RESEARCH ARTICLE

Bubble Formation After a 20-m Dive: Deep-Stop vs. Shallow-Stop Decompression Profiles

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Schellart NAM, Brandt Corstius J-J, Germonpré P, Sterk W. *Bubble formation after a 20-m dive: deep-stop vs. shallow-stop decompression profiles.* **Aviat Space Environ Med 2008; 79:488–94.**

Objectives: It is claimed that performing a "deep stop," a stop at about half of maximal diving depth (MDD), can reduce the amount of detectable precordial bubbles after the dive and may thus diminish the risk of decompression sickness. In order to ascertain whether this reduction is caused by the deep stop or by a prolonged decompression time, we wanted to test the "deep stop" theory without increasing the total decompression time. From a modeling point of view, Haldanian theory states that this situation would increase the probability of observable bubbles, because of a longer stay at depth. Under these conditions, we examined whether a "deep-stop dive" (DSD) produces more bubbles or less than a "shallow-stop dive" (SSD). ***Methods:*** Recreational divers performed either a DSD or a SSD. Both groups were matched biometrically. MDD was 20 msw, bottom time 40 min and total diving time 47 min. In DSD, the "deep" stop (10 msw) replaced 3 min of the 7 min stop at 4 msw of SSD. ***Results:*** DSD produced significantly more precordial bubbles than SSD after knee bends (*P*-values ranging from 0.00007 to 0.038). ***Discussion:*** Our results indicate that at least for the tested dive profile, the higher supersaturations after surfacing overruled any possible beneficial effects of the deep stop on bubble formation. The usefulness of substituting a shallow stop with a deep stop in dives up to 20 msw can be questioned; at the least, more research is needed.

Keywords: diving, shallow stop, deep stop, VGE, bubble grade, decompression theory.

IN RECENT YEARS, several investigators of decompression phenomena, dive authorities, and manufacturers of dive computers have advised making a short deep decompression stop during decompression dives. As a consequence, in diving practice some type of deep stop seems to be performed more and more often. Common advice is to make the deep stop at half of the difference between maximal diving depth (MDD) and the depth of the first decompression stop (the decompression ceiling). The idea is that this will reduce bubble formation and growth, and consequently the risk of neurological decompression sickness (e.g., 7,15,16,18). The deep stop was originally not intended for shallow or moderately deep non-decompression dives but for deep dives just within non-decompression limits or for decompression dives (e.g., 16).

The theoretical effect of a deep stop on bubble formation and growth can be considered from the point of view of the theories of bubble dynamics (7,15,18), considering dissolved and free gas (dual phase models), and from the aspect of models only considering dissolved N_2 (single-phase models such as Haldanian models) (2,7). Although Haldanian models are formal descriptions (black box models) of complex physiology, they help to design experiments, formulate hypotheses, and may help with evaluating experimental results.

In the theory of bubble dynamics, at the depth of the deep stop the inward pressure gradient between the expanded bubble and surrounding tissue is reduced compared to that at the decompression ceiling. A small gradient is supposed not to result in N_2 transport (14). At the end of a deep stop, the bubble may even release some gas due to off-gassing of a surrounding fast tissue. Going directly to the decompression ceiling will result in N_2-uptake by the bubble when the tissue bubble pressure gradient is sufficiently large (15,18). In the dual phase theories such as the Varying Permeability Model (VPM) (18), assuming a surfactant monolayer around the bubble, the direct ascent may result in incorporation of new surfactant molecules in the monolayer, since the increase of strain in the monolayer is too large. This results in extra uptake. On the basis of these mechanisms, VPM theory predicts that dives with a deep stop allow shortening of the shallow stop(s), resulting in a shorter or at most equal total ascent time (7,15–18).

From the point of view of single-phase models, it is obvious that a dive with any deep stop replacing a shallower stop but without increasing total diving time will show higher saturations in all tissues from the start of the deep stop. Therefore, based on single-phase theory, a dive with a deep stop and equal ascent time is expected

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This manuscript was received for review in July 2007. It was accepted for publication in January 2008.

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DOI: 10.3357/ASEM.2164.2008

to result in higher gas load after surfacing and may result in more detectable bubbles. If, however, the strategy of replacing a shallow stop by a deep stop were shown to be beneficial, i.e., less bubbles, this would indicate that the process of suppressing bubble growth is predominantly a phenomenon of bubble dynamics.

Published experimental investigations into the deep stop within the depth range of air dives are scarce and, moreover, conflicting. Some decades ago, long air dives (about 3 h with a bottom time of 50 min) to a depth of 69 msw with an additional 3-min deep stop at 23 msw produced less venous bubbles and less DCS than the same dives with only shallow stops starting at 20 msw (10). However, it was found recently that adding several deep stops (starting at 27 msw in a 60-msw 15-min dive and starting at 18 msw in a 50-msw 20-min dive) produced more bubbles and adding a single short deep stop at 25 msw in a 60-msw 15-min profile did not change bubble occurrence (1). Using VPM the latter findings are surprising since the gradient between bubble and surrounding tissue during the first shallow stop in the control dive would be 4–5 bar (0.4–0.5 MPa). The diverging results of the 69 and 50–60 msw dives make it unlikely, even for large MDDs, that the effect of the deep stop is substantial.

Also recently, the effect of a deep stop was investigated for air dives to 25 msw during 25 min and to 25 msw during 20 min with an ascent rate of $10 \text{ m} \cdot \text{min}^{-1}$. Decompression was performed with or without a deep stop (15 msw during 5 min), and with a shallow stop at 6 msw during 5 min (9). Both profiles with the deep stop showed a significant decrease in bubble grades. The lengthening of decompression time was suggested as an alternative explanation for the benefit of this staged decompression (12), although lengthening of the ascent time by reducing the speed of ascent did not prove to be beneficial (9).

To prevent the influence of lengthening the total ascent time, we evaluated the effect of a deep stop during a dive with a moderate MDD while keeping the total ascent time unchanged (9). Therefore, the control dive without a deep stop comprised a shallow stop of a longer duration. Bubble grades are determined in a controlled and reliable manner (11). In order to obtain some understanding of the experimental findings, the N_2 saturations will be modeled with halftimes.

On the basis of the above mentioned investigations with their diverging results, we hypothesize that the beneficial effect predicted by the dual phase models for a deep stop dive (DSD) within a dive with moderate MDD is so small that it is overruled by the higher supersaturation after the deep stop compared to the control dive, the Shallow-Stop Dive (SSD). This will result in more bubbles in DSD.

METHODS

Subjects

Recreational divers participating in a diving medicine course volunteered to participate in the study. In total 56 divers took part (29 in the first week and another 27 one week later). The study protocol was approved in advance by the board of the Scott Haldane Foundation and is in accordance with the tenets of the Declaration of Helsinki. Each subject provided written informed consent before participating.

A week before the course, all subjects completed a questionnaire about age, sex, diving experience (number of years of diving and total number of open water dives), height, weight, and rest values of HR, systolic and diastolic BP. Based on these data, divers were matched into pairs. One member of each pair was randomly assigned to DSD, the other to SSD.

Because we wanted to avoid any influence of previous dives, it was impossible to perform DSD and SSD with the same subjects. Therefore, much attention was given to matching the biometrical data of both groups as closely as possible.

On the first day after their arrival, the experimental dive was made, either DSD or SSD. The morning of the dive, before breakfast, each diver was subjected to a medical examination, again measuring the above-mentioned parameters, as well as body fat with a bio-impedance meter (Omron) and with the skin fold method. Discrepancies between the questionnaire and examination lead to a new, ultimate measurement. From height and weight, the body mass index ($\text{BMI} \equiv \text{weight}/\text{height}^2$) was calculated.

Divers were asked to adhere to the prescribed profile so that the difference between intended and performed depth at any time was limited to 1.0 msw.

Dive Profile and Conditions

Both types of dives followed the same square dive profile to 20 msw, on a wreck close to the shore of Mahé, Seychelles, November 2005. Bottom time at 20 msw was 40 min, including the descent time (20 msw/min). Then, at 10 msw/min an ascent was made either to 10 msw (DSD) or to 4 msw (SSD). DSD comprised a stop at 10 msw during 4 min (including ascent time, as also holds for the shallow stop), and a stop at 4 msw during 3 min. For SSD a 7-min stop was performed at 4 msw. Thus, irrespective of the type of dive performed, total ascent time was 7 min 24 s.

All dive profiles were recorded with Uwatec Smart Pro or Mares M1 dive computers. Subjects were instructed to use the dive computer solely as a watch and depth meter. Buddy pairs had one or two dive computers at their disposal. Subjects who lacked a dive computer were instructed to 'stick' to their buddy. For the Smart Pro, calibrated in meters fresh water, depth was calculated in meters sea water. After the dive, the dive profiles were retrieved and inspected for validity.

Water temperature at the surface and at 20 msw was approximately 28.5°C and 27.5°C, respectively. Current at 20 msw was nil and at stop depths rather weak (stops at a buoyancy line), water visibility was about 12 m (overcast sky), sea state 1-2.

Bubble Detection and Nitrogen Saturation

The occurrence of venous gas emboli (VGE) was measured precordially at the left 3rd intercostal space, 40 and 100 min after surfacing, with a continuous-wave Doppler DBM9008 and array probe bubble detector (Techno Scientific, Toronto). All measurements were performed by the same two experienced Doppler investigators. A session was comprised of four measurements with intervals of 1 min. The first measurement was performed while standing at rest. The other three were directly after a deep knee bend (flex). The intervals of 40 and 100 min were dictated by the duration of a Doppler examination of a single subject, the number of subjects, the availability of two examiners and the transport time from dive site to examination room. The Doppler sounds were digitally recorded on an MP3-recorder and scored blinded, with bubble grades (BG) expressed in KM units (Kisman-Masurel units, see 11). The resting value and the highest value of the three knee bends were used for statistical analysis.

Nitrogen saturations were modeled exponentially with halftimes of 5, 12.5, 27, 54.3, 109, 187, 305, and 635 min.

Statistics

When numbers of subjects and/or differences are small, the type of test may determine significance or nonsignificance. Since both hold true with these data, several tests were used. The *t*-test and Kolmogorov Smirnov (KS) test were applied to examine the (log)normal and not-(log)normal distributed biometrical data, respectively.

To calculate means and differences, the KM flex scores were transformed to the logarithm of the number of bubbles per centimeter squared (logB) (11). LogB of KM 0 was estimated at −3 [from the data of Nishi et al. (11), fitted with $\log B = -2.18 + 0.76KM - 0.78\sin(\pi KM)/(\pi KM)$, with SEM 0.077 KM]. Paired *t*-tests were applied to examine differences between the 40 and 100 min logB values of DSD as well as SSD. The nonparametric Yates Cochran test was applied to the KM rest scores.

In order to reduce the large number of KM classes of the flex scores, the KM values were transformed to Spencer units (SU, see 11) before analysis. First, a Yates-Cochran test was performed on the categorical data. Then, since the largest of the 40 and 100 min scores is deviating least from the unknown maximum BG, the larger scores for each test subject were subjected to a Yates-corrected Chi-square test (11).

It has been recognized that SU 0 and SU 1 scores are sometimes hard to distinguish and more subjected to temporal variability than SU 2 and SU 3 scores. Therefore, analogous with previous studies (e.g., 9), the frequencies of occurrence of SU 0 and SU 1 were added into a "Low-Spencer score" category and similarly those of SU 2 and 3 were added into a "High-Spencer score" category. These data were also subjected to a (Yates-corrected) Chi-square test.

The Chi-square test does not take into account the BG values themselves as do, for instance, the Yates Cochran test and the mixed models test. The pooled 40 and 100 min Spencer data were subjected to a Yates Cochran test with the Hotteling correction for the correlation of the 40 and 100 min data [being $(1/1+R)^{0.5}$ with R the weighted root mean square of both correlation coefficients].

A mixed models analysis (unstructured, SPSS 12.0.1) that corrects for correlated repeated measurements was applied to the combined 40 and 100 min scores (SUs). All *P*-values refer to similarity and they were evaluated two-sided with $\alpha = 0.05$.

RESULTS

Subjects

All subjects who deviated more than 2 min from the intended times of descent, MDD, ascent, or stop time(s), or who deviated more than 1.2 msw from MDD or more than 1.5 msw from intended stop depths were removed from the data base, leaving 32 divers (26 males and 6 females).

The biometrical data age (52.8 ± 10.5 yr), BMI (25.9 ± 4.1 $kg \cdot m^{-2}$), body fat (Omron, 24.5 ± 7.9% and skin folds, 28.9 ± 7.2%), the rest values of HR (62 ± 8.4 min^{-1}), systolic BP (129 ± 15 mm Hg), diastolic BP (84 ± 8.2 mm Hg), years of dive experience (13.2 ± 11.3 yr), and number of performed dives per year (22.1 ± 17.0) between the DSD and SSD divers were very similar (*P*-values between 0.20 and 0.90), except the last one ($P = 0.17$ with the KS test).

Dive Profiles

The average of the mean MDD of the profile per subject calculated from 1 to 40 min diving time was 19.47 ± 0.40 and 19.62 ± 0.56 msw (m ± SD) for DSD and SSD, respectively. The two top curves of **Fig. 1A** present the mean profile of DSD (solid squares) and SSD (drawn line), both expressed as pressure ($P_{ambient}$). At MDD, standard deviations of the depth calculated over subjects per instant of time and then averaged over time were 0.9 msw for both DSD and SSD. Although the intended descent and ascent speeds were nearly 1.5 times slower than the intended 20 and 10 $m \cdot min^{-1}$, respectively, both profiles were practically identical, neglecting the deep stop interval (Fig. 1A). The difference between both profiles is depicted in **Fig. 1B** (solid line). This difference was very close to the intended difference of zero before the ascent. In the 41–45 min interval, the difference between DSD and SSD profiles becomes evident. This difference was slightly less than the intended 6 msw.

N_2 Saturations

Fig. 1A presents the saturation (in units of 0.1 bar) of the four fastest compartments (halftimes 5, 12.5, 27, and 54.3 min) and the 635 min compartment. The saturations are depicted for both DSD (symbols) as well as SSD (solid curves). The partial N_2 pressure of inspired air (pN_{2in}, dashes), is only depicted for DSD.

The three curves of Fig. 1B, indicated by symbols, present the differences in saturation between DSD and

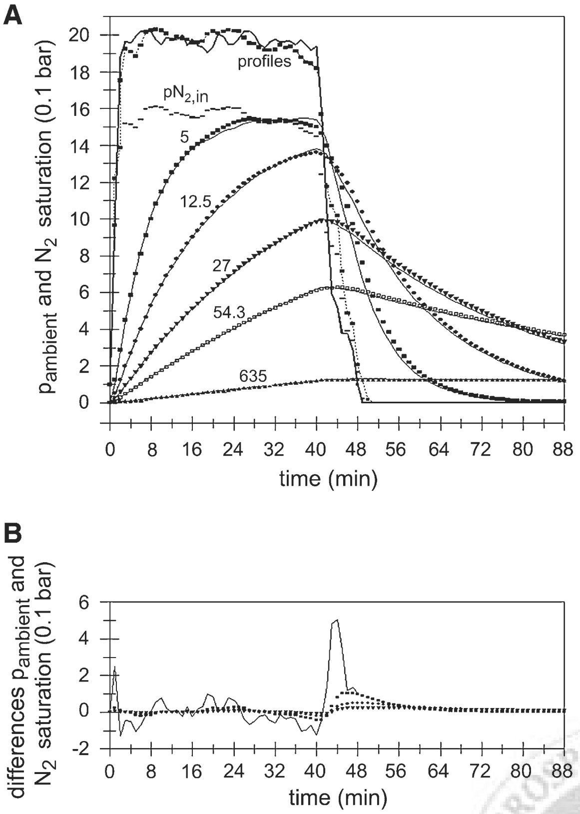

Fig. 1. A. Averaged dive profiles and N_2 saturations of the various compartments of DSD and SSD. The dotted curve with solid squares is the profile of DSD and the thickly drawn curve that of SSD. The saturations were calculated with ZH-L16C parameters. Curves with drawn lines present saturations of SSD, curves with symbols denote saturations of DSD. Numbers present the halftimes of five compartments. The thick dashed curve present pN_2 of the inspired air of DSD. (Depth, the pressure $P_{ambient}$, is expressed in units of 0.1 bar, i.e., 1 msw or 0.01 MPa). **B.** Differences in pressure and in N_2 saturations of DSD and SSD. The drawn curve presents the mean difference in ambient pressure of the two profiles. The three curves indicated by symbols are $N_{2compi,DSD} - N_{2,compi,SSD}$ of the 5, 12.5, and 27 compartments, from top to bottom, respectively.

SSD of the three fastest compartments (upper, 5; middle, 12.5; lower, 27 min). Until the ascent, all differences were restricted to approximately 0.01 bar (0.001 MPa). From the instant of the deep stop and afterward, the differences were small but systematic.

Bubble Grades

Table I presents the occurrence of KM scores after a surface interval of 40 and 100 min at rest and after the knee bend with the highest BG. Nonzero scores during rest occurred in about 12% of the cases. This was about three times less than after the flex and, moreover, the scores were lower. Six of the eight nonzero resting KM scores occurred in the DSD group. The pooled resting data showed no tendency of producing more bubbles in DSD (Yates Cochran test, $P = 0.22$). Values at 40 and 100 min as well as rest and flex values of DSD were uncorrelated.

Table II shows the occurrence of the Spencer scores after the flex and the logB transformations of the KM flex scores of the two groups, and further medians and logB means.

TABLE I. DOPPLER RECORDINGS FOR DSD AND SSD AFTER 40 AND 100 MIN, AT REST AND AFTER MOVEMENT (FLEX).

	40 min				100 min			
	Rest		Flex		Rest		Flex	
KM Grades	DSD	SSD	DSD	SSD	DSD	SSD	DSD	SSD
0	15	13	4	6	15	13	4	8
1-	1	1	1		2	1		
1	2		1	4	1		5	3
1+								1
2			11	2			8	2
3−			1	2			1	
n	18	14	18	14	18	14	18	14

The highest flex scores were those of DSD at 40 min, but they were not different from those at 100 min (paired *t*-test on logB values yielded $P = 0.74$). For SSD the 40 min scores were also highest and not different from the 100 min scores ($P = 0.33$). The DSD 40 and 100 min logB values have a correlation coefficient (Spearman) of 0.59 ($P = 0.010$) and that of SSD 0.45 ($P = 0.10$). The frequency of occurrence of BG of SSD diminishes with increasing BG. With DSD, BG = 2 occurs most frequently (61% of the scores).

Yates-Cochran tests, applied to both 40 and 100 min flex values, indicate that the DSD profile tended to produce more bubbles than the SSD profile. For the 100 min data, this difference was significant ($P = 0.020$). Analysis of the larger of the 40 and 100 min scores (Yates-corrected Chi-square test) indicated significantly more bubbles after DSD ($P = 0.0024$).

The same test applied to "High-Spencer score" and "Low-Spencer score" data of 40 as well as 100 min showed significantly more bubbles for DSD ($P = 0.0009$ and $P = 0.00007$, respectively).

The Yates Cochran test applied to the pooled 40 and 100 min Spencer data showed significantly higher bubbles for DSD ($P = 0.038$).

Since the 40 min and 100 min scores were not different, a mixed models test could be applied to the flex data. Its outcome indicates that DSD produced significantly more bubbles ($P = 0.022$).

DISCUSSION

The measurements of postdive Doppler detectable bubbles show that a deep stop, partially replacing a shallow stop, appears to increase bubble grade. The next paragraphs will especially consider possible confounders, limitations, and possible explanations.

Subject Matching and Dive Profiles

Age, a parameter known to affect BG (3,4,5,13), was well matched (mean difference 1.7%, $P = 0.82$). Vo_{2max} also affects BG (3). Vo_{2max} of the divers could not be determined directly, but the related parameter "hours endurance sport per week" was used. The DSD group performed 1.1 h aerobic sport per week more than did

TABLE II. DESCRIPTIVE STATISTICS OF FLEX BUBBLE GRADES OF DSD AND SSD DIVES.

	Frequency of Occurrence			
	40 min		100 min	
BG Spencer	DSD	SSD	DSD	SSD
0	4	6	4	8
1	2	4	5	4
2	11	2	8	2
3	1	2	1	0
n	18	14	18	14
Median	2	1	1.5	0
Mean logB	−1.25	−1.82	−1.37	−2.21

the SSD group (not significant). This may diminish BG slightly (probably between 0.1 and 0.01 logB, estimated from ref. 3, 8, and 11). In how far body fat (or the related BMI) affects BG as an independent parameter is disputable, since body fat is highly cocorrelated with age and Vo_{2max}. Irrespective of the influence of body fat, body fat and BMI were also similar for both groups (differences 4–14%, $0.2 < P$-values < 0.6). Similarity also holds for the remaining characteristics, but less for the number of dives per year. Analysis of the "dives per year" in each group (DSD and SSD not significantly different) showed that only the 40-min BG scores of DSD were significantly correlated with "dives per year". Therefore, it seems unlikely that the observed BG differences between DSD and SSD are noticeably attributable to this factor.

It may be concluded that the close match of the two groups diminishes the drawback that the divers could not serve as their own control.

Whether some combination of the above characteristics makes a diver a "bubbler" or a "non-bubbler" is not known, and which characteristics are other possible candidates is also unknown. Since the number of subjects was rather small, it is possible that a higher proportion of "bubblers" (with KM ≥ 2) were present in one group compared to the other. Therefore, this comparison is supposed to have extra 'noise' and may introduce a bias in statistics.

Dive Profiles

The differences between the realized DSD and SSD profiles were so small (Fig. 1B), except for the deep stop, that it is safe to assume that they did not confound the measurements and calculations.

Both profiles had a slower ascent speed than originally planned (ca. 7 msw/min). This realized ascent speed was the same as recommended in UWATEC dive computers for depths shallower than 10 msw and 2 m · min^{-1} slower than the constant speed of ascent recommended by Comex air tables. With single-phase models this would make an irrelevant difference. Also, it seems unlikely that this speed substantially changes bubble-to-compartment and compartment-to-blood gradients. However, it has been shown (9) that very slow ascent speeds (3 msw/min) provoke higher bubble grades than the 10-msw/min profiles with equal total ascent times.

Bubble Grades

For practical reasons, Doppler measurements could only be performed 40 and 100 min after surfacing (see Methods). Consequently, the deviation of the larger of the two from the maximum in the KM versus time curve is not known. This makes any statistical analysis less robust. Adding the occurrence of Spencer scores < 2 and those ≥ 2 yielded very significant outcomes and the same holds for the method of selecting the larger of the two (40 and 100 min).

With regards to statistical theory, combining or pooling the 40 and 100 min data is an optimal approach, especially with small data sets. However, from present knowledge it is not known whether the maximum BG during the time-course of VGE or a kind of time-integral of the time course of VGE is the dominant factor in the underlying mechanism of DCS. Therefore, physiologically, combining or pooling may be subject to debate. With only two instants in time measured, the assumption should be made that the shape of the time-courses in both conditions is similar. From published VGE data and theory (11) and the fact that the 40 and 100 min data (logB) did not differ, similarity is likely to hold.

To address the problem of the possible imbalance of high bubblers in both groups, two subjects with the highest BG score at both 40 and 100 min could be changed from "High-Spencer score" to the "Low-Spencer score" group while maintaining a significant outcome of the Chi-square test. A similar procedure applied to the highest of the two (40 or 100 min) with the Chi-square test, to the pooled data with the Yates Cochrane test and the combined data with the mixed models test showed that the scores of one to four subjects with the highest scores could be changed to a class with 1 or 2 SU less without affecting significance.

Considering the outcomes of all tests, it is concluded that DSD produced significantly more bubbles than SSD. The reliability of the outcomes appears sufficient since replacing the scores of the subjects with the highest scores by lower scores did not affect significance.

Theoretical Considerations

The PN_2 differences between DSD and SSD were generally small, and even smaller the larger the halftimes. From the compartment with a halftime of 54.3 min and beyond they are irrelevant. The largest differences, up to 0.1 bar (0.01 MPa), were found from the end of the deep stop until about 10 min after surfacing (Fig. 1B). The larger supersaturations of DSD are assumed to have resulted finally in more VGE bubble formation of DSD.

In a semiquantitative way, the risk on DCS and consequently bubble formation can be established with the %M-value formalism, which can be helpful in evaluating the severity of supersaturations for bubble formation.

Until the end of the 4 msw stop, the %M-values (here $100pN_2$/M-values in percent, based on absolute pressures and modeled with Bühlmann ZH-L16C) of all compartments never exceeded 75%, with DSD showing smaller values than SSD. This suggests from Haldanian models that bubble formation is limited, especially in DSD. However, after surfacing the %M-values of the three fastest compartments deviated only 10–20% from hypersaturation (100%). The value of the 27 min compartment of DSD was highest, 89%, three percent more than that of SSD. The small deviations from 100% suggest that after surfacing bubbles may be formed and progressively more in DSD.

Theories of bubble dynamics are aimed at preventing bubble growth in tissues and blood by limiting the pressure gradient between bubble and surrounding tissue ($G = pN_{2,\text{compartment}} - P_{\text{bubble}}$). During an ascent, a bubble originally formed at MDD expands (although less than in accordance Boyle's law, due to the surfactant monolayer). In the 5-min compartment, this gradient of SSD is at most ~0.6 bar (0.06 MPa), and in the 12.5 min compartment ~0.8 bar (0.08 MPa). These values last only a few minutes. In the other compartments G is (much) smaller. The monolayer stabilizes the bubble, such that small positive and negative values of G prevent growing and shrinking. Since DSD shows more bubbles than SSD, apparently the G values of SSD were not large enough to cause a final bubble formation similar or larger than DSD.

It may be concluded that the effect of free gas seems to be negligible for the MDD and dive time chosen here, and the effect of dissolved gas seems to be predominant.

Experimental bubble studies of divers suffer from the limitation that tissue bubbles cannot be measured. Bubble grades and DCS incidence are related (11). However, this relation is not known for the type of DCS, blood-bubble or tissue-bubble related. In our investigation, and similar ones (9), %M-values were calculated and VGE bubble grades were measured. Whether and, if so, how high %M-values in tissues may give rise to high VGE bubble grades is enigmatic, since blood is a very fast compartment with a "halftime" of less than a minute, as can be derived from literature data (8).

The time-maximum of VGE bubble grades has seldom been found before 0.5 h after surfacing. Despite the theories of bubble dynamics, the physiological mechanism of the generation of VGE bubbles and their relationship with the dissolved and free gas in the tissues is unknown. We speculate that after surfacing, coalescence in the blood is one of the possible reasons for the delayed occurrence of VGE bubbles. More importantly, blood bubbles can grow by competing with the blood liquid phase for the dissolved nitrogen released by the supersaturated tissues. Then, the higher supersaturations of DSD after surfacing are a substantial disadvantage.

Conclusions

Published results of Doppler VGE investigations with added deep stops are divergent: extreme dives showed a decrease (10); dives with a moderate depth also showed a decrease of bubble generation (9); and deep dives resulted in an increase (1).

For our chosen dive profile (20 msw, 40 min bottom time) a deep stop partially replacing a shallow stop showed a significant increase in postdive Doppler detectable bubbles. This suggests that, at equal total dive times, the supposed smaller bubble growth during the time of the deep stop (as predicted by VPM) plays only a minor role.

As yet, based on the above findings, with MDD until about 20 msw, there seems to be no benefit from exchanging a 4-msw stop for a deeper stop without changing total decompression time.

Evaluating all Doppler VGE investigations described in literature and the present one, it seems likely that a possible benefit of a deep stop caused by an effect of bubble dynamics is dependent on depth, bottom time, and ascent profile.

More research is necessary to determine the dissolved and free gas effect, both assumed to play a role in VGE bubble generation. Then it will become clear for which dive profiles a deep stop may be most beneficial.

ACKNOWLEDGMENT

The authors greatly acknowledge Eelco J. Sterk of the Dadcodat Foundation for performing half of the Doppler measurements and Dr. A. H. Zwinderman for statistical advice and performing the mixed models analysis. Also, they acknowledge Casper Baarda and Tjeerd van Rees Vellinga for the bio-impedance measurements and Topsport Diving for providing the dive computers. Finally, the authors thank all subjects for their participation.

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