Difference in Bubble Formation Using Deep Stops is Dependent on Bottom Time;

Experimental Findings and Theoretical Support

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Introduction

Deep decompression stops compared to more conventional shallower stops have recently been introduced in decompression. Most findings and theoretical work on excess gas phase models suggest an apparent advantage of using deeper stops. However, some reports indicate that the incidence and/or risk of decompression sickness (DCS) may actually increase following such procedures *(Blatteau et. al. 2005)*. The motivation behind this paper is to investigate the mechanisms behind these diverging results.

Deep stops

The idea behind deep stops are not really revolutionary. It is basically a comprehension of the fact that you need to stop during your ascent to reduce the risk of DCS. If a deco stop is considered a “deep stop” or a “conventional stop” is just a matter of depth definitions, a number. One extremity of a deep deco stop is to just extend your bottom time. The other extreme of a shallow stop is to go straight to the surface. Both cases will obviously promote more bubble growth. The optimal stop depth is somewhere in between and whether we call it a “deep stop” or not is not relevant.

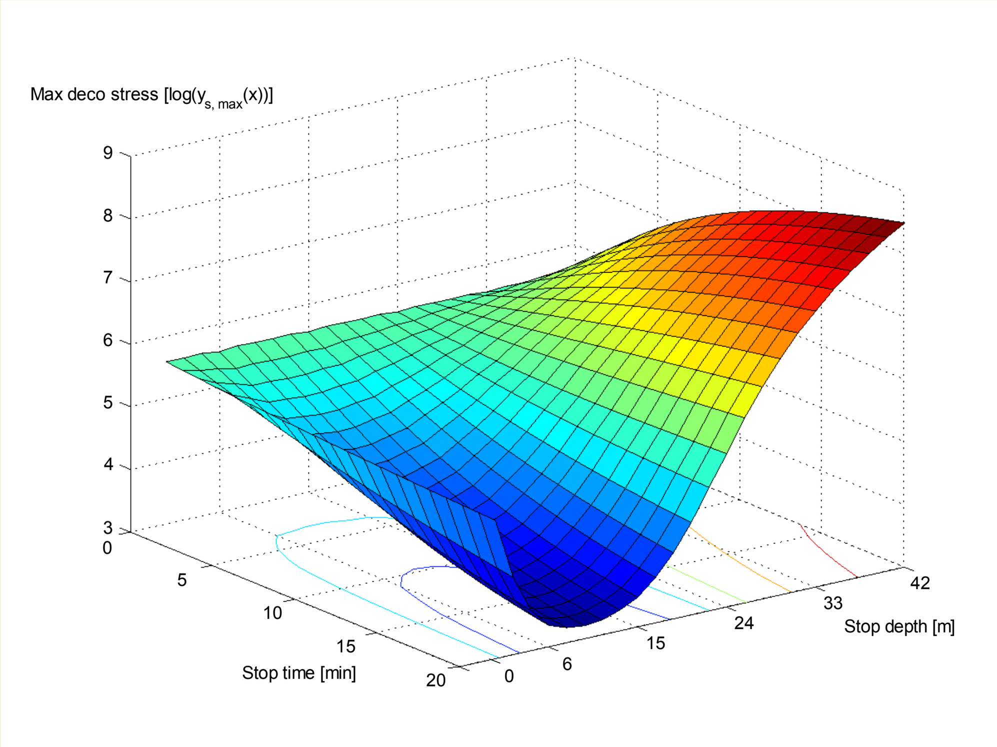


Figure 1: Mathematical definition of optimal stop

Experimental setup

The impact of different decompression schedules was tested on pigs compressed in a dry chamber monitored using ultrasonic imaging. A total of 26 pigs were divided into 4 groups of 6 and one group of 2 (aborted protocol). Two groups performed a shallow/long (30 msw / 70 min) dive. One group followed a Bühlmann procedure while the other followed an experimental deep stop procedure (DS1). The three last groups did a deep/short (65 msw / 20 min) dive following a Bühlmann procedure, an experimental deep stop procedure (DS2, n=2) and a revised shallow stop procedure (SS2) respectively.

30 msw / 70 min dive

Depth [msw]	Bühlmann	DS1
9m	-	14
6m	22	21
3m	47	25
Total deco	69	60

65 msw / 20 min dive

Depth [msw]	Bühlmann	DS2	SS2
12m	2	1	-
9m	5	9	-
6m	9	13	9
3m	27	15	33
Total deco	43	38	42

Results

The shallow/long dive achieved a significant decrease of vascular bubbles following the deep stop procedure (DS1) compared to the controls (Bühlmann schedule) - despite having a shorter total decompression time. However, on the deep/short dive the procedure with deeper stops (DS2, n=2) gave a dramatic increase of bubble formation, resulting in the protocol to be aborted after two trials. The shallow stop procedure (SS2) gave a significant decrease of vascular bubble formation.

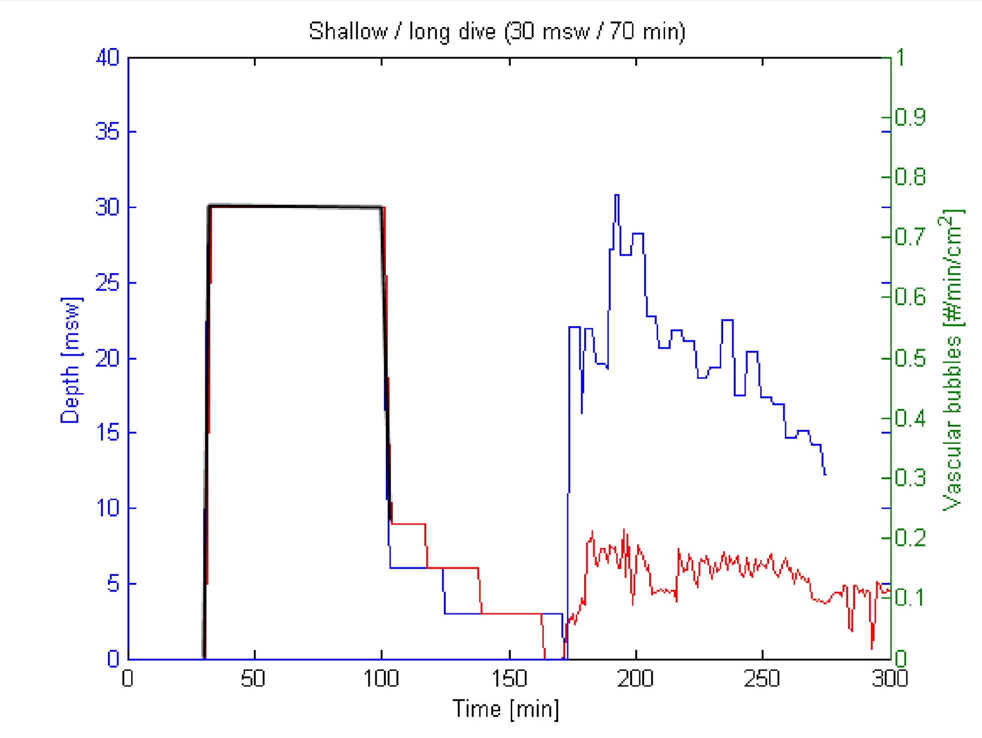


Figure 2: DS1 gave a significant reduction of vascular bubbles

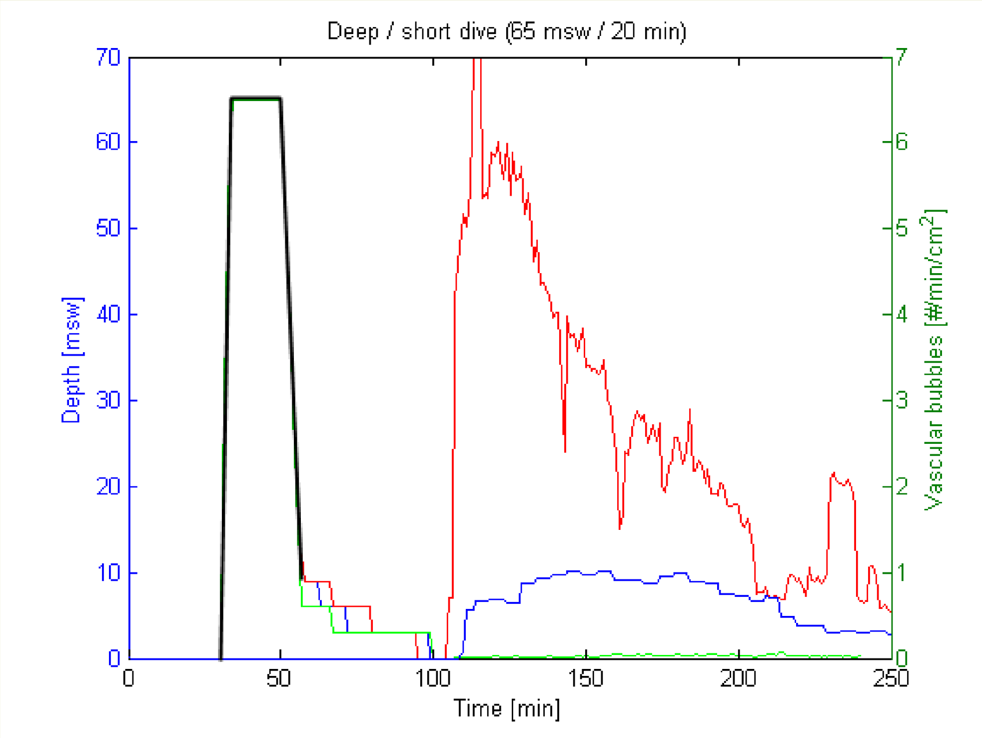


Figure 3: DS2 increased vascular bubbles while SS2 gave significantly less bubbles

Discussion

For any bubble nuclei to exist there has to be a stabilizing force opposing the surface tension. This stabilizing mechanism is suggested to be caused by crevices, stabilizing surfactants and hydrophobic caveolas i.e. Regardless of origin, it is a fact that it will at some point get stronger than the surface tension and resist further shrinkage of the bubble.

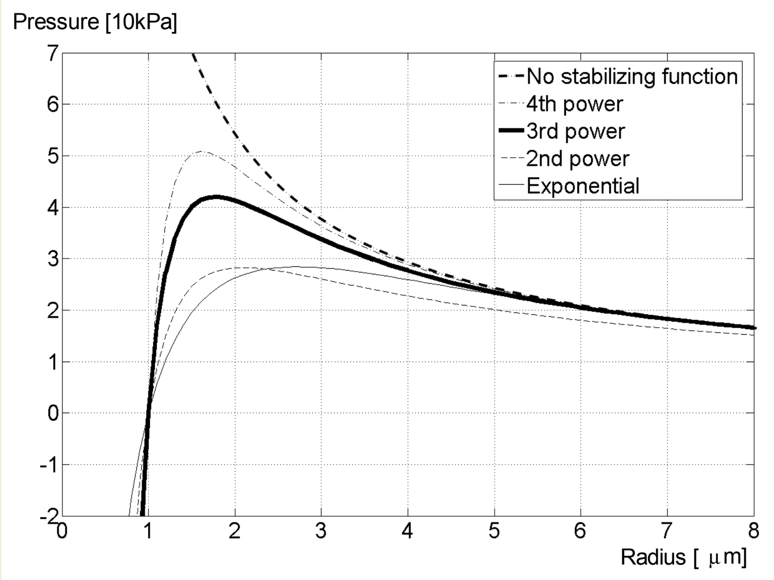


Figure 4: Suggestions for stabilizing mechanism function $\Gamma(r, P_{amb})$. Pressure difference vs bubble radius. Equilibrium at 1 µm

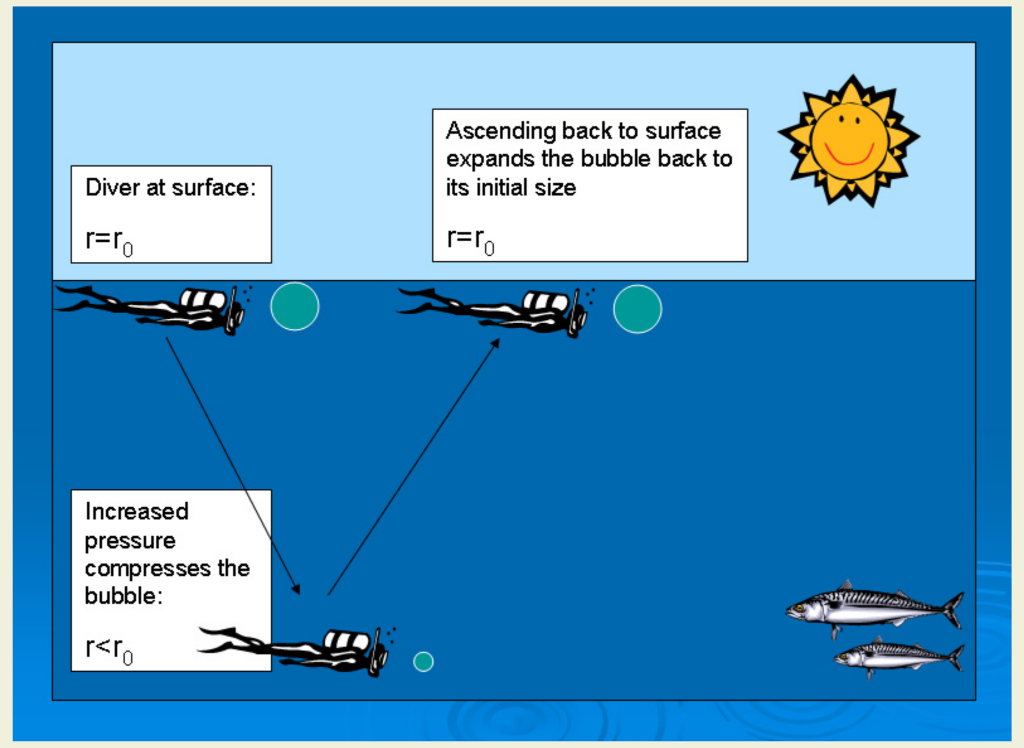
Under normabaric, desaturated conditions, any bubbles in the body will, according to traditional bubble theory, shrink due to surface tension:

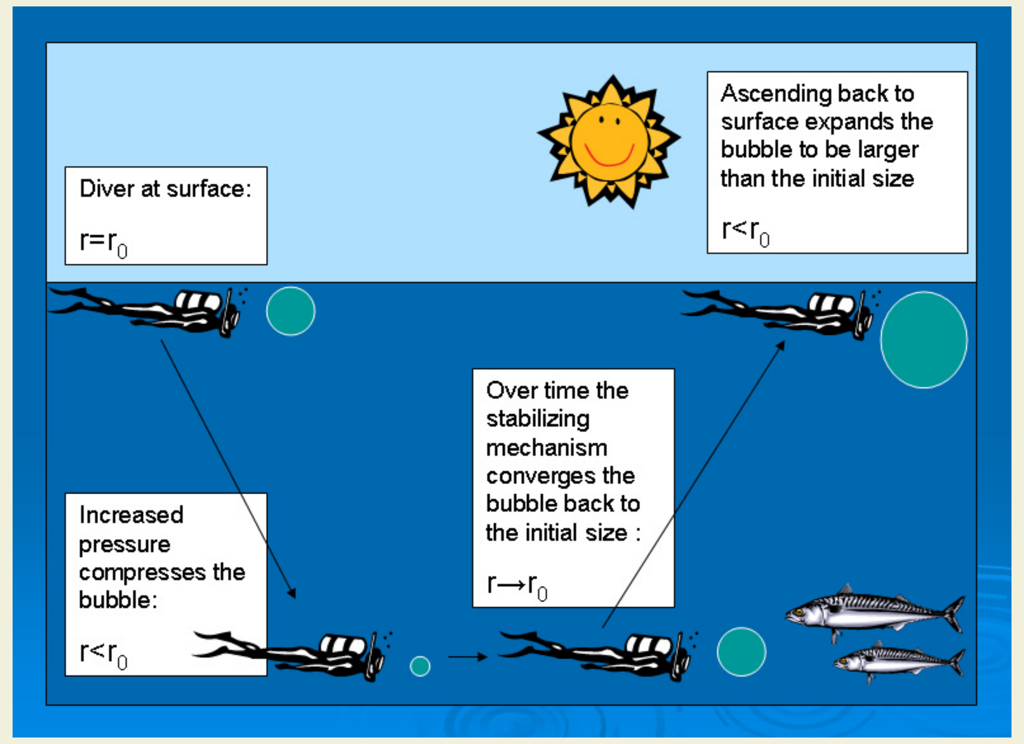
$$P_b = P_{amb} + \frac{2\gamma}{r}$$

Stabilized bubble equation:

$$\Gamma(r, P_{amb}) + P_b = P_{amb} + \frac{2\gamma}{r}$$

Any bubble nuclei present in the body before the dive will immediately be compressed upon descending. On short dives, the bubble will return approximately back to its original size when the diver start to decompress. Assuming that this initial size is relatively small, the diver can tolerate relatively large pressure gradients. If the bottomtime is longer it is reasonable to believe that the bubble will grow back to its initial size while the diver is at the bottom. When the diver then starts his ascent the bubble will be much bigger than the initial size when the decompression starts and deeper stops are needed to control the bubble growth. Higher blood perfusion and faster uptake may also contribute to faster nuclei regeneration during the bottom phase.





Conclusions

A new stabilizing mechanism for bubble nuclei had to be developed in order to simulate and reproduce the findings in this study. “Traditional bubble models” will in general suggest that adding some deep stops is beneficial for decompression outcome, however this may not always be true. The presented studies suggest that deep stops are not recommended on shorter dives and/or dives with very low activity. Deep stops seem to still be beneficial on longer dives, high-activity dives and altitude exposures.

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