Dive Computer Profile Data and on the Fly and End of Dive Risk Estimators

Abstract

Dive computers and diveware are important underwater tools and staging devices across sport, technical, commercial, military, scientific, exploration and research diving sectors. They are supplanting traditional dive tables and their use is growing as decompression activities grow. While important dive computer parameters are displayed throughout the dive, DCS risk associated with arbitrary ascents to depths above the diver and surfacing risks are not yet encoded into underwater devices and diveware and that is the focus here. Risk estimation is needed for diver safety and sensible dive planning. We define and discuss end of dive (EOD) and on the fly (OTF) exponential risk functions for dissolved gas and bubble models using profile data correlated with the LANL Data Bank, a collection of computer downloaded mixed gas decompression profile with DCS outcomes across OC and RB diving. Risk estimates are based on profile supersaturations in excess over permissible supersaturations which is a standard metric. Comparative results are given for both nonstop and deep decompression diving on OC and RB systems. Computer implementation is easily accomplished within existing dive computers and diveware platforms. Techniques are underscored and results are discussed. References detail background information and work extends earlier published analyses for end of dive risk estimation.

Keywords: Dive computers; DCS risk; Decompression models; Profile data; Data banks

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Abbreviations: EOD: End Of Dive; OTF: On The Fly; GM: Gas Model; BM: Bubble Model; EOS: Equation-Of-State; OT: Oxygen Toxicity; DAN: Divers Alert Network; LANL: Los Alamos National Laboratory; PDE: Project Dive Exploration; DSL: Diving Safety Laboratory; CNS: Central Nervous System; WLM: Weibull-Levenberg-Marquardt; NLLS: Non Linear Least Squares Data Fit; ICD: Isobaric Counter Diffusion; CCRs: Circuit Re-Breathers

Introduction

Dive computers and diveware are useful tools across recreational and technical diving [1-6]. They are supplanting traditional dive tables and their use is growing as diving activities grow [7-13]. Able to process depth-time readings in fractions of a second, modern dive computers routinely compute and display hypothetical dissolved gas loadings, bubble buildup, ascent and descent rates, diver ceilings, time remaining, decompression staging, oxygen toxicity and many related variables. Computations of dive parameters made at any point on the dive are nested within two basic models [4,6,8], namely, the classical dissolved gas model (GM) and the modern bubble phase model (BM). Both have seen meaningful correlations with real dive data over limited ranges but differ in staging regimens. Dissolved gas models (GM) focus on controlling and eliminating hypothetical dissolved gas by bringing the diver as close to the surface as possible. Bubble phase models (BM) focus on controlling hypothetical bubble growth and coupled dissolved gas by staging the diver deeper before surfacing. Useful and popular computer models include the USN, ZHL, VPM and RGBM algorithms. The USN and ZHL algorithms fall into the GM class while the VPM and RGBM fall into the BM class and all will be employed in this analysis. All have been used safely and sanely in dive computers to date.

Today, some 15-25 companies manufacture dive computers and associated dive planning software employing both GM and BM algorithms in another 70-90 model by last count. Recreational dive computers mainly rely on the GM while technical dive computers use the BM. In the limit of nominal exposures and short time (nonstop diving), the GM and BM converge in diver staging. Dive planning and decompression software are also readily available from Vendors. But risk estimation for arbitrary ascents is not yet encoded into existing dive computers and diveware. It is sorely needed for diver safety and sensible dive planning. Risk estimation is needed and the paper suggests a simple correlated approach to estimating risk for any gas mixture, OC and RB system, deep or shallow dive, long and short bottom time, nonstop and decompression dive and staging algorithm presently embedded in any computer of the GM or BM genre. Risk estimators for end of dive (EOD) and on the fly (OTF) underwater are defined and discussed and subsequent applications focus on both nonstop and decompression diving on mixed gas, OC and RB systems.

Basic Dive Computer Models

Instantaneous estimates of parameters needed to stage divers with underwater computers rely an mathematical relationships coupled to pressure sensors and clocks in the unit. Basic ones follow [4,6,8] as well as quantification of oxygen toxicity in diving [2,3,6].

Dissolved gas models (GM)

The GM algorithms typically bring divers into the shallow zone for decompression (shallow stops). Ascent rates are nominally a slow 30 *fsw/min*. Critical tensions, *M*, have little to nothing to do with actual bubble formation in the tissue and blood but are (statistical) medical limit points to observed nonstop diving outcomes using arbitrary tissue compartments, $\hat{o}$. The approach dates back to Haldane and the 1900s and has been used extensively since then with little change and some tweaking of values. Much testing by World Navies has ensued on the medical side. Notable are the USN [14] and ZHL [15] models as follow:

USN Model [14]: In the Workman USN approach, the permissible gas tension, Π, (nitrogen plus helium) is limited by,

$$\Pi \le M \quad \text{.................... (1)}$$

with *M* critical tensions listed in for depth, *d*,

$$M = M_0 + \Delta M d \quad \text{.................... (2)}$$

Where depth, *d*, is the difference between total ambient pressure, *P*, and surface pressure, P_0,

$$d = P - P_0 \quad \text{.................... (3)}$$

Corresponding permissible gradients, *G*, then satisfy,

$$G = \Pi - P \le M - P = (M_0 - \Delta M P_0) + (M - 1)P \quad \text{.................... (4)}$$

With P_0 ambient pressure at the surface as noted,

$$P_0 = 33 exp(-0.038h) \quad \text{.................... (5)}$$

For elevation, *h*, in multiples of 1000 *f t*.

ZHL Model [15]: The Buhlmann ZHL approach was tested at low altitude and is similar to the Workman USN approach, that is, the permissible gas tension Π (nitrogen plus helium again), is limited by fit parameters, *a* and *b*, lumped in Table 2,

$$\Pi \le Z \quad \text{.................... (6)}$$

with critical tensions, *Z*, given by,

$$Z = a + \frac{P}{b} = a + \frac{P_0 + d}{b} = Z_0 + \Delta Z d \quad \text{.................... (7)}$$

with,

$$Z_0 = a + \frac{P_0}{b} \quad \text{.................... (8)}$$

$$\Delta Z = \frac{1}{b} \quad \text{.................... (9)}$$

Accordingly, we have,

$$G = \Pi - P \le a + \left[\frac{1}{b} - 1\right]\left(P_0 + d\right) \quad \text{.................... (10)}$$

For constants, *a* and *b* defining *Z* at sea level $(P_0 = 33 fsw)$ in Table 2. The expressions put the ZHL Z-value model in the same computational framework as the USN M-value model

Table 1: Workman USN M-Values.

Nitrogen			Helium		
τ_{N_2} (min)	M_0 (*fsw*)	ΔM	τ_{He} (min)	M_0 (*fsw*)	ΔM
5	104	1.8	5	86	1.5
10	88	1.6	10	74	1.4
20	72	1.5	20	66	1.3
40	56	1.4	40	60	1.2
80	54	1.3	80	56	1.2
120	52	1.2	120	54	1.2
160	51	1.1	160	54	1.1
200	51	1.1	200	53	1
240	50	1.1	240	53	1

Table 2: Buhlmann Swiss Z-Values.

Nitrogen			Helium		
τ_{N_2} (min)	Z_0 = a + 33/b (*fsw*)	ΔZ = 1/b	τ_{He} (min)	Z_0 = a + 33/b (*fsw*)	ΔZ = 1/b
4	106.2	1.91	1.5	134.5	2.36
8	83.2	1.54	3	102.4	1.74
12.5	73.8	1.39	4.7	89.4	1.53
18.5	66.8	1.28	7	79.8	1.38
27	62.3	1.23	10.2	73.6	1.32
38.3	58.4	1.19	14.5	68.2	1.25
54.3	55.2	1.15	20.6	63.7	1.21
77.1	52.3	1.12	29	59.7	1.17
109.2	49.8	1.09	41.1	57.1	1.14
146	48.2	1.08	55.2	55.1	1.12
187	46.8	1.07	70.7	54	1.11
239	45.6	1.06	90.3	53.3	1.1
305	44.5	1.05	115.3	53.1	1.09
390	43.5	1.04	147.4	52.8	1.09
498	42.6	1.04	188.2	52.6	1.08
635	41.8	1.03	240	52.3	1.07

Bubble models

In similar fashion, BM algorithms are used across recreational and technical diving on both OC and RB systems. Staging starts in the deep zone and continues into the shallow zone (deep stops). Ascent rates are also 30 *fsw/min*. Bubbles are assumed using realistic properties and exponential distributions in size but have never been really measured in humans. The phase volume limit point, Φ, is also deduced and fitted from diver exposure profiles using data from the LANL Data Bank within statistical correlations of bubble model and exposure data. Testing is nowhere near as extensive as dissolved gas approaches but is growing. The model

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relies on correlations with actual mixed gas diving across OC and RB, deep and decompression diving on arbitrary breathing mixtures. Application and use is growing, particularly in the technical diving sector, over the past 20-25 years with new computers implementing bubble models. In particular, the VPM [16] and RGBM [17] models are noteworthy and used extensively within recreational and technical diving sectors and follow:

Varying permeability model [16]: The tissue compartments in the Yount VPM for nitrogen consist of the set,

$$\tau_{N_2} = (1,2,5,10,20,40,80,120,160,240,320,400,480,560,720)\,min$$

With the helium compartments scaling,

$$\tau_{He} = \frac{\tau_{N_2}}{3} \quad \text{.................... (11)}$$

The VPM model links to bubble experiments in gels and related strata. In gel experiments, Yount divided gas diffusion across bubble interfaces into permeable and impermeable regions. For dive applications, the regions separate around 165 *fsw*. Bubbles of nitrogen and helium are excited into growth by pressure changes during the dive from some minimum excitation radius, ε, in the 0.5μm range, with nitrogen bubbles slightly larger than helium bubbles and the excitation radius decreasing with increasing absolute pressure, *P*. The excitation radius separates growing from shrinking bubbles. The radial bubble distribution, *n*, in the VPM is given by,

$$n = n_0 exp(-\beta r) \quad \text{.................... (12)}$$

with n_0 an experimental normalization factor for gel sample size and β on the order of $\frac{1}{\varepsilon}$ μm^{-1} for diving applications. The staging protocol in the VPM limits the permissible super saturation, G to prevent bubble growth on ascent,

$$G = \Pi - P \le \frac{\gamma}{\gamma_c}\left[\frac{2\gamma_c}{å} - \frac{2\gamma}{å_0}\right] \quad \text{.................... (13)}$$

with γ the usual bubble surface tension and γ_c the crushing bubble surface tension, roughly 20 dyne/cm and 150 dyne/cm respectively. The radius, ε_0, is an experimental metric, somewhere near 0.7μm. For diving, VPM ascents are limited by *G* at each stage in the decompression and staging profiles are iterated to convergence across all stops.

Reduced gradient bubble model [17]: Nitrogen tissue compartments in the Wienke RGBM range,

$$\hat{o}_{N_2} = (2,5,10,20,40,80,120,160,200,240,300)\,min$$

With helium compartments,

$$\tau_{He} = \frac{\tau_{N_2}}{2.65} \quad \text{.................... (14)}$$

Using the ratio of the square root of atomic weights as the scaling factor. The bubble dynamical protocol in the RGBM model amounts to staging on the seed number averaged, free-dissolved gradient across all tissue compartments, *G*, for, *P*, permissible ambient pressure, Π, total inert gas tissue tension, *n*, excited bubble distribution in radius (exponential), γ, bubble surface tension and, *r*, bubble radius,

$$G\int_{\varepsilon}^{\infty} ndr = (\Pi - P)\int_{\varepsilon}^{\infty} ndr \le \int_{\varepsilon}^{\infty}\left[\frac{2\gamma}{r}\right]ndr \quad \text{.................... (15)}$$

So that,

$$G = (\Pi - P) \le \beta exp(\beta\varepsilon)\int_{\varepsilon}^{\infty} exp(-\beta r)\left[\frac{2\gamma}{r}\right]dr \quad \text{.................... (16)}$$

For ε the excitation radius at *P*. Time spent at each stop is iteratively calculated so that the total separated phase, Φ, is maintained at, or below, its limit point. This requires some computing power but is attainable in diver wrist computers presently marketed with the same said for the VPM. The USN and ZHL models are less complex for computer implementation. The limit point to phase separation, Φ, is near 600μm³ and the distribution scaling length, β, is close to 0.60 μm^{-1} for both nitrogen and helium. Both excitation radii, ε, and surface tension, γ, are functions of ambient pressure and temperature and not constant. The equation-of-state (EOS) assigned to the bubble surface renders the surface tension below lipid estimates, on the order of 20dyne/cm, and excitation radii are below 1 μm.

These well known USN, ZHL, VPM and RGBM algorithms implemented across a majority of marketed and tested dive computers have seen widespread and safe usage over many years with GM computers around since the 1970s and BM computers more recent and gaining in popularity since the 1990s especially in the technical diving community. With extensive computer implementations and safe utilization record without noted neither DCS nor oxtox spikes and staging issues, they can be considered user validated across nominal recreational and technical diving. It is also reasonable to assume they can and will be safely modified to accommodate diving *beyond the envelope* in the future. None presently support risk estimation.

By way of aside, USN, ZHL, VPM and RGBM models and protocols were comparatively correlated with profiles in the LANL DB using maximum likelihood techniques as mentioned and published [20]. Nominal model and user parameters were used in calculations, representative of values used in decompression meters, dive tables and dive planning software. Correlation functions were the model constrained permissible supersaturations at each point on the dive. Dissolved gas models admit greater supersaturations than bubble models to also be seen in following EOD and OTF applications. Statistically, outcomes of DCS *hit* or *no-hit* were used as endpoints for correlations. Other endpoints employed include Doppler bubble counts and various imaging metrics. All have their merits and the latter collect different information. Correlation of the USN and ZHL models in χ^2 fit metrics yielded,

$$\text{USN} - \chi^2 = 0.081$$

$$\text{ZHL16} - \chi^2 = 0.131$$

And correlation of the VPM and RGBM models had χ^2 fit metrics,

$$\text{VPM} - \chi^2 = 0.717$$

$$\text{RGBM} - \chi^2 = 0.861$$

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Such was to be expected in various quarters and so that analysis both affirmed and quantified those speculations. While the correlation of VPM and RGBM with deep stop data is expected to be high, the correlation of USN and ZHL was surprisingly higher than expected. Perhaps then the optimal approach to safe diving is a model somewhere between the extremes of each. That is just speculation of course.

Oxygen toxicity (OT)

Both pulmonary and CNS toxicity are tracked by both GM and BM dive computers in a relatively simple way [4,6]. Pulmonary toxicity is tracked with a dose-time estimator, Γ , written,

$$\Gamma = \sum_{n} \left[\frac{ppo_2 - 0.5}{0.5} \right]_n^{0.83} t_n \le 750 \min \text{ .... (17)}$$

With, ppo_2 , oxygen tension (atm) and, t, exposure time (min). Dive segments, n, are tallied every 5-10sec and Γ updated. Central nervous system toxicity is similarly tallied over dive segments, n, by a CNS clock, Ω , using the oxygen limit points, to_2, for exposure to oxygen partial pressure, ppo_2 (atm), for time, t (min),

$$\Omega = \sum_{n} \left[\frac{t}{to_2} \right]_n \le 1 \text{ .... (18)}$$

With approximate CNS oxygen time limits (min),

$$to_2 = 4140 exp(-2.7 ppo_2) min \text{ .... (19)}$$

In both cases, violations of OT limit points result in dive computer warnings. Variations in tested oxygen limit points are greater than variations in tested nonstop limits in air and nitrox exposures. This is probably a reason why technical divers often exceed CNS oxtox clock limits by large amounts in the 2-3 range from some reports. With further testing in the future, one might reasonably expect some tuning of the oxtox dose-time relationships. Without noted oxygen toxicity problems in computer users of the above oxygen dose-time relationships, the present oxtox model seems safe and user validated across popular GM and BM computers on the whole. Reports of oxygen toxicity in divers are fewer and far more between than DCS reports [3,11].

Dive Computer Profile Data

To validate computer models [6,7,18], diving data is necessary. In the past, data consisted mostly of scattered Open Ocean and dry chamber tests of specific dive schedules. In such instances, the business of correlating model and diving data was only scratched. Today, profile collection across diving sectors is proceeding more rapidly. Notable are the efforts [1,4] of Divers Alert Network (DAN) and Los Alamos National Laboratory (LANL). DAN USA is collecting profiles in an effort called Project Dive Exploration (PDE) here and DAN Europe has a parallel effort called Diving Safety Laboratory (DSL). The DAN focus has been recreational dive profiles for air and nitrox. The LANL Data Bank collects profiles from technical dive operations on mixed gases for deep and decompression diving on OC and RB systems. Profile collection efforts such as these can enormously benefit divers and diving science. Without downloadable profile data from dive computers, meaningful algorithm and protocol analysis is very difficult. Profile data banks are important resources for all kinds of diving.

Profile data collection is an ongoing effort and profile information can be narrowed down to its simplest form coming from dive computer downloads tagging information across variable time intervals (5-10 sec) which is then processed into a more manageable format for statistical analysis:

i. Bottom mix/ppo_2, depth and time

ii. Ascent and descent rates

iii. Stage and decompression mix/ppo_2, depths and times

iv. Surface intervals

v. Time to fly

vi. Diver age, weight, sex and health complications

vii. Outcome rated 1-5 in order of bad to good

viii. Environmental factors (temperature, current, visibility, equipment)

LANL DB

Some 3569 profiles now reside in the LANL DB. There are 28 cases of DCS in the data file. The underlying DCS incidence rate is, p=28/3569= 0.0078, below but near 1%. Stored profiles range from 150 *fsw* down to 840 *fsw*, with the majority above 350 *fsw*. All data enters through the Authors, that is, divers, profiles and outcomes are filtered. The following summary breakdown of DCS hit (bends) updates our earlier reporting and data consists of the following:

i. OC deep nitrox reverse profiles - 5 hits (3 DCS I, 2 DCS II)

ii. OC deep nitrox- 3 hits (2 DCS I, 1 DCS II)

iii. OC deep trimix reverse profiles- 2 hits (1 DCS II, 1 DCS III)

iv. OC deep trimix- 4 hits (3 DCS I, 1 DCS III)

v. OC deep heliox- 2 hits (2 DCS II)

vi. RB deep nitrox- 4 hits (2 DCS I, 2 DCS II)

vii. RB deep trimix- 4 hits (3 DCS I, 1 DCS III)

viii. RB deep heliox- 4 hits (3 DCS I, 1 DCS II)

DCS I means limb bends, DCS II implies central nervous system (CNS) bends, and DCS III denotes inner ear bends (occurring mainly on helium mixtures). Both DCS II and DCS III are fairly serious afflictions while DCS I is less traumatic. Deep nitrox means a range beyond 150 *fsw*, deep trimix means a range beyond 200 *fsw* and deep heliox means a range beyond 250 *fsw* as a rough categorization. The abbreviation OC denotes open circuit while RB denotes re-breather. Reverse profiles are any sequence of dives in which the present dive is deeper than the previous dive. Nitrox means an oxygen enriched nitrogen mixture (including air), trimix denotes a breathing mixture of nitrogen, helium, oxygen and heliox is a breathing mixture of helium and oxygen. None of the trimix nor heliox cases involved oxygen enriched mixtures on OC and RB hits did not involve elevated oxygen partial pressures above 1.4atm. Nitrogen to helium (*heavy-to-light*) gas switches occurred in 4 cases, violating contemporary ICD (isobaric counter

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diffusion) protocols. Isobaric counter diffusion refers to two inert gases (usually nitrogen and helium) moving in opposite directions in tissues and blood. When summed, total gas tensions (partial pressures) can lead to increased supersaturation and bubble formation probability.

None of the set exhibited pulmonary (full body) nor CNS (central nervous system) oxygen toxicity (*oxtox*). The 28 cases come after the fact that is diver distress with hyperbaric chamber treatment following distress. Profiles originate with seasoned divers as well as from broader field testing reported to us, coming from divers using wrist slate decompression tables with computer backups. Most profiles reach us directly as computer downloads, which we translate to a requisite format for further code processing. Approximately 88% of all LANL DB entries emanate from computer downloads (3569 profiles) and the rest are controlled C & C Team staging tests performed in the 1980s (491 test profiles). The latter are not used in this analysis.

The data is relatively coarse grained making compact statistics difficult. The incidence rate across the whole set is small, on the order of 1% and smaller. Fine graining into depths will be useful in the following but first breakout of data into gas categories (nitrox, heliox, trimix) is repeated as tabulated earlier. Table 3 indicates the breakdown.

In the above set, there are 49 *marginals*, that is, DCS was not diagnosed but the diver surfaced feeling badly. In such cases, many do not weight the dive as a DCS hit. Others might weight the dive 1/2. The corresponding depth-DCS hit summary for Table 3 follows in Table 4.

Profile data in the above Table 3 & 4 were used for model validations in the past and will also be employed in parameterizing risk estimators for dive computers and associated diveware in the following section.

Table 3: Profile Gas-DCS Summary.

Mix	Total Profiles	DCS Hits	Incidence
OC nitrox	459	8	0.0174
RB nitrox	665	4	0.006
all nitrox	1124	12	0.0107
OC trimix	771	6	0.0078
RB trimix	869	4	0.0046
all trimix	1640	10	0.0061
OC heliox	166	2	0.012
RB heliox	639	4	0.0063
all heliox	805	6	0.0075
total	3569	28	0.0078

Risk Estimators

Risk estimation, on the fly (OTF) or end of dive (EOD), is not yet implemented in dive computers nor planning software as already mentioned. The following suggests appropriate methodology for implementation of both. As dive computers working in the recreational (air and nitrox) depth regime, $d < 130$ *fsw* roughly, use GM models for speed and simplicity and dive computers working in the technical (mixed gases and decompression) depth regime, $d > 130$ *fsw*, employ BM models, we will use GM risk functions in comparative applications for shallow recreational diving, $d < 130$ *fsw*, and BM risk functions in comparative applications for deep and decompression technical diving, $d > 130$ *fsw*.

End if Dive risk estimator (EOD)

In performing risk analysis with the LANL DB, the tissue gradient is useful. As detailed [4,6,8], the gradient is cast into normalized risk function, ρ, form,

$$\rho(\kappa,\omega,t) = \kappa\left[\frac{\Pi(t) - P(t)}{P(t)}\right] - \kappa exp(-\omega t) \quad \text{.................... (20)}$$

with $\Pi(t)$ and $P(t)$ total tissue tension and ambient pressure in time, *t*, respectively. Risk is quantified by the difference between total tissue tension and ambient pressure divided by ambient pressure summed over time. Risk increases with increasing tissue tension and decreasing ambient pressure and increasing time. The approach was used before for overall dive risk estimation [1,6,7]. An asymptotic exposure limit is used in the risk integrals, that is, *tmx*= 48 *hrs* after surfacing across all compartments, τ, in time, *t*,

$$1 - r(\kappa,\omega) = \left[-\int_0^{t_{mx}} \rho(\kappa,\omega,t)dt\right] \quad \text{.................... (21)}$$

with $r(\kappa,\omega)$ the usual cumulative risk after time, *t*. The first term in the risk function, ρ, links to dynamical supersaturation in the models while the second term is a smoothing function over dive time.

To estimate κ and ω within maximum likelihood (ML), a Weibull-Levenberg-Marquardt (WLM) [4] package was employed (SNLSE, Common Los Alamos Mathematical and Statistical Library [19]), a non linear least squares data fit (NLLS) to an arbitrary exponential function with a minimization of variance over 3569 data points and L2 error norm. The computational program is straightforward but massive. Across all tissue compartments, τ, the maximum value of the gradient is cumulated in the risk integral every 5-10 sec until surfacing and across all profiles. A resulting 3659 x 3659 matrix is stored for further manipulation, inversion and minimization. Across GM and BM algorithms (US Navy, ZHL, VPM, RGBM) and using Table 4, there then obtains a range for the fit, parameters [20],

$$\kappa = 0.698 \pm 0.283 min^{-1}$$
$$\omega = 0.810 \pm 0.240 min^{-1} \quad \text{.................... (22)}$$

While EOD risk estimators are important for general analysis of diving protocols and staging regimens, EOD risk estimators are obviously not helpful to divers during a dive. The EOD risk estimates extend out to 2hrs (t_{mx}) after the dive. Some important EOD risk estimates do follow though [6,21,22] for select profiles and staging for completeness. Risk estimators are denoted, r_{GM} and r_{BM} to distinguish algorithms. For numerics the ZHL or USN

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and RGBM or VPM models were used comparatively but results are trend wise generic for GM and BM classes of algorithms. In the following depth, *d* = 130 *fsw*, separates GM and BM applications. Some 3659 EOD risk estimators generated from the LANL DB serve as surfacing bootstraps for OTF risk estimators in the next section. The 3659 EOD risks are equated to surfacing 3659 OTF risk estimators using standard NLLS techniques to scale the OTF estimators.

Table 4: Profile Gas-Depth DCS Summary.

	100 to 200 fsw	200 to 250 fsw	250 to 300 fsw	300 to 350 fsw	350 to 400 fsw	400+ fsw	Total
OC nitrox	5	3					8
RB nitrox		2	2				4
OC trimix		2	2	1		1	6
RB trimix		2	1	1			4
OC heliox			2				2
RB heliox		1	2	1			4
total	5	10	9	3		1	28

Test profiles and EOD risk

Following examples are taken from the LANL DB and have been discussed and published earlier [4,22] with regards to models, staging comparisons, deep and shallow stops, tests and data.

Deep OC trimix dive: Consider a deep trimix dive with multiple gas switches on the way up. This is a risky technical dive performed by seasoned professionals. Table 5 contrasts stop times for two gas choices at the 100 *fsw* switch. The dive is a short 10 min at 400 *fsw* on TMX 10/65 with switches at 235 *fsw*, 100 *fsw* and 30 *fsw*. Descent and ascent rates are 75 *fsw/min* and 25 *fsw/min*. Obviously, there are many other choices for switch depths, mixtures and strategies. In this comparison, oxygen fractions were constant in all mixes at all switches. Differences between nitrogen and helium based decompression strategy, even for this short exposure, are nominal. Such usually is the case when oxygen fraction is held constant in helium or nitrogen mixes at the switch.

Table 5: Comparative Helium and Nitrogen Gas Switches and Risk.

Depth (fsw)	Time (min)	Time (min)
	TMX 10/65	**TMX 10/65**
400	10	10
260	1.5	1.5
250	1	1
240	1	1
	TMX 18/50	**TMX 18/50**
230	0.5	0.5
220	0.5	0.5
210	0.5	0.5
200	0.5	0.5
190	1	1
180	1.5	1.5
170	1.5	1
160	1.5	1.5
150	1.5	2
140	2	1.5
130	2	2.5
120	4	4
110	4.5	4
	TMX 40/20	**EAN40**
100	2.5	2
90	2.5	2
80	2.5	2
70	5	4
60	6.5	5.5
50	8	6.5
40	9.5	7.5
	EAN80	**EAN80**
30	10.5	10.5
20	14	14
10	21	20.5
run time	123	116
	r_{BM} = 6.42%	r_{BM} = 6.97%

Comparative and anecdotal diver reports suggest that riding helium to the 70 *fsw* level with a switch to EAN50 is a good strategy, one that couples the benefits of well being on helium with minimal decompression time and stress following isobaric switches to nitrogen. Shallower switches to enriched air also work with only a nominal increase in overall decompression time, but with deeper switches off helium to nitrox a source of isobaric counter diffusion (ICD) issues that might best be avoided. Note the risk, r_{BM}, for the helium strategy, TMX 40/20 at 100 *fsw*, is slightly safer than the nitrogen strategy, EAN40 at 100 *fsw*, but in either case the risk is high

The logistics of such deep dives on OC are formidable for both diver and support crew if any. The number of stage bottles (decompression tanks) is forbidding for a single diver, of course,

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but surface support teams, themselves at high risk for placing bottles on a line at depth, can effect such a dive. These support teams are vested with immense responsibility for diver safety.

Hydrospace EXPLORER extreme RB profile: Table 6 is a deep RB dive downloaded off the Hydrospace EXPLORER computer. From a number of corners reports of 400 *fsw* dives on re-breather systems are becoming commonplace. Consider this one to 444 *fsw* for 15 min. Diluent is TMX 10/85 and ppo_2 set point is 1.1 atm. From a decompression standpoint, re-breather systems are the quickest and most efficient systems for underwater activities. The higher the ppo_2, the shorter the overall decompression time. That advantage, however, needs to be played off against increasing risks of oxygen toxicity as oxygen partial pressures increase, especially above 1.4 atm. The higher percentage of oxygen and lower percentage of inert gases in higher ppo_2 set points of closed circuit re-breathers (CCRs) results in reduced risks simply because gas loadings and bubble couplings are less in magnitude and importance. This shows up in any set of RB comparative ppo_2 calculations as well as in OC versus RB risk estimates. Risk associated with this 444 *fsw* dive is less than a similar dive on trimix to roughly same depth for shorter time, that is, looking at Table 6. Certainly, this reduction relates to the higher oxygen fraction in RB systems.

Table 6: Extreme RB Dive and Risk.

Depth (fsw)	Time (min)	Depth (fsw)	Time (min)
444	15	150	2
290	0.5	140	2
280	0.5	130	2
270	0.5	120	2.5
260	0.5	110	3
250	0.5	100	3.5
240	0.5	90	4
230	1	80	4.5
220	1	70	5
210	1	60	7
200	1	50	7.5
190	1.5	40	8
180	1.5	30	12.5
170	1.5	20	14
160	1.5	10	15.5

While the above approach across all profiles using DCS outcomes is amenable to implementation in dive planning software with suitable computer processor speeds and storage resources (PCs Workstations, Mainframes, etc.), it is not always optimal in present generation underwater dive computers. They are more limited in computing speed and storage capabilities. Divers also want to know risks during a dive not just at the end. So a modified approach using the data in Table 3-5 is suggested using permissible supersaturation during the dive. Consider the following model risk estimators easily generated on the fly by present dive computers. Unlike the previous cumulative estimators these can be viewed underwater as the dive progresses.

On the fly risk estimator (OTF)

As DCS outcomes for excursions from any point on a dive to the surface or elsewhere above the diver are unknown the approach used for EOD risk is not portable directly to OTF risks. The foregoing does suggest another computational approach at any depth in terms of model limit points above the diver, specifically, critical gradients, *G* and *H*, for GM and BM models respectively. For GM risk, we have,

$$r(\alpha,\beta,\varepsilon,t) = \alpha exp\left[-\left(\frac{\Pi(t)-P(t)-G(t)}{P(t)}\right)\right] + \beta[1-exp(-\varepsilon t)] \quad \text{...... (23)}$$

with published permissible gradient, *G*, in the M-value picture (USN),

$$G = M - P \quad \text{.................... (24)}$$

and similarly published gradient, *G*, in the Z-value picture (ZHL),

$$G = Z - P \quad \text{.................... (25)}$$

Accordingly, for BM algorithms,

$$r(\alpha,\beta,\varepsilon,t) = \alpha exp\left[-\left(\frac{\Pi(t)-P(t)-H(t)}{P(t)}\right)\right] + \beta[1-exp(-\varepsilon t)] \quad \text{...... (26)}$$

One published permissible BM bubble-tissue gradient, *H*, is averaged over the bubble seed distribution (RGBM),

$$H = 2\gamma\zeta\int_{r_c}^{\infty}\frac{exp[-\zeta(r-r_c)]}{r}dr \quad \text{.................... (27)}$$

with surface tension, ζ, given by,

$$2\gamma = 44.7\left[\frac{P}{T}\right]^{1/4} + 24.3\left[\frac{T}{P}\right]^{1/2} dyne/cm \quad \text{........ (28)}$$

for *T* temperature (°*K*), *P* ambient pressure (*fsw*) and r_c critical radius (μm) for ζ a fitted constant (order 0.7 μm^{-1}) for the bubble distribution with nitrogen,

$$r_c = 0.007655 + 0.001654\left[\frac{T}{P}\right]^{1/3} + 0.041602\left[\frac{T}{P}\right]^{2/3} \quad \text{.................... (29)}$$

and for helium,

$$r_c = 0.003114 + 0.015731\left[\frac{T}{P}\right]^{1/3} + 0.025893\left[\frac{T}{P}\right]^{2/3} \quad \text{........... (30)}$$

Another published BM permissible bubble-tissue gradient, *H*, takes the gel form (VPM),

$$H = \frac{2\gamma(\gamma_c-\gamma)}{\gamma_c r_c} = \frac{11.01}{r_c}(fsw) \quad \text{.................... (31)}$$

for γ and γ_c film and surfactant surface tensions, that is, γ_c = 17.9 dyne/cm and γ_c = 257 dyne/cm with critical bubble radius r_c in μm given by,

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$$\frac{1}{r_c} - \frac{1}{r_i} = \frac{p - p_i}{2} \quad \text{.................... (32)}$$

with r_i = 0.6 μm at sea level, that is, P_i = 33 *fsw*. These BM permissible gradients range at 10-40 *fsw* roughly. These OTF functions are quantified by the difference between existing and permissible supersaturation divided by ambient pressure. Risk increases with increasing difference between existing and permissible supersaturation and decreasing anbient pressure. First terms are measures of permissible supersaturation differences and second terms are overall smoothing functions that increase with dive time, *t*. Similarly, we define the instantaneous risk function, *r*, for ascents above the diver to arbitrary depths with critical parameters, *G* and *H*, and its complement, ρ ,

$$\rho(\alpha,\beta,\varepsilon,t) = 1 - r(\alpha,\beta,\varepsilon,t) \quad \text{.................... (33)}$$

as OTF risk estimators depending on instantaneous depth, *d*, final ascent level, d_0, bottom time, t_b, and dive run time, *t*. In analogy with the EOD compilation, the maximum value of the risk function across all tissue compartments, τ , is tallied and used. This occurs with the (ascent) controlling tissue compartment with shortest nonstop bottom time or maximal level decompression stop time. As data for OTF risk estimation does not exist, we use an extrapolation scheme that fits the OTF risk estimator close to the surface to the EOD risk estimator for all the profiles in the LANL DB using standard NLLS software. This is a task requiring LANL supercomputers with teraflop speeds (10^{12} floating point operations per second) and fast access mass storage accommodating a 3569 x 3569 matrix for NLLS inversion. What this amounts to is fitting the OTF risk function at the end of the decompression stop or NDL for nonstop diving to the EOD risk estimator at time, t_{mx}, across all 3569 profiles, that is,

$$r(\alpha,\beta,\varepsilon,t_{mx}) = r(\kappa,\omega,t_{mx}) \quad \text{.................... (34)}$$

with EOD risk estimation computed for each profile using,

$$\begin{aligned} \kappa &= 0.698 \\ \omega &= 0.810 \end{aligned} \quad \text{.................... (35)}$$

and α, β and ε then extracted in the NLLS fit to $r(\kappa,\omega, t_{mx})$. The resulting OTF risk functions are then used to estimate OTF risks at any point, d_0, above the diver with the surfacing case, d_0= 0, the focus here. Obviously, for points above the diver but below the surface, risk decreases compared to surfacing risk. For GM algorithms, we obtain using the ZHL critical gradient, *G*,

$$\begin{aligned} \alpha &= 0.350 + 0.00125(d - d_0) \pm 0.081 \\ \beta &= 0.025 \pm 0.004 \\ \varepsilon &= 1/t_b \pm 0.106 min^{-1} \end{aligned} \quad \text{.................... (36)}$$

For BM algorithms we find employing the RGBM seed averaged permissible supersaturation, *H*,

$$\begin{aligned} \alpha &= 0.550 + 0.00118(d - d_0) \pm 0.053 \\ \beta &= 0.022 \pm 0.005 \\ \varepsilon &= 1/t_b \pm 0.079 min^{-1} \end{aligned} \quad \text{.................... (37)}$$

The critical parameters, *G* and *H* (permissible tissue and bubble supersaturation gradients) are evaluated at the ascent point (d_0). Possible tissue out gassing and bubble growth during the ascent are included in the analyses assuming an ascent rate of 30 *fsw/min*. In GM staging, tissues outgas during ascent, reducing tissue tensions and risk. In BM staging, bubbles grow on ascent when not controlled by stops and risk increases. For surfacing ascents from any point on the dive, d_0 = 0. The risk for GM algorithms increases as the difference between actual tissue tension and critical tension at any point on the dive increases. For BM algorithms, risk increases as the difference between actual supersaturation and permissible bubble supersaturation increases.

In gassing and out gassing during descent sand ascents are incorporated easily into the tissue equations by assuming ambient pressure, p_a, is changing in time. For assumed linear ascent rate, *v*, we have,

$$p_a = p_0 - vt \quad \text{.................... (38)}$$

with speed, *v*, positive for descents and negative for ascents (convention). The corresponding tissue equation becomes,

$$\frac{\partial p}{\partial t} = -\lambda\left(p - p_0 + vt\right) \quad \text{.................... (39)}$$

with straightforward solution , $p = p_i$, at, t = 0,

$$p = p_0 + \left(p_i - p_0 + \frac{v}{\lambda}\right) exp(-\lambda t) - vt - \frac{v}{\lambda} \quad \text{.................... (40)}$$

At initial time, *t* = 0, or stationary diver, *v* = 0, the equation reduces to the usual form. For long ascents or descents, tissue loadings become important and changes in gas tensions, *p*, need be included in calculations of risk for helium and nitrogen separately, If omitted on descent tissue tensions are smaller and if omitted on ascent tissue tensions are larger than estimated with the static equation. Effects are seen in both GM and BM algorithms. For GM algorithms changes in gas loadings with ascent are fairly simple as seen above. For BM algorithms the situation is more complex in that changes in gas loadings on ascent affect gas diffusion across bubble interfaces with bubble behavior additionally becoming a matter of surface tension and bubble size. In the following, gas loadings and bubble changes are tracked during ascents and descents.

On the fly risk estimates for various trimix, nitrox and heliox dives follow. OTF surfacing risks at the end of the decompression stop time or NDL are tabulated using $r(\alpha,\beta,\varepsilon)$ as defined.

Test profiles and OTF risk

As with EOD profiles, the following examples are taken from the LANL DB having been discussed and published earlier [4,18,22] with regards to models, staging comparisons, deep and shallow stops, tests and data.

Recreational nonstop air diving: Many hundreds of air dives were analyzed by the USN permitting construction of decompression schedules with 95% and 99% confidence (5% and 1% bends probability). These tables were published by USN investigators [1,7] and Table 7 tabulates the corresponding nonstop time limits (σ=0.05,0.01) and also includes the old USN (Workman) limits for comparison in the fourth column. They date back to the 1950s. Later re-evaluations of the standard set of nonstop time limits estimate a probability rate of 1.25% for the limits. In actual usage, the incidence rates are below 0.01% because users do not dive to the limits generally. In the last column are listed risk estimates, r_{GM}, for the 1% DCS probability

USN limits, σ = 0.01, using on the fly estimators. Again, $d_0 = 0$ in the nonstop case for the conservative NDLs. The GM risk estimates in the last column include out gassing during ascent with ascent rate of 30 *fsw/min* and in gassing during descent with descent rate of 60 *fsw/min*.

It is clear in Table 7 that the USN 1% and corresponding on the fly risks, r_{GM} and r_{BM}, are very close. Both GM and BM risks in Table 7 are, however, slightly larger and so more conservative in dive computer and diveware applications. As noted before, GM and BM algorithms overlap in the nonstop diving limit because phase separation is minimal in BM algorithms [6,20]. Over nonstop air diving to recreational limits, we have across the ZHL,

$$1.60\% \le r_{GM} \le 2.08\%$$

with for the RGBM,

$$r_{BM} \le r_{GM}$$

Table 7: Nonstop Air Limits and Risk.

Depth d(fsw)	Nonstop Limit t_n(min) σ = 0.05	Nonstop Limit t_n(min) σ = 0.01	Nonstop Limit t_n(min) USN	Risk r_{GM}	Risk r_{BM}
30	240	170		0.016	0.016
40	170	100	200	0.0162	0.0161
50	120	70	100	0.0166	0.0163
60	80	40	60	0.0166	0.0165
70	80	25	50	0.0177	0.0169
80	60	15	40	0.0174	0.0173
90	50	10	30	0.0179	0.0178
100	50	8	25	0.019	0.0184
110	40	6	20	0.0199	0.0192
120	40	5	15	0.0204	0.0196
130	30	4	10	0.0208	0.02

for USN corresponding 1% risk. The decrease in nonstop time limits as risk drops into the 1% range is interesting compared to early USN compilations (Workman). This was run with GAP and CCPlanner.

Deep trimix OC dive: The following is a deep TMX 16/46 dive with helium-oxygen mirroring and constant nitrogen gas fraction on all ascent switches, that is, $f_{N_2} = 0.38$ until a final switch to EAH80 at 20*fsw*. The switches are TMX 18/44 at 220 *fsw*, TMX 20/42 at 140 *fsw*, TMX 22/40 at 80 *fsw* and EAH80 at 20 *fsw*. This is an optimal strategy on many counts. Table 8 lists pertinent dive variables and corresponding on the fly risks for immediate (emergency) surfacing ascent at any of the stops. The variable *psat* is the permissible supersaturation. Other entries are self explanatory. This and following examples were tabulated using CCPlanner with nominal parameter settings corresponding to settings in meters and software.

Table 8: Deep Trimix OC Dive and Risk.

Depth (fsw)	Wait (min)	Tissue (min)	Tension (fsw)	psat (fsw)	ppo_2 (atm)	Risk r_{RGBM}
300	15	3.3	274.5	30.7	1.6	0.407
190	0.5	3.3	205.5	32.3	1.2	0.33
180	0.5	5.3	202.3	33.3	1.2	0.32
170	1	5.3	189.4	33.3	1.1	0.308
160	1	5.3	182	33.3	1.1	0.236
150	1	5.3	170.6	33.3	1	0.2
140	1	8.2	162.6	34.3	1	0.197
130	1.5	8.2	151.7	34.1	1	0.195
120	1.5	8.2	141.7	34.1	0.9	0.193
110	1.5	12.2	134.1	34.9	0.9	0.189
100	2.5	12.2	123.7	34.9	0.8	0.184
90	2.5	12.2	114.1	34.9	0.7	0.179
80	3	17.8	105.1	35.5	0.8	0.17

70	4	17.8	94.9	35.5	0.7	0.16
60	4.5	25.3	85.6	35.9	0.6	0.147
50	6.5	25.3	75.4	35.9	0.6	0.132
40	7.5	35.9	66.1	36.2	0.5	0.112
30	10.5	35.9	56	36.2	0.4	0.087
20	8.5	50.8	46.2	36.3	1.3	0.051
10	12.5	72	36.3	36.4	1	0.031
	101.5					

Shallow nitrox OC dive: A decompression dive on EAN32 without any gas switches is analyzed in Table 9. The profile is EAN32 at 100 *fsw* for 65 min. Entries are the same as Table 8. The OTU and CNS entries are the full body and CNS cumulations at each level. Decompression profile and surfacing risks are listed.

Heliox RB dive: The last on the fly risk example is a pure heliox CCR dive to 344 *fsw* for 15 min with three set point changes on the way up. The diluent is heliox 21/79. Set points are 1.0atm at the bottom, 1.1atm at 200 *fsw*, 1.2atm at 100 *fsw* and 1.3atm at 30 *fsw*. Table 10 gives the decompression profile with risks for surfacing from stops.

Table 9: Shallow Nitrox OC Dive and Risk.

Depth (fsw)	Wait (min)	Tissue (min)	Tension (fsw)	psat (fsw)	ppo_2 (atm)	OTU (min)	CNS (%)	Gas (ft^3)	Risk r_{GM}
100	65	18.5	89.4	49.1	1.3	95	0.42	200	0.173
20	5.5	27.1	43.5	43	0.5	0.3	0	7	0.067
10	24	54.4	23.9	32.9	0.4	0	0	23	0.019
	99.5					95.3	0.42	230	

Table 10: Heliox RB Dive and Risk.

Depth (fsw)	Wait (min)	Tissue (min)	Tension (fsw)	psat (fsw)	ppo_2	OTU (min)	CNS (%)	Risk r_{BM}
344	15	1.9	344.1	43.6	1	15	0.04	0.206
240	0.5	3	269.8	43.9	1.1	0.6	0	0.183
230	0.5	4.7	260.5	43.4	1.1	0.6	0	0.184
220	0.5	4.7	252.4	43.4	1.1	0.6	0	0.182
210	1	4.7	239.2	43.4	1.1	1.2	0	0.178
200	1	4.7	230.8	43.4	1.2	1.3	0.01	0.176
190	1	7	222.8	43.1	1.2	1.3	0.01	0.177
180	1.5	7	210.1	43.1	1.2	2	0.01	0.172
170	1.5	7	201	43.1	1.2	2	0.01	0.17
160	1.5	7	191.8	43.1	1.2	2	0.01	0.167
150	1.5	10.2	182.6	42.8	1.2	2	0.01	0.165
140	2	10.2	171.6	42.8	1.2	2.6	0.01	0.16
130	2	10.2	160.7	42.6	1.2	2.6	0.01	0.156
120	1.5	10.2	152.1	42.6	1.2	2	0.01	0.152
110	2.5	14.5	141.3	42.4	1.2	3.3	0.01	0.147
100	2.5	14.5	131.6	42.4	1.3	3.7	0.02	0.141
90	2.5	14.5	121.9	42.4	1.3	3.7	0.02	0.134
80	3	20.5	111.9	42.2	1.3	4.4	0.02	0.127
70	4	20.5	101.6	42.2	1.3	5.9	0.03	0.116
60	4	20.5	91.2	42.1	1.3	5.9	0.03	0.103
50	5	29.1	81.4	42	1.3	7.4	0.03	0.09

40	5.5	29.1	71.6	41.9	1.3	8.1	0.04	0.074
30	6.5	41.2	61.6	41.7	1.3	9.6	0.04	0.053
20	8.5	41.2	51.2	41.6	1.3	12.6	0.06	0.041
10	10	55.2	41.3	41.4	1.3	14.8	0.07	0.033
	102.2					115.1	0.47	

Overall risks for the deep heliox CCR dive are smaller than corresponding risks for OC dives to the same depths. The higher oxygen and lower helium gas fractions in the breathing loop lower risk as requisite. Both tissue tensions and bubbles remain smaller. Said another way, RB diving is safer for given depth and time.

Recap

Methods were presented and quantified for estimating diver surfacing DCS risk from arbitrary points on a dive for both dissolved gas (GM) and bubble model (BM) computer and diveware implementations. Risk functions were defined and correlated with profiles in the LANL Data Bank. The EOD and OTF risk functions are exponential representations of differences between actual supersaturations and permissible supersaturations. Both nonstop and decompression examples were given and compared for OC and RB applications. In the ascent, out gassing and bubble impacts were included in model risk estimates. Methodology is easily encoded into modern GM and BM dive computers and dive planning software within existing coding. Major players in the dive computer business include Suunto, Mares, Cochrane, Atomic Aquatics, Sherwood, Shearwater, Uwatec, Cressisub, Oceanic, Aeris, UTC, Ratio and new ones coming online in Japan, South Korea and China. Diveware purveyors include Abyss, ProPlanner, VPlanner, GAP, DecoPlanner, RGBM Simulator, Analyst, Free Phase RGBM Simulator, DiveLogger, DiveSim and CCPlanner to name a few. Hope this paper helps in the implementation of both EOD and OTF risk estimation in modern dive computers and coupled diveware. Risk assessment for arbitrary underwater exposures in recreational and technical diving is needed for diver safety and sensible dive planning.

Biosketch

Bruce Wienke is a Program Manager in the Weapons Technology/Simulation Office at LANL. He received a BS in physics and mathematics (Northern Michigan), MS in nuclear physics (Marquette) and a PhD in particle physics (Northwestern). He has authored 250+ articles in peer reviewed journals, media outlets, trade magazines, workshop proceedings and has published 12 books on diving science, biophysics and decompression theory. He heads up the C & C Dive Team vested with worldwide underwater search, assessment and disablement of nuclear, chemical and biological WMDs. He is a Fellow of the APS, Technical Committee Member of the ANS, Member of the UHMS and serves as a Consultant to the EPA, DHS, ADA, US Military and Dive Industry. Bruce is an Editor/Reviewer for CBM, PR, TTSP, NSE, JQSRT and CEO of Southwest Enterprises Consulting. He is the developer of the Reduced Gradient Bubble Model (RGBM) implemented in decompression meters, tables and dive software worldwide. Bruce has dived all over the world on OC and RB systems in military, scientific, exploration, testing and training activities. He is a NAUI Tec/Rec Instructor Trainer and Course Director. Interests include USSA Masters ski racing, USTA Seniors tennis, golf and windsurfing. Bruce is a Certified Ski Instructor (PSIA) and Racing Coach (USSCA). He has won Masters National Titles in SL, GS, SG and DH and Quarterbacked the Northern Michigan Wildcats to a NCAA II Title in the Hickory Bowl.

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Conflict of Interest

Author Bruce Wienke has no conflicts of interest in publishing this paper.

Animal Disclaimer

Humans and animals were not used for testing in this paper. Certainly animals and humans were employed in cited references.

References

1. Brubakk AO, Neuman TS (2003) Physiology and Medicine of Diving. Saunders Publishing, London, UK.
2. Hills BA (1977) Decompression Sickness: The Biophysical Basis of Prevention and Treatment. Wiley and Sons Publishing, New York, USA, pp. 322.
3. Bove AA, Davis JC (2004) Diving Medicine. Saunders Publishing, Philadelphia, USA.
4. Wienke BR (2015) Science of Diving. CRC Press, Boca Raton, USA.
5. Joiner JJ (2001) NOAA Diving Manual: Diving for Science and Technology. Best Publishing, Flagstaff, USA.
6. Wienke BR (2016) Biophysics and Diving Decompression Phenomenology. Bentham Science Publsihers, Sharjah, UAE.
7. Schreiner HR, Hamilton RW (1989) Validation of Decompression Tables. Undersea and Hyperbaric Medical Society Workshop, UHMS Publication 74(VAL) 1-1-88, Washington DC, USA.
8. Wienke BR (2003) Basic Decompression Theory and Application. Best Publishing, San Pedro, USA, PP. 316.
9. Wienke BR, Graver DL (1991) High Altitude Diving. NAUI Technical Publication, Montclair, USA.
10. Blogg SL, Lang MA, Mollerlokken A (2011) Validation of Dive Computers Workshop. EUBS/NTNU Proceedings, Gdansk, Poland.
11. Lang MA, Hamilton RW (1989) Proceedings of the AAUS Dive Computer Workshop. University of Southern California Sea Grant Publication, USCSG-TR-01-89, Los Angeles, USA.

12. Vann RD, Dovenbarger J, Wachholz (1989) Decompression Sickness in Dive Computer and Table Use. DAN Newsletter 3-6.
13. Westerfield RD, Bennett PB, Mebane Y, Orr D (1994) Dive Computer Safety. Alert Diver Mar-Apr: 1-47.
14. Workman RD (1965) Calculation of decompression schedules for nitrogen--oxygen and helium- oxygen dives. Res Rep 6-65. Rep US Navy Exp Diving Unit 26: 1-33.
15. Buhlmann AA (1984) Decompression: Decompression Sickness. Springer-Verlag Publishing, Berlin, Germany.
16. Yount DE, Hoffman DC (1986) On the Use of a Bubble Formation Model to Calculate Diving Tables. Aviat Space Environ Med 57(2): 149-56.
17. Wienke BR (2003) Reduced Gradient Bubble Model in Depth. CRC Press, Boca Raton, USA.
18. Wienke BR (2010) Computer Validation and Statistical Correlations of a Modern Decompression Diving Algorithm. Comput Biol Med 40(3): 252-260.
19. Kahaner D, Moler C, Nash S (1989) Numerical Methods and Software: CLAMS. Prentice-Hall, Engelwood Cliffs, USA.
20. Wienke BR (2009) Diving Decompression Models and Bubble Metrics: modern Computer Syntheses. Comput Biol Med 39(4): 309-331.
21. Wienke BR (2015) Deep Stop Model Correlations. J Bioengineer & Biomedical Sci 5: 12-18.
22. Bennett PB, Wienke BR, Mitchell S (2008) Decompression and the Deep Stop Workshop. UHMS/NAVSEA Proceedings, Salt Lake City, USA.

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