User settings on dive computers: reliability in aiding conservative diving

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User settings on dive computers: reliability in aiding conservative diving

Martin DJ Sayer, Elaine Azzopardi and Arne Sieber

Abstract
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Introduction: Divers can make adjustments to diving computers when they may need or want to dive more conservatively (e.g., diving with a persistent (patent) foramen ovale). Information describing the effects of these alterations or how they compare to other methods, such as using enriched air nitrox (EANx) with air dive planning tools, is lacking.
Methods: Seven models of dive computer from four manufacturers (*Mares*, *Suunto*, *Oceanic* and *UWATEC*) were subjected to single square-wave compression profiles (maximum depth: 20 or 40 metres' sea water, msw), single multi-level profiles (maximum depth: 30 msw; stops at 15 and 6 msw), and multi-dive series (two dives to 30 msw followed by one to 20 msw). Adjustable settings were employed for each dive profile; some modified profiles were compared against stand-alone use of EANx.
Results: Dives were shorter or indicated longer decompression obligations when conservative settings were applied. However, some computers in default settings produced more conservative dives than others that had been modified. Some computer-generated penalties were greater than when using EANx alone, particularly at partial pressures of oxygen (PO_2) below 1.40 bar. Some computers 'locked out' during the multi-dive series; others would continue to support decompression with, in some cases, automatically-reduced levels of conservatism. Changing reduced gradient bubble model values on *Suunto* computers produced few differences.
Discussion: The range of possible adjustments and the non-standard computer response to them complicates the ability to provide accurate guidance to divers wanting to dive more conservatively. The use of EANx alone may not always generate satisfactory levels of conservatism.

Key words
Computers – diving; decompression; safety; altitude; persistent (patent) foramen ovale (PFO); enriched air – nitrox; review article

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Introduction

There are a number of physical or physiological conditions that may increase the risk of divers getting decompression sickness (DCS).[1] These include having a persistent (patent) foramen ovale (PFO),[1,2] congenital heart disease,[3] previous DCS events,[4,5] increasing age and/or higher body-mass indices.[1,6,7] Medical advice to some of these divers is usually to consider a more conservative approach to their diving.[3,8–11] For instance, the recent position statement on PFO and diving, published jointly by the South Pacific Underwater Medicine Society (SPUMS) and the United Kingdom Sports Diving Medical Committee (UKSDMC),[12] provides examples of more conservative types of diving. These include: reducing dive times; restricting dive depths; eliminating multiple dives per day; diving using enriched air nitrox while managing decompression with air-based methods; and increasing the duration of safety or decompression stops.

Some dive computers have the capability to generate more conservative dive profiles by modifying decompression management based on a number of settings that can be altered by the user.[13] Forty out of 47 dive computers reviewed in one study possessed some form of adjustment that was capable of producing more conservative decompression management.[14] However, there are potential risks to applying these adjustments without knowing what the implications of those changes are. The case has been reported of a diver who, following the closure of a PFO, had set their computer to calculate decompression at an heightened altitude but also employed a less conservative version of the decompression software.[15] The diver was unaware of the impact the alterations made and, as a result of improper dive management, the computer locked up on surfacing. The diver continued diving with a new computer clear of any prior pressure/time exposure and, as a consequence, they experienced a relatively severe episode of DCS, with post-treatment relapse and significant sequellae.[15] It was suggested in that report that a better knowledge of the implications of employing some of the adjustable computer safety features may have prevented the DCS event.

The present study reviews the exact forms of adjustment that can be made on a representative sample of dive computers in current use by recreational scuba divers. A series of pressure/time exposures is used to compare the effects of employing one or more of the available changes. The scales of the possible computer adjustments are compared against default settings and also against the use of enriched air nitrox while managing the dive using air-based decompression procedures as if this had been used as the

Table 1
The seven models of dive computer employed in the study and the settings available for adjustment by the diver; MB – microbubble level; P – personal setting; PF – personal factor; A – altitude; RGBM – reduced gradient bubble model

Brand	Model	Personal settings	Altitude settings	Other adjustments
Mares	Icon HD	P0, P1, P2	A0, A1, A2, A3	
Mares	Nemo Excel	PF0, PF1, PF2	A0, A1, A2, A3	
Suunto	D9	PF0, PF1, PF2	A0, A1, A2	RGBM 100%, RGBM 50%
Suunto	Vyper Air	PF0, PF1, PF2	A0, A1, A2	RGBM 100%, RGBM 50%
Oceanic	Atom 2	On, Off		
UWATEC	Galileo Sol	MB0, MB1, MB2, MB3, MB4, MB5		
UWATEC	Tec 2G	MB0, MB1, MB2, MB3, MB4, MB5		

Figure 1
Nominal multi-level depth/time dive profile (see text for details) with five sampling points (A–E)

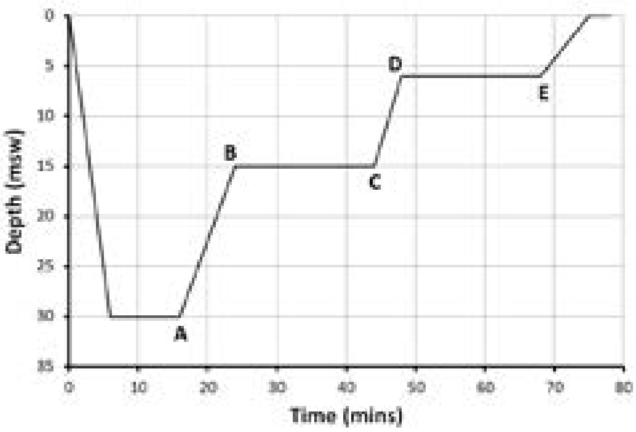
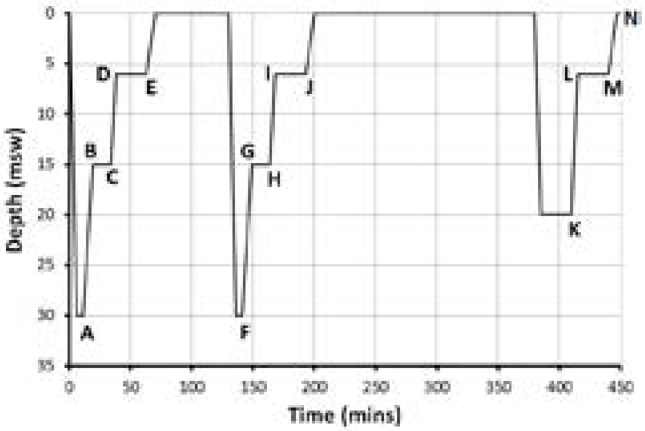


Figure 2
A series of three multi-level depth/time dive profiles (see text for details) with 14 sampling points (A–N)



only modification. Breathing nitrox gas mixtures while using air-based decompression management tools is a stand-alone conservative diving practice that could be recommended by medical practitioners for divers at risk.[9,11,12] We also review adjustments to computers which are untested in the present study but which advisors should be aware of when providing guidance to divers who wish to dive more conservatively.

Methods

Seven models of dive computer were studied, being representative of the current four main manufacturers (*Mares, Suunto, Oceanic* and *UWATEC*; Table 1). Personal settings were described as P values on the *Mares Icon HD*, personal factor (PF) settings on the *Mares Nemo Excel*, *Suunto D9* and *Suunto Vyper Air* and micro-bubble (MB) settings on the two *UWATEC* models; the *Oceanic Atom 2* has simply an On/Off setting for a 'conservatism factor' feature (Table 1). Both *Mares* and *Suunto* models had altitude settings: *Mares* computers had four altitude settings (A0-3; although sometimes given as P0-3) where A0 was for diving at altitudes of 0–700 m, A1 for 700–1,500 m, A2 for 1,500–2,400 m, and A3 for 2,400–3,700 m; *Suunto* computers had three altitude settings (A0–2) where A0 was for diving at 0–300 m, A1 for 300–1,500 m and A2 for 1,500–3,000 m; the *UWATEC* models and the *Oceanic Atom 2* reportedly measured altitude automatically and so they were unable to be tested for these settings in the present study. In all cases where there were multiple settings, it was assumed that the higher numbered settings corresponded with a more conservative approach to decompression management. In addition, the decompression modelling could be altered on the *Suunto* models between the default *Suunto* reduced gradient bubble model (RGBM) 100% and the purportedly less conservative RGBM 50% settings.

Testing took place in a compression chamber located at near sea level following the protocols outlined in a previous paper.[16] The pressure exposures were identical for all the dive computers as they were exposed to the test dive profiles at the same time. Units of pressure are nominally given in metres' sea water (msw); this followed the gauge depth of the chamber used but makes no allowances for the salinity of the water the computers were tested in. Single examples of all seven models were subjected to four independent dive profiles with one dive made per profile for each dive computer:

- square-wave excursion to a nominal depth of 40 msw

held until 30 min of staged decompression had been registered or exceeded;
- square-wave excursion to a nominal depth of 20 msw held until 30 min of staged decompression had been registered or exceeded;
- a multi-level dive to a maximum depth of 30 msw with ascents to 15 and 6 msw, with five sampling points (A–E; Figure 1);
- a series of three multi-level dives: two to maximum depths of 30 msw with ascents to 15 and 6 msw with an one hour surface interval, followed three hours later by a dive to a maximum depth of 20 msw with a single ascent to 6 msw, with 14 sampling points (A–N; Figure 2).

The square-wave profile tests examined the effects of personal settings and altitude settings; the multi-level tests only examined the effects of personal settings; the effects of applying RGBM 100 and 50% were compared on the *Suunto D9* during the multi-dive series. For the two square-wave profiles, downloaded data were used to collate the relative times taken to reach the maximum *no staged decompression limit* (NSDL) and to generate or exceed 3, 5, 8, 10, 12, 15, 20 or 30 min of staged decompression. For the single multi-level dives, downloaded data were sampled after 10 min at the maximum depth 30 msw (Point A), on reaching 15 msw (B), after 20 min at 15 msw (C), on reaching 6 msw (D) and after 20 min at 6 msw (E; Figure 1).

For the series of multi-level dives, downloaded data were sampled after 5 min at the maximum depth 30 msw (A and F; one hour surface interval between dives), on reaching 15 msw (B and G), after 15 min at 15 msw (C and H), on reaching 6 msw (D and I), after 25 min at 6 msw (E and J), after 25 min at 20 msw (K: three hour surface interval between dives two and three), on reaching 6 msw (L), after 25 min at 6 msw (M), and at the surface (N; Figure 2). No replicate tests were made for any of the experiments; data logging rates for the seven computers varied from 1 to 20 s.

Comparisons between computer personal settings and diving enriched air nitrox (EANx) using air-based decompression methods were made on the 20 and 40 msw square-wave profiles; EANx32 (32% oxygen: 68% nitrogen) and EANx36 on the 20 msw profile, and EANx28 was used on the 40 msw profile. EANx28 was chosen as the maximum oxygen content for a depth of 40 msw if the maximum allowable partial pressure of oxygen was set at 1.4 bar; EANx32 and 36 are commonly used recreational breathing gas mixtures. The two square-wave profiles were run for all the personal factor settings to give the dive-times at which the NSDL was reached; the EANx dives used the same dive-times as for the non-modified computers. Hempleman's Exposure Factor (EF)[17] was used to make comparisons:

$$EF = P_{abs}\sqrt{t} \qquad (1)$$

where P_{abs} is the absolute pressure (in bar using the nominal conversion of 1 bar = 10 msw) and t is time (min); the EANx dives used the same equation to generate EF values but these were based on pressure values equivalent to their respective equivalent air depths (EAD):

$$EAD = ((D + 10) \times (FN_2/0.79)) - 10 \qquad (2)$$

where D is gauge depth in msw, and FN_2 is the fraction of nitrogen in the mixture.

Results

20-msw SQUARE-WAVE PROFILE

For all the dive computers tested over the 20-msw square-wave dive profile, the time indicated to reach the nominal endpoints (the NSDL and all of the staged decompression values) was less when personal settings were applied (Table 2). The scale of some of these time variations occasionally varied with exposure; for example the MB3 and MB5 settings for the *UWATEC Galileo Sol* produced time values that were 50 and 21% respectively of those generated by the default (MB0) settings at the NSDL point at 20 msw, but were 80 and 68% respectively of the default value when 30 min of staged decompression was indicated by the computers (Table 2; Figure 3).

In other cases, the scale of variation was almost constant; P1 and P2 settings on the *Mares Icon HD* produced time reductions of 73–79% and 63–67% respectively of the P0 values for all dive durations tested (Table 2; Figure 4). Even when set to a personal setting, some of the less conservative computers produced similar decompression schedules at 20 msw to the more conservative units in default mode (e.g., the *Oceanic Atom 2* in "*On*" mode, compared with the *Mares Nemo Excel* on P0 setting; Table 2). The two *SuuntoD9* exposures that could compare the effect of altering the RGBM setting (A1/RGBM 100% versus A1/RGBM 50%; and A2/RGBM 100% vs A2/RGBM 50%) produced no major differences in NSDL or decompression times (Table 2).

40-msw SQUARE-WAVE PROFILE

A similar trend was observed in the 40-msw test where both *UWATEC* units showed time values converging with increased levels of decompression penalty. Both models when set to MB3 recorded 62% of the MB0 time at the NSDL but 84% when registering 30 min of decompression (Table 3); MB5 values for both units were 47% of the MB0 time values when 10 min of staged decompression was displayed but 72% when the computer displayed 30 min of staged decompression (Table 3). All the other units tested retained almost consistent differences across the nominal decompression penalty scale. For example, the PF1 and PF2 settings on the *Suunto Vyper Air* produced values that were 82–92% and 68–92% of the PF0 time values, respectively (Table 3; Figure 5). When the conservative factor feature was "*On*", the *Oceanic Atom 2* values were always between 86 and 90% of the time values when set to "*Off*" mode (Table 3; Figure 6). As above, the *Oceanic Atom 2* with the conservative factor feature "*On*" produced similar decompression schedules at 40 msw as the *Mares Nemo Excel* on P0 setting (Table 3). Setting the *Suunto D9* to either RGBM 50 or RGBM 100% produced identical NSDL or decompression times (Table 3).

ENRICHED AIR NITROX

The effects caused by employing a range of computer personal settings compared against the use of EANx during the 20 and 40 msw square-wave dive profiles are shown in Tables 4 and 5, respectively. At 20 msw, the computer default settings dived with air generated EF values of 18.2–20.6 at the NSDL (Table 4). At the same time limit, the most conservative settings produced EF values of 8.5–18.2 whereas values for EANx32 and 36 were 15.7–17.7 and 14.8–16.7, respectively. On the 40 msw dive, the default air NSDL EF values ranged 17.3–18.7, the most conservative settings were 14.1–17.3 and EANx28 produced 9.5–10.2 (Table 5).

MULTI-LEVEL DIVE PROFILE

The multi-level dive profile produced mixed responses (Table 6). The decompression management demonstrated by some computer units varied in appearance across the dive profile with both convergence and divergence of the time values being caused by the different settings during the dive (e.g., *Mares Icon HD*). Other units produced more constant differences between the settings (e.g., *Suunto Vyper Air*). Both *Mares* computers displayed missed decompression on surfacing after the multi-level dive when set to the PF1/PF2 and P1/P2 settings. The *Oceanic Atom 2* with the conservative factor feature "*On*" gave similar decompression schedules to the *Mares Icon HD* unit in P0 mode.

MULTI-DIVE SERIES

Results for the multi-dive series shown in Figure 2 are presented in Table 7. The majority of computer models set to default settings permitted decompression to be managed across all three dives. The exception was the *Mares Nemo Excel* which did not complete decompression after 25 min at 6 msw (point J). In this case, along with the *Mares Nemo Excel* set to PF1 and the *Mares Icon HD* set to P1 at J, and both *Mares* models set to P2 or PF2 at point E, the computers 'locked out' of decompression control and instead converted to 'gauge mode' only (referred to as 'bottom timer' in Table 7). The *Oceanic Atom 2* in both modes and both *UWATEC* models at MB0 and MB1 levels were largely free of decompression obligation across the three dives, with only small amounts of decompression obligation indicated at points H and I during the second dive.

When set to their maximum level of conservatism (MB5), both *UWATEC* models were still indicating the need for staged decompression at the end of the 6 msw stop on the second dive (point J). In both cases, the third dive was permitted and the decompression managed but the computers indicated that this was achieved through a reduction in the MB level.

When set at PF0, the two *Suunto* models managed the decompression for the three dive series even though staged decompression of 4 min was indicated in all cases at the end of the 6 msw stage of dive 2 (J). Irrespective of their RGBM adjustments, when set to PF1 or PF2, both *Suunto* models indicated significant amounts of decompression at point J on dive 2 (38–65 min); neither model locked out and both permitted and managed the decompression of the third dive.

There were no major differences between the results of the first dive for the *Suunto D9* between the RGBM 50 and 100% adjustments at any of the three PF settings. At the end of the 30 msw stage of the second dive (F), the RGBM 50% setting indicated longer bottom times at each PF setting. This relationship continued when the computer was set to PF0; for most of the second dive (G-I), the RGBM 50% adjustment either indicated longer bottom or shorter staged decompression times. A much shorter decompression time was indicated at PF1 for the RGBM 50% adjustment at the beginning of the 15 msw stage in dive 2 (G) but apart from that, there were no major differences indicated between the RGBM 50 and 100% adjustments for the remainder of the dive series.

Discussion

The main reason for undertaking the present study was to evaluate whether reasonable guidance could be provided to divers needing or wishing to dive more conservatively, or to the diving medical experts advising them, through modifying the decompression management provided by dive computers when adjusted by user-settings. This guidance could, for example, be used in support of the need to dive more conservatively following diagnosis of a PFO that may produce an increased DCI risk (Statement 5: joint position statement on PFO and diving of SPUMS and the UKSDMC).[12] Some guidance will be suggested at the end of this Discussion; however, the strength of that guidance will be compromised by the range in responses of the dive computers tested. This is in addition to the existing range in decompression strategies reported previously.[16,18–20] The present study was limited to single examples of seven dive computers and was based on single examples of the chosen range of diving exposures. Previous studies have shown relatively standard responses by dive computers tested over a series of replicated pressure/time exposures.[16]

In all the profiles tested, adjusting the user settings by increasing the personal factors and/or adding altitude levels,

Table 2

Dive times required to reach the no staged decompression limit (NSDL) or to generate 3−30 min of staged decompression* for a square-wave dive profile to 20 msw expressed as time (t) min or percentage change of default setting (Δ%); results are for seven models of dive computer set to varying settings; MB − microbubble level; P − personal setting; PF − personal factor; A − altitude; RGBM − reduced gradient bubble model; blank cells − missing data; *n* = 1 in each case

Brand & Model	Settings	NSDL		3 min		5 min		10 min		15 min		20 min		30 min	
		t	Δ%	t	Δ%	t	Δ%	t	Δ%	t	Δ%	t	Δ%	t	Δ%
Mares															
Icon HD	P0	41	100	42	100.0	44	100	50	100	54	100	57	100	64	100
	P1	30	73			33	75	39	78	42	78	45	79	49	77
	P2	26	63			28	64	33	66	35	65	37	65	40	63
	P0/A1	24	59			26	59	31	62	34	63	36	63	39	61
	P0/A3	12	29			12	27			17	32			18	28
Nemo Excel	PF0	37	100			38	100	46	100	51	100	54	100	61	100
	PF1	31	84			32	84	40	87	44	86	46	85	51	84
	PF2	27	73			27	71	34	74	37	73	38	70	42	69
	P1/A1	27	73			28	74	35	76	37	73	40	74	43	71
	P3 /A3	15	41			15	40	19	41	21	41	21	39	22	36
Suunto															
D9	PF0/RGBM 100%	41	100	42	100	46	100	50	100	54	100	60	100	74	100
	PF1/RGBM 100%	32	78	33	79	37	80	42	84	45	83	49	82	62	84
	PF2/RGBM 100%	26	63	26	62	28	61	34	68	37	69	40	67	49	66
	A1/RGBM 100%	33	81	33	79	37	80	42	84	45	83	49	82	62	84
	A1/RGBM 50%	33	81	33	79	37	80	42	84	45	83	49	82	62	84
	A2/RGBM 100%	25	61	26	62	28	61	34	68	37	69	40	67	49	66
	A2/RGBM 50%	26	63	26	62	28	61	34	68	37	69	40	67	49	66
Vyper Air	PF0/RGBM 100%	40	100	41	100	45	100	49	100	54	100	59	100	73	100
	PF1/RGBM 100%	32	80	33	81	37	82	41	84	45	83	49	83	62	85
	PF2/RGBM 100%	25	63	26	63	28	62	34	69	36	67	39	66	49	67
	A1/RGBM 100%	33	83	33	81	37	82	41	84	45	83	49	83	62	85
	A2/RGBM 100%	25	63	26	63	28	62	34	69	36	67	40	68	49	67
Oceanic															
Atom 2	Off	47	100	47	100	51	100	55	100	59	100	64	100	76	100
	On	37	79	37	79	41	80	46	84	49	83	52	81	61	80
UWATEC															
Galileo Sol	MB 0	38	100	39	100	44	100	47	100	51	100	56	100	69	100
	MB 3	19	50	21	54	29	66	38	81	43	84	47	84	55	80
	MB 5	8	21	10	26	15	34	22	47	31	61	40	71	47	68
Tec 2G	MB 0	38	100	39	100	44	100	47	100	51	100	56	100	69	100
	MB 3	19	50	21	54	28	64	38	81	43	84	47	84	55	80
	MB 5	8	21	10	26	15	34	21	45	30	59	39	70	46	67

reduced the NSDL, reduced the dive time taken to generate nominal staged decompression values and/or increased the amount of staged decompression required. Only one user setting, RGBM 50% on the *Suunto* computers, was capable of reducing conservatism. This was a setting possibly used incorrectly in a case reported previously if the intention was to generate more conservative diving, although that in itself was not the reason for the eventual poor outcome.[15] The results from the present study suggest that adjusting the settings to RGBM 50% has limited effect within the context of the typical types of recreational diving.

An altitude setting was also used in the reported case to increase safety. It is probably prudent to advise divers to only employ altitude settings when diving at altitude as that is their design purpose. However, there are examples in the present study that indicate that some computer models apply the same penalties irrespective of the actual settings used. In the *Mares* and *Suunto* computers, which had manual altitude settings, the effect of the addition of an altitude penalty was nearly identical to a matching personal setting. In both the 20 and 40 msw tests, both *Mares* computers displayed near identical times to reach the nominal decompression times when set at either P2 or PF2, or at the matching P0/A1 or P1/

*** Footnote:**
The data for 8 min and 12 min decompression times are not shown in this table but are available from the author at <*mdjs@sams.ac.uk*>

Table 3

Dive times required to reach the no staged decompression limit (NSDL) or to generate 5–30 minutes of staged decompression for a square-wave dive profile to 40 msw expressed as time (t) min or percentage change of default setting (Δ%); results are for seven models of dive computer set to varying settings; MB – microbubble level; P – personal setting; PF – personal factor; A – altitude; RGBM – reduced gradient bubble model; blank cells – missing data; *n* = 1 in each case; † gave 62 minutes of decompression after a dive time of 11 min

Brand & Model	Settings	NSDL		5 min		10 min		15 min		20 min		30 min	
		t	Δ%	t	Δ%	t	Δ%	t	Δ%	t	Δ%	t	Δ%
Mares													
Icon HD	P0	12	100	13	100	17	100	20	100	22	100	26	100
	P1	11	92			15	88	18	90	20	91	22	85
	P2	10	83			13	77	16	80	17	77	19	73
	P0/A1	10	83			14	82	15	75	17	77	19	73
	P0/A3					8	47			10	46	†	†
Nemo Excel	PF0	12	100			16	100	20	100	23	100	26	100
	PF1	11	92			15	94	18	90	20	87	23	89
	PF2	10	83			13	81	16	80	18	78	20	77
	P1/A1	10	83			13	81	15	75	18	78	20	77
	P3 /A3					8	50	10	50	11	48	11	42
Suunto													
D9	PF0/RGBM 100%	12	100	12	100	19	100	22	100	24	100	27	100
	PF1/RGBM 100%	11	92	11	92	16	84	19	86	20	83	23	85
	PF2/RGBM 100%	10	83	10	83	14	74	16	73	18	75	20	74
	A1/RGBM 100%	11	92	11	92	16	84	19	86	20	83	23	85
	A1/RGBM 50%	11	92	11	92	16	84	19	86	20	83	23	85
	A2/RGBM 100%	10	83	10	83	14	74	15	68	18	75	20	74
	A2/RGBM 50%	10	83	10	83	14	74	15	68	18	75	20	74
Vyper Air	PF0/RGBM 100%	12	100	12	100	18	100	22	100	23	100	27	100
	PF1/RGBM 100%	11	92	11	92	16	89	18	82	20	87	23	85
	PF2/RGBM 100%	10	83	11	92	14	78	15	68	17	74	20	74
	A1/RGBM 100%	10	83	10	83	16	89	18	82	20	87	23	85
	A2/RGBM 100%	10	83	11	92	14	78	15	68	17	74	20	74
Oceanic													
Atom 2	Off	14	100	16	100	20	100	22	100	25	100	28	100
	On	12	86	14	88	18	90	19	86	22	88	24	86
UWATEC													
Galileo Sol	MB 0	13	100	13	100	19	100	21	100	22	100	25	100
	MB 3	8	62	9	69	13	68	16	76	19	86	21	84
	MB 5					9	47	12	57	14	64	18	72
Tec 2G	MB 0	13	100	13	100	19	100	21	100	22	100	25	100
	MB 3	8	62	8	62	13	68	16	76	19	86	21	84
	MB 5					9	47	12	57	14	64	18	72

A1 levels (Tables 2 and 3). Similarly, there was no difference in performance of both *Suunto* computers if they were set to either PF1 or A1, or PF2 or A2 at RGBM 100% during either the 20 or 40 msw tests (Tables 2 and 3). However, this is not the case for all computers (see below).

Figures 3 to 6 illustrate the overall responses to differing levels of conservatism of some of the tested dive computers measured over dive series that had a range of NSDL and staged-decompression endpoints. A set of curves that were parallel would indicate that the penalties being applied were probably in the form of a relatively simple adjustment that was proportionate to the time taken to reach each nominal decompression value when unmodified. If the adjustments were achieved through a simple set-time penalty then the relationships would converge, while a set of curves that were diverging would suggest that progressively larger penalties were being applied with increasing decompression stress. Determining the exact relationships was complicated by the variable precision of the data that were retrievable from the download information plus some of the relatively large step changes in those data. Although it is possible that all three relationships (and thus all three methods of computer modification) were present in the recorded curve sets, the differences were slight. What was evident, however, was that there were no recorded instances where a markedly accelerated termination of the dive was indicated by a computer being subjected to what may be considered unwise diving practices (i.e., a considerable accumulation in the amount of staged decompression) for a diver who has employed some or many levels of conservatism.

Table 4
Hempleman's Exposure Factor (EF) values for seven models of dive computer calculated at the maximum no staged decompression limit (NSDL) at 20 msw; comparisons are between breathing air against breathing enriched air nitrox (EANx) with 32 or 36% oxygen (EANx32 or EANx36) when at the default computer settings; EF values are also given for other dive computer personal settings

Brand	Model	Settings		NSDL	
			Air	EANx32	EANx36
Mares	Icon HD	P0	19.2	16.5	15.6
		P1	16.4		
		P2	15.3		
		P0/A1	14.7		
		P0/A3	10.4		
Mares	Nemo Excel	PF0	18.2	15.7	14.8
		PF1	16.7		
		PF2	15.6		
		P1/A1	15.6		
		P3 /A3	11.6		
Suunto	D9	PF0/RGBM 100%	19.2	16.5	15.6
		PF1/RGBM 100%	17.0		
		PF2/RGBM 100%	15.3		
		A1/RGBM 100%	17.2		
		A2/RGBM 100%	15.0		
Suunto	Vyper Air	PF0/RGBM 100%	19.0	16.3	15.4
		PF1/RGBM 100%	17.0		
		PF2/RGBM 100%	15.0		
		A1/RGBM 100%	17.2		
		A2/RGBM 100%	15.0		
Oceanic	Atom 2	Off	20.6	17.7	16.7
		On	18.2		
UWATEC	Galileo Sol	MB 0	18.5	15.9	15.0
		MB 3	13.1		
		MB 5	8.5		
UWATEC	Tec 2G	MB 0	18.5	15.9	15.0
		MB 3	13.1		
		MB 5	8.5		

Figure 3
Scatter and linear regression relationships between decompression penalty and the dive time required to generate that penalty for the *UWATEC Galileo Sol* dive computer subjected to a 20-msw profile and set to microbubble settings 0 (MB0, black), 3 (MB3, dark grey) and 5 (MB5, light grey); MB0: $y = 1.008x + 37.239$, $R^2 = 0.983$; MB3: $y = 1.227x + 22.287$, $R^2 = 0.920$; MB5: $y = 1.414x + 8.040$, $R^2 = 0.972$

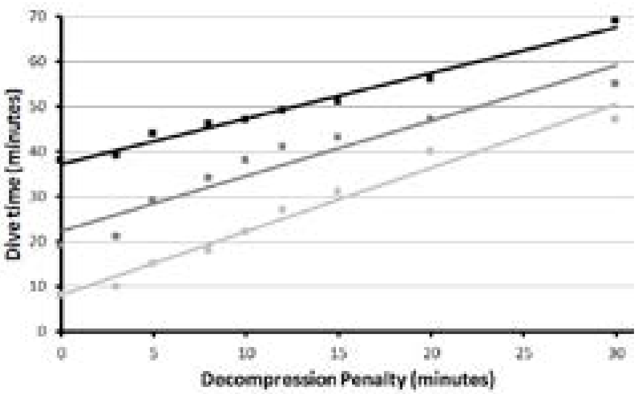


Figure 4
Scatter and linear regression relationships between decompression penalty and the dive time required to generate that penalty for the *MARES Icon HD* computer subjected to a 20-msw profile and set to personal settings 0 (P0, black), 1 (P1, dark grey) and 2 (P2, light grey); P0: $y = 0.8008x + 41.058$, $R^2 = 0.9817$; P1: $y = 0.6464x + 31.42$, $R^2 = 0.948$; P2: $y = 0.4712x + 27.235$, $R^2 = 0.932$

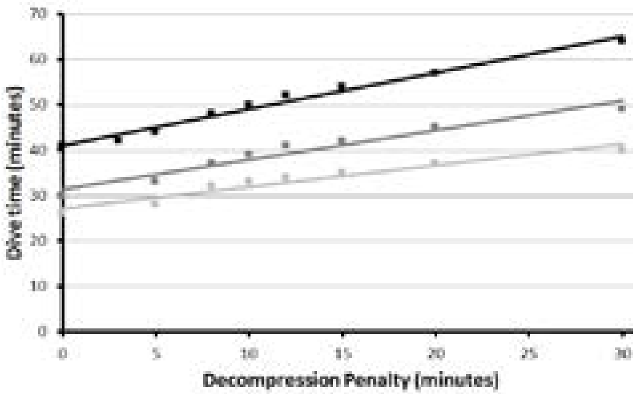


Table 5

Hempleman's Exposure Factor (EF) values for seven models of dive computer calculated at the maximum no staged decompression limit (NSDL) at 40 msw; comparisons are between breathing air against breathing enriched air nitrox (EANx) with 28% oxygen (EANx28) when at the default computer settings; EF values are also given for other dive computer personal settings

Brand	Model	Settings	NSDL	
			Air	EANx28
Mares	Icon HD	P0	17.3	9.5
		P1	16.6	
		P2	15.8	
		P0/A1	15.8	
Mares	Nemo Excel	PF0	17.3	9.5
		PF1	16.6	
		PF2	15.8	
		P1/A1	15.8	
Suunto	D9	PF0/RGBM 100%	17.3	9.5
		PF1/RGBM 100%	16.6	
		PF2/RGBM 100%	15.8	
		A1/RGBM 100%	16.6	
		A2/RGBM 100%	15.8	
Suunto	Vyper Air	PF0/RGBM 100%	17.3	9.5
		PF1/RGBM 100%	16.6	
		PF2/RGBM 100%	15.8	
		A1/RGBM 100%	15.8	
		A2/RGBM 100%	16.6	
Oceanic	Atom 2	Off	18.7	10.2
		On	17.3	
UWATEC	Galileo Sol	MB 0	18.0	9.9
		MB 3	14.1	
UWATEC	Tec 2G	MB 0	18.0	9.9
		MB 3	14.1	

The responses to the multi-level dive profile are even more complex to determine as the decompression stress does not increase linearly as would be expected in a square-wave pressure exposure. When registering a staged decompression obligation between points B and D (Figure 1), the trends for the computers set to a personal factor setting tended towards a form of parallel relationship between the conservative levels that, again, suggested either a consistent set value or proportional mathematical adjustment was being made.

The range of decompression strategies employed by dive computers means that there is the potential for overlap between computers that have some personal settings turned on and those that are still on default settings. This was repeatedly the case in this present study where the *Oceanic Atom 2* computer set to 'conservative factor ON' produced similar results to the *Mares* computers on default. The decompression algorithm in the *Oceanic Atom 2* is a modified version of the *DSAT* (Diving Science and Technology) tables that also employs some US Navy decompression theory to extrapolate outside of the *DSAT* tables for decompression dives and/or dives deeper than 27 msw.[14,21] Newer versions of *Oceanic* dive computers now employ dual decompression algorithms: the *DSAT* algorithm is now called the *Pelagic DSAT* and there is an added algorithm, the *Pelagic Z+*, based on the Bühlmann ZHL-16C decompression model.[22] Although amongst the least conservative of the dive computers tested here and in previous studies,[16] the *Oceanic* computers employing the *DSAT* algorithm are supposed to impose additional restrictions for repetitive decompression dives.[22] The *Pelagic Z+* algorithm, however, will produce NSDLs that are considerably more conservative, especially at shallower depths. The dual algorithm *Oceanic* computers default to the less conservative *DSAT* algorithm and require to be physically altered to *Pelagic Z+*.[22]

Figure 5

Scatter and linear regression relationships between decompression penalty and the dive time required to generate that penalty for the *Suunto D9* dive computer subjected to a 40-msw profile and set to personal settings PF0 (black), PF1 (dark grey) and PF2 (light grey); PF0: $y = 0.549x + 12.269$, $R^2 = 0.911$; PF1: $0.434x + 11.072$, $R^2 = 0.924$; PF2: $y = 0.3692x + 9.760$, $R^2 = 0.943$

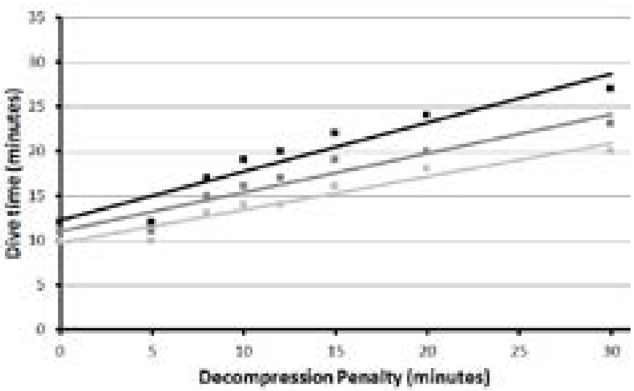


Figure 6

Scatter and linear regression relationships between decompression penalty and the dive time required to generate that penalty for the *Oceanic Atom 2* dive computer subjected to a 40-msw profile and set to 'conservatism factor Off' (black), and 'On' (grey); Off: $y = 0.549x + 12.269$, $R^2 = 0.911$; On: $0.410x + 11.631$, $R^2 = 0.967$

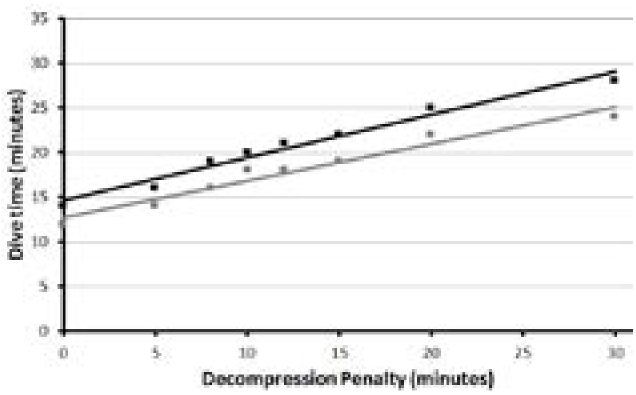


Table 6

Decompression times (min) given by seven models of dive computer with varying settings taken at five points (A–E) on a multi-level dive profile to a maximum depth of 30 msw (Figure 1 and text); positive values denote a staged decompression penalty; negative values are the times available before reaching the no staged decompression limit (NSDL); values of -99 and -199 denote that the computer had cleared of any decompression obligation; surface values are only given where there was missed decompression; all *Suunto* settings were at RGBM 100%; 'deepstop' is where a deep stop was indicated on the download but no other decompression information was given

Brand/Model	Settings	A	B	C	D	E	Surface
Mares							
Icon HD	P0	-2	-13	5	2	-99	
	P1	0	6	16	18	12	10
	P2	7	9	36	36	30	28
Nemo Excel	PF0	-3	deepstop	deepstop	-99	-99	
	PF1	5	4	12	15	9	3
	PF2	5	7	31	32	26	21
Suunto							
D9	PF0	-4	-27	-7	-99	-99	
	PF1	0	4	11	11	4	
	PF2	4	9	23	22	17	
Vyper Air	PF0	-5	-26	-7	-99	-99	
	PF1	0	4	12	11	0	
	PF2	4	10	23	23	15	
Oceanic							
Atom 2	Off	-6	-37	-18	-99	-99	
	On	-1	-9	4	3	0	
UWATEC							
Galileo Sol	MB 0	-2	-21	-1	-199	-199	
	MB 3	8	9	15	13	2	
	MB 5	15	17	22	20	10	
Tec 2G	MB 0	-2	-21	0	-99	-99	
	MB 3	8	9	15	13	3	
	MB 5	15	18	23	21	11	

There would remain the need, therefore, for a diver relying on setting more conservative personal settings in order to reduce potential decompression stress to still have a good understanding of the relative performance and working of specific dive computer models. To that end, there is relatively little information given by manufacturers in their supporting technical literature for a diver to base informed decisions as to how the computers operate in default or personal setting modes.

Of the computers used in the present study, *Oceanic* provides information on altitude[21] but only the literature supplied for the two *Suunto* models contained tables indicating the effects of personal settings on dive times.[23–25] However, it should be noted that the NSDLs (termed "*no decompression time limits*" in the *Suunto* manuals) quoted for similar computers marketed by *Suunto* do differ markedly.[23,25] For example, *Suunto* markets the *Vyper* dive computer plus the *Vyper Air*. When both models are set to default settings (P0/A0) and dived for the first dive of a series, there is little difference in the NSDL times (Table 8). However, when set to P2/A0, the *Suunto Vyper Air* permits much longer NSDL times than the *Suunto Vyper*; this relationship is reversed when set to P0/A2 (Table 8) and the differences continue at the other combinations of settings.[23,25] This suggests that in this case the manufacturer has, in a newer computer, moved from treating personal settings in the same way as ones used to compensate for diving at altitude. In particular, the penalty scale for altitude diving has increased compared to personal settings. While there will be added conservatism if a diver used altitude settings on a *Suunto Vyper Air* for sea-level diving, the reverse situation where a diver employs personal settings alone for altitude diving may produce dive times that are not as 'safe'. In providing guidance on this, it would reduce the likelihood for confusion if divers were advised only to use the altitude settings for when diving at altitude.

The *Galileo sol* computer gives the user the option of combining the wrist-mounted unit with a heart monitor and a tank pressure transmitter. The diver has the choice of either employing heart or breathing rate as an indicator of 'workload'.[26] A detection of rapid increases in workload will cause the *Galileo* to shorten the NSDLs and further modifications can occur if there is a temperature gradient detected in the water column.[26] Both aspects were not assessed in the present study but indicate that any published decompression data for this model of computer are liable to be modified in some circumstances. Even though many

Table 7

Decompression times (min) given by seven models of dive computer with varying settings taken at 14 points (A–N) on a series of multi-level dives (Figure 2 and text); positive values denote a staged decompression penalty, negative values are the times available before reaching the no staged decompression limit (NSDL); values of -99 and -199 denote that the computer had cleared of any decompression obligation; 'Bottom timer' indicates the computer has locked out of decompression management and now only operates in gauge mode

Brand/Model	Settings	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Mares															
Icon HD	P0	-7	-30	-16	-99	-99	-7	-12	4	6	-99	-9	-99	-99	-99
	P1	-4	-13	-2	-99	-99	-4	0	25	26	18	Bottom timer			
	P2	-3	-4	8	13	11	Bottom timer								
Nemo Excel	PF0	-7	-31	-17	-99	-99	-4	-1	15	16	5	Bottom timer			
	PF1	-5	-19	-4	-99	-99	0	19	35	37	27	Bottom timer			
	PF2	-2	-6	6	8	5	Bottom timer								
Suunto															
D9	PF0 RGBM 100%	-10	-38	-23	-99	-99	-3	-2	13	13	4	-10	-99	-99	-99
	PF0 RGBM 50%	-10	-38	-23	-99	-99	-6	-10	7	6	4	-12	-99	-99	-99
	PF1 RGBM 100%	-6	-23	-8	-192	-176	-1	13	33	39	38	-2		-194	
	PF1 RGBM 50%	-6	-23	-8	-199	-172	-4	7	33	39	38	-3		-188	
	PF2 RGBM 100%	-3	-3	7	8	-73	8	26	60	65	65	8	8	3	
	PF2 RGBM 50%	-3	-3	7	8	-76	-1	27	60	65	64	7	7	-93	
Vyper Air	PF0 RGBM 100%	-9	-37	-22	-99	-99	-3	-1	14	13	4	-10	-99	-99	-99
	PF1 RGBM 100%	-5	-22	-7	-192	-176	-1	14	33	40	39	-2		-194	
	PF2 RGBM 100%	-3	-3	7	8	-73	10	27	60	66	65	8	8	-89	
Oceanic															
Atom 2	Off	-11	-48	-34	-553	-528	-9	-31	-16	-379	-355	-17	-318	-294	-599
	On	-6	-30	-16	-375	-350	-6	-13	3	2	-195	-6	-157	-133	-599
UWATEC															
Galileo Sol	MB 0	-7	-32	-17	-199	-199	-7	-13	5	3	-199	-10	-199	-199	-199
	MB 1	-4	-27	-12	-199	-199	-4	-8	8	5	-199	-5	-199	-199	-199
	MB 5	10	11	13	8	-199	10	11	24	20	8	14	8	-199	
Tec 2G	MB 0	-7	-31	-16	-99	-99	-7	-11	6	3	-99	-10	-99	-99	-99
	MB 1	-4	-27	-12	-99	-99	-4	-8	8	6	-99	-5	-99	-99	-99
	MB 5	10	11	13	8	-99	11	11	24	21	9	14	9	-99	

dive computers sold in the EU are stamped with "CE" marks, there is a range in what European Normatives and/or Directives are used to justify this, none of which specifically refer in any detail to decompression management.[27]

The decompression algorithm used by the *Suunto* models examined in the present study employs a specific *Suunto* version of the RGBM but in two user-selectable versions: RGBM 100% and RGBM 50%.[23] The RGBM 100% is the default setting and is described by *Suunto* as giving the "*full RGBM effect*" and is the setting that *Suunto* strongly advises for use.[23] RGBM 50% is termed an "*attenuated RGBM*" that has smaller RGBM effects and which may carry higher risk.[23] This increased risk is shown by longer times to achieve NSDLs and reduced decompression obligations; these were only noticeable on the multi-dive series of this study as would be expected from a model that has a specific factor that accounts more for repetitive diving over periods of many days.[27] Although the effect of the RGBM 50% setting appears limited, it is obviously an adjustment that should not be used by divers seeking to increase their diving safety.

In the multi-dive series (Figure 2; Table 7), the *Oceanic Atom 2* in default mode permitted all three dives without any decompression and only some minor decompression penalties were incurred when the conservative setting was on. The *Mares Icon HD* also incurred minor decompression penalties in default mode but in all its other settings, and for all settings for the *Mares Nemo Excel*, either the third or both the second and third dives were not permitted. The response of the *Mares* models contrasts with those of the *Suunto* and *UWATEC* models which supported a third dive even when there appeared to be missed decompression after the second dive in the series (point J; both *UWATEC* models on the MB5 setting; both *Suunto* models on all settings). Both *UWATEC* models will automatically reduce the MB level set by one if the diver ascends more than 1.5 msw above the required level stop and the diving can continue at that modified MB level; in both cases, successive level stop violations will result in the MB levels dropping down towards or to MB0.[26,28]

The mechanism being employed by the *Suunto* models is

Table 8

NSDL times (min) for the first dive of a series for the *Suunto Vyper* and the *Suunto Vyper Air* for three different personal/altitude setting combinations; times are extracted from the user manuals;[22,24] Δ is the *Vyper* time subtracted for the corresponding *Vyper Air* value

Depth (m)	**P0/A0**			**P2/A0**			**P0/A2**		
	Vyper	**Vyper Air**	**Δ**	**Vyper**	**Vyper Air**	**Δ**	**Vyper**	**Vyper Air**	**Δ**
9	-	205		130	160	30	130	97	-33
12	124	124	0	67	93	26	67	54	-13
15	72	71	-1	43	59	16	43	34	-9
18	52	51	-1	30	43	13	30	24	-6
21	37	37	0	23	31	8	23	17	-6
24	29	29	0	19	25	6	19	11	-8
27	23	22	-1	15	19	4	15	8	-7
30	18	17	-1	12	14	2	12	6	-6
33	13	13	0	9	11	2	9	4	-5
36	11	10	-1	8	9	1	8	4	-4
39	9	8	-1	6	7	1	6	3	-3
42	7	6	-1	5	5	0	5	3	-2
45	6	5	-1	5	4	-1	5	2	-3

less clear. Manuals for both the tested *Suunto* models state that safety stops can be violated but the NSDL time will be reduced for the next dive.[23,24] However, the manuals also state that any violations of the decompression ceiling will result in the computer entering a locked out 'Error mode'. It would be anticipated that all the *Suunto* runs with PF1 or PF2 settings would have violated the decompression ceiling after leaving 6 msw on the second dive (J) because the required decompression was recorded as 38–65 min. The fact that the third dives were all allowed suggests some form of personal factor level cascade, similar to the *UWATEC* models, is also occurring in the *Suunto* computers. For the *UWATEC* and *Suunto* computer models, any advice that recommends the use of additional levels of conservatism must also highlight the cascading effect which could result in less conservative diving occurring part way through a multi-dive series, although only where staged decompression is required.

Using EANx as a breathing gas while employing air-based methods for managing decompression, has been advanced as one method for generating more conservative dive profiles, usually for divers with a PFO who want to avoid closure, or for those returning to diving following closure of a PFO.[9,11,12] The present study compared the use of three EANx mixtures against dive computer personal settings and whereas the use of EANx28 on the 40 msw square-wave profile dive produced a much lower level of decompression stress than the whole range of personal factor settings, using EANX 32 or 36 at 20 msw produced reductions in decompression stress that were no greater than one or two personal factor settings in many cases. There is, of course, a large difference in the PO_2 being breathed at all three combinations; breathing EANx28 at 40 msw has a PO_2 of 1.40 bar whereas EANx32 and 36 at 20 msw have PO_2 of 0.96 bar and 1.08 bar respectively.

The obvious advice, if using nitrox was the only method of delivering conservative dive profiles, would be for the diver to try and use EANx mixtures that deliver PO_2 closer to the maxima for the depths being dived. However, this is rarely possible for recreational divers; diving operators typically only supply a single standard EANx mix which tends to be relatively low in oxygen in order to minimise issues with the management of maximum operating depths, and to avoid the need for separate oxygen-clean diving equipment. Therefore, for dives at relatively shallow depths and with relatively lean EANx mixtures, using EANx alone may not produce the desired levels of conservatism and so the recommendations should include adding in at least one personal factor level on the dive computer in the knowledge that the vast majority of recreational divers use dive computers to manage their decompression.

The present study has focussed on personal and altitude settings on dive computers. Another method by which dive computers can be modified by the user to generate more conservative dive profiles is through the use of gradient factors.[17,29] Gradient factors are another way of modifying the background decompression algorithm in the computer to best suit the diver's own diving preferences; however, similarly to personal factors, gradient factors have yet to be validated in a scientific study. Whereas personal factors appear to be relatively simple proportional re-adjustments made at one to five set levels, gradient factors are used in pairs with, theoretically, dozens of combinations (although there are a much smaller number of typical settings).[29] Gradient factors were, until recently, mainly used by the technical diving sector but their use is increasing in recreational diving and the ability to apply gradient factors using more mainstream recreational dive computers may become more common.

Conclusions

For a diver with a physiological need or a personal wish to dive more conservatively, most dive computers do have user settings to make this possible. However, there is inter-model variability in how more conservative the modified profiles generated are and so, if a diver needs advice on continuing diving with a requirement to reduce DCS risk and intends using a dive computer to manage their decompression, the following recommendations should be considered in addition to other non-dive-computer-related advice.

- Where information exists, the diver should be aware of the baseline level of conservatism of their computer. Additional clues may come from comparing the operation of their computer against those of diving colleagues or by wearing two computers made by different manufacturers and decompressing as guided by the more conservative of the pair. The diver should make themselves aware of the operational implications of a dual-algorithm computer.
- Never use the RGBM 50% settings where available.
- Avoid any staged-decompression diving. In addition to possible increased risks, the computer may automatically cascade down the conservatism levels towards the default algorithm.
- Use higher-level personal factors if more conservatism is required.
- Employ altitude settings only when diving at altitude as that is their design purpose.
- When EANx is used below high PO_2 levels (i.e., in shallow waters with lean EANx mixtures) consideration should be made for adding at least one personal factor level to the dive computer but while still in air mode.
- If a computer 'locks up', or enters error or gauge-only mode, because of a violation then observe the period it becomes locked for (usually 24 h but may be longer when personal settings are applied) and do not dive during that period.

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Conflicts of interest

AS develops diving computers for commercial sale; however, no computer he has been involved in developing is included in the present study.

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