3). The Oceanic and Aeris computers (along with the EDGE) made it through all nine dives without needing to be reset. The Atmos 1 and Versa went into decompression at the end of the first day and cleared out of error mode by the next morning. However, the Smart Pro went into decompression at the end of the first dive and did not clear out of error mode until the morning after the third day of diving. The Archimede did not activate at the start of the first dive and only calculated two days of diving. The Nemesis II was not activated at the start of second dive.

The "moderate risk" single multi-level dives (Figure 2) results ranged from 11 minutes NDT to 12 minutes of TDT at the end of MLD 1 (Table 4) and from 20 minutes NDT to 19 minutes TDT at the end of one MLD 2.

None of the computers permitted the "high risk" decompression profile (Figure 3). However, all cleared before the end of the first 30-fsw decompression stop of the "moderate risk" 165-fsw decompression profile.

DISCUSSION

Since dive computer manufacturers do not validate their algorithms with human subject tests, running the algorithms against a battery of previously tested dive profiles provides some rudimentary level of validation. Since most dive computer manufacturers do not release their decompression algorithms it is very difficult to run simulations on a personal computer. Running the computers side-by-side in a chamber is the next option. This allows the computers to be simultaneously exposed to a specific controlled profile.

There were striking variations between decompression algorithms. Variations within algorithms were minimal with the exception of the Oceanic and Aeris computers at 40 fsw. This is likely due to pressure transducer variations and decompression control switching between compartments at ~40 fsw. A deeper depth reading will give shorter NDT based on a faster compartment while a shallower reading gives a longer NDT based on a slower compartment.

None of the dive computers received a "high" risk rating. They all required more decompression than the tested DCIEM "high" risk decompression profile. However, they all received a "moderate" risk rating when compared to the standard Catalina Hyperbaric Chamber 165-fsw orientation dive. Response to the 165-fsw dive indicates that more conservative dive computer algorithms would be appropriate for short deep decompression dives.

The Oceanic and Aeris dive computers received a "moderate" risk rating by permitting additional NDT when run against the PADI/DSAT RDP test profiles. For MLD 1 they permitted 9-11 additional minutes of NDT and to a lesser extent with MLD 2 where the Atmos ai allowed 8 additional minutes and the Pro Plus 2 allowed 20 minutes more. This is of interest since the Rogers/Powell model in these computers is based on the PADI/DSAT RDP model and testing. However, the M1 and Darwin which use a version of the Rogers/Powell model end up with a "low" risk rating due to their conservative responses.

From the "low" risk multi-day, multi-level repetitive dive series the Archimede, Darwin, M1, and Smart Pro were rated as very conservative, by not allowing the first dive of the day to be performed without requiring decompression. The Atmos 1, Solution, Versa, and Vytec and were rated as conservative since they ended up in decompression at the end of Day 1 – Dive 3. It is notable that both the Atmos 1 and Versa required the same decompression while the other computers in their algorithm group allowed 44-53 minutes of additional NDT.

Establishing a battery of previously tested dive profiles against which to run dive computer decompression algorithms would permit dive computer manufacturers to test their algorithms without the need of human subjects tests and could provide a baseline for dive computer comparisons. Any suggestions for additions to this profile pool would be welcomed.

Dive Computer	No-Decompression Time (+) or Required Decompression Time (-) at the end of the last step in the dive profile (minutes)								
	Day 1			Day 2			Day 3		
	Dive 1	Dive 2	Dive 3	Dive 1	Dive 2	Dive 3	Dive 1	Dive 2	Dive 3
Atmos 1	+50	+239	-2	+16	+192	+25	+178	+220	+84
Atmos 2	+55	+241	+52	+17	+199	+26	+135	+225	+87
Atmos ai	+56	+94A	+50	0T	+92A	+25	+73	+79A	+62A
Pro Plus 2	+49	+203A	+44	0T	+175A	+25	+170	+204A	+83
Versa	+56	+239	-2	+16	+192	+25	+179	+224	+85
Versa Pro	+55	+242	+53	+17	+199	+26	+185	+225	+88
Darwin	-2	V	V	-2R	V	V	+65R	+99*	+47
M1	-2	V	V	-2R	V	V	+64R	+99*	+49
Smart Pro	-5	V	V	V	V	V	V	V	V
Archimede	did not activate			-4	V	V	+169R	+200	+47
Vytec	+6	+110	-7	+1R	+10	+10	+89	+95	+54
Nemesis II	+17	not activated		+10	+168	+20	+166	+224	+86
Solution	+9	+150	-3	V	V	V	+108R	+130	+61
EDGE	+20	+HRS*	+15	+2	+35	+13	+91	+68	+43

A = Air time remaining – NDT greater than this time
T = Tank not turned on - 0 minutes air time remaining
V = Violation mode – TDT from previous dive not completed
R = Reset dive computer at start of day after going into violation the day before
*Maximum NDT displayed

Table 3: Response of dive computers to multi-day, multi-level repetitive dive series.

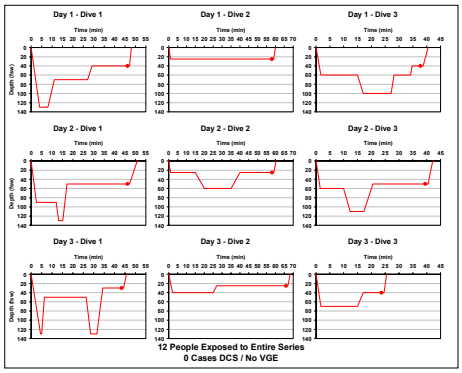

Figure 1: Orca Multi-day, multi-level repetitive dive series.

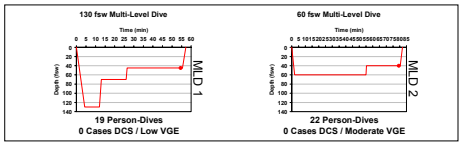

Figure 2: Multi-level dives from PADI/DSAT RDP test series.

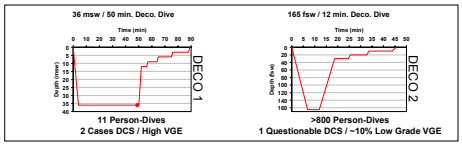

Figure 3: Decompression dives from DCIEM (36 msw) and Catalina Hyperbaric Chamber (165 fsw).

Dive Computer	No-Deco Time (+) or Required Deco Time (-) at the end of the last step in the dive profile (minutes)		Required Deco prior to ascent Ceiling / 1st Stop / Total Ascent Time	Time after reaching 30 fsw until decompression obligation cleared (min::sec)
	MLD 1	MLD 2	DECO 1	DECO 2
Atmos 1	+9	+4	30'/ 10/ 85	0::53
Atmos 2	+11	+2	30'/ 8/ 70	1::04
Atmos ai	+11	+8	30'/ 8/ 70	1::01
Pro Plus 2	+11	+20	30'/ 8/ 68	0:48
Versa	+9	+3	30'/ 10/ 88	1::02
Versa Pro	+11	+1	30'/ 8/ 70	1::02
Darwin	-9	-19	30'/ 5/ na	4::39
M1	-10	-19	30'/ 5/ na	4::39
Smart Com	S	-14	40'/ 2/ 98	S
Smart Pro	-12	-14	40'/ 2/ 97	3::44
Archimede	-12	-16	39'/ 2/ 106	4::34
Vytec	-12	-13	35'/ na/ >99	3::17
Nemesis II	-4	-4	50'/ 3/ 96	1::00
Solution	-7	-10	35'/ na/ >99	3::17
EDGE	-4	-5	46'/ na/ 147	0::46
S = Service Mode – Computer not responding				

Table 4: Response of dive computers to multi-level no-decompression and decompression dives

Figure 4: Dive computers in water bath used for tests.