A Simple Phenomenological Approach for Improving DCS Risk Predictions in Repetitive Diving

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THE PHENOMENOLOGICAL RISK COEFFICIENT EXPRESSION

In the probabilistic approach to DCS risk predictions,

$P(DCS) = 1 - \exp(R)$, where the integrated risk "R" is given by:

$R = \int r(t)dt$; $r(t) = C\Delta P(t)^2$, where the "gradient" "$\Delta P(t)$" is given by:

$$\Delta P(t) = P_B(t) - P_0(t).$$

The constant "C" (determined from calibration) is for a single non-repetitive dive.

There is anecdotal yet compelling evidence (Douglas and Milne, Br. Med. J, 1991; 302:1244) that "yo-yo" diving (which is common in commercial fish farming) entails a much greater DCS risk than what would be expected from the simple accumulation of dissolved inert gas on repetitive diving. It has been suggested that this elevated risk also arises (albeit to a lesser extent) in less extreme forms of yo-yo diving that sometimes arise in both recreational and in military diving.

DCS is believed to arise from the expansion of pre-existing endogenous inert gas bubbles in susceptible tissue(s).

A physical explanation for the extra risk, beyond that caused by increasing amounts of inert gas accumulation, is that with increasing numbers of compression/decompression cycles, the initial density of pre-existing bubbles in susceptible tissues is increased prior to a repetitive dive, beyond its long-time stable value that is relevant to a single dive. This causes an increase in the likelihood of incurring DCS, beyond that arising from excess inert gas accumulation alone.

Here this additional repetitive diving risk was built into the risk coefficient "C", by making "C" dependent on the number of repetitive dives and the length of the surface intervals. Accordingly, for repetitive dives we write:

$$R_n = \int r_n(t)dt; \qquad r_n(t) = C_n \Delta P(t)^2 .$$

The subscript "n" refers to the "n^{th}" repetitive dive in a series of dives.

"C_n" will be constructed so that it increases, relative to its previous value, "C_{n-1}", for each new repetitive dive. It also decreases by exponential decay during a surface interval. For an infinitely long surface interval it will decrease to its long-time stable value "C".

The following 2-parameter recursive expression is proposed as very simple and practical approximation for the risk coefficient "C_n" for the n^{th} repetitive dive:

$$C_n / C_1 = 1 + (C_{n-1}/C_1)\exp[-k(SI_{n-1} - SI_{crit})].$$

The term C_1 is the long-time stable value of C, which is determined, together with the kinetic parameters of the model, by calibration against single-dive data. C_{n-1} and SI_{n-1} are respectively, the value of the risk coefficient and the length of the surface interval for the $(n-1)^{th}$ dive.

Also "k" and "SI_{crit}" are two adjustable parameters determined by calibration against repetitive diving data. "k" is a rate constant that determines the rate at which C_n, the risk coefficient for repetitive dive "n", decays to the long-time stable value C_1 during a surface interval. "SI_{crit}" stands for the **critical surface interval**. For surface intervals greater than "SI_{crit}", the DCS risk rises slowly with increasing numbers of repetitive dives and for surface intervals less than "SI_{crit}", the DCS risk rises rapidly with increasing numbers of repetitive dives.

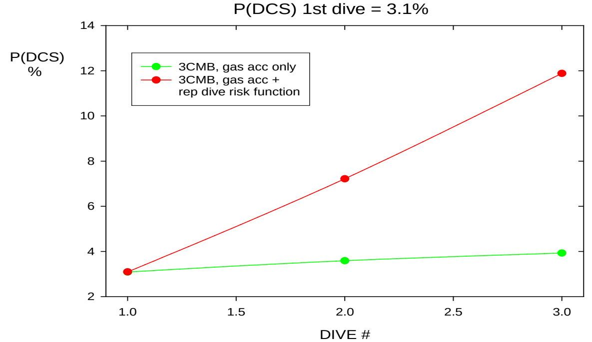
This repetitive dive risk coefficient was grafted on to the interconnected 3CMB model. The kinetic parameters "k" and "SI_{crit}" were determined by calibration against all the USN repetitive dive data for air that exists. Physically reasonable values were found for these parameters. Specifically it was determined from the calibration that:

$$k = .0297\ \text{min}^{-1}; \qquad SI_{crit} = 61.7\ \text{min}$$

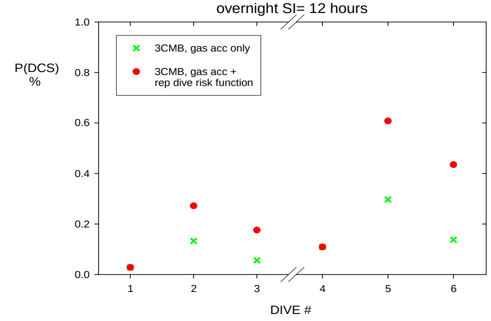
The value $SI_{crit} = 61.7$ min indicates that for surface intervals beyond about 1 hour, the additional DCS risk increases slowly with increasing numbers of repetitive dives, while for surface intervals less than about 1 hour, the additional DCS risk increases rapidly with increasing numbers of repetitive dives. The benefit of longer surface intervals will be illustrated in one of the figures. Considering the simplicity of this repetitive dive risk model, this value of the critical surface interval (about 1 hour) is remarkable for its consistency with diving experience.

Repetitive dive to 150 fsw
BT=5 min; SI=60 min, no-stop
D/A RATES=60fsw /min
(profile from Leitch & Barnard)

P(DCS) 1st dive = 3.1%

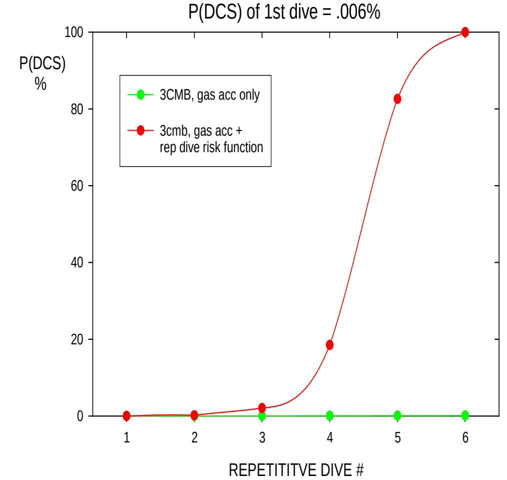


Risk in repetitive recreational diving over two days;
3 dives/day: 120 fsw, 10 min
80 fsw, 20 min
40 fsw, 60 min
ascent and descent rates = 60 fsw/min
stops at 15 fsw for 3 min; intra-day inter-dive SI= 60 min,
overnight SI= 12 hours



Repetitve dives to 60 fsw, BT= 4 min
no-stop, rate ascent/descent = 60fsw/min
all surface intervals 1 second. Profile is
roughly representitive of fish farming dives.

P(DCS) of 1st dive = .006%



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