A deep stop during decompression from 82 fsw (25 m) significantly reduces bubbles and fast tissue gas tensions.

A. MARRONI[1,2], P. B. BENNETT[4,5], F. J. CRONJE[5,7], R. CALI-CORLEO[1,2], P. GERMONPRE[1,6], M. PIERI[1], C. BONUCCELLI[1], C. BALESTRA[1,3]

[1]DAN Europe Foundation, Research Division. [2]Division of Baromedicine, University of Malta Medical School. [3]Haute Ecole Paul Henri Spaak, Occupational and Environmental Physiology Dept., Bruxelles, Belgium. [4]Divers Alert Network (DAN) America. [5]Duke University Medical Center, Durham, NC, USA. [6]Center for Hyperbaric Oxygen Therapy, Military Hospital Bruxelles. [7]DAN Southern Africa

Marroni A, Bennett PB, Cronje FJ, Cali-Corleo R, Germonpre P, Pieri M, Bonuccelli C, Balestra C. A deep stop during decompression from 82 fsw (25 m) significantly reduces bubbles and fast tissue gas tensions. Undersea Hyperb Med 2004; 31(2):233-243. In spite of many modifications to decompression algorithms, the incidence of decompression sickness (DCS) in scuba divers has changed very little. The success of stage, compared to linear ascents, is well described yet theoretical changes in decompression ratios have diminished the importance of fast tissue gas tensions as critical for bubble generation. The most serious signs and symptoms of DCS involve the spinal cord, with a tissue half time of only 12.5 minutes. It is proposed that present decompression schedules do not permit sufficient gas elimination from such fast tissues, resulting in bubble formation. Further, it is hypothesized that introduction of a deep stop will significantly reduce fast tissue bubble formation and neurological DCS risk. A total of 181 dives were made to 82 fsw (25 m) by 22 volunteers. Two dives of 25 min and 20 min were made, with a 3 hr 30 min surface interval and according to 8 different ascent protocols. Ascent rates of 10, 33 or 60 fsw/min (3, 10, 18 m/min) were combined with no stops or a shallow stop at 20 fsw (6 m) or a deep stop at 50 fsw (15 m) and a shallow at 20 fsw (6 m). The highest bubbles scores (8.78/9.97), using the Spencer Scale (SS) and Extended Spencer Scale (ESS) respectively, were with the slowest ascent rate. This also showed the highest 5 min and 10 min tissue loads of 48% and 75%. The lowest bubble scores (1.79/2.50) were with an ascent rate of 33 fsw (10 m/min) and stops for 5 min at 50 fsw (15 m) and 20 fsw (6 m). This also showed the lowest 5 and 10 min tissue loads at 25% and 52% respectively. Thus, introduction of a deep stop significantly reduced Doppler detected bubbles together with tissue gas tensions in the 5 and 10 min tissues, which has implications for reducing the incidence of neurological DCS in divers.

INTRODUCTION

Decompression procedures and tables have been modified many times over the last 40 years since scuba diving was initiated as a sport. However, in spite of the current prevalence of dive computers to assist decompression, the incidence of decompression sickness (DCS) has changed very little (1). This may be because critical factors, such as rate of ascent and shallow stops, provide insufficient time to offload enough inert gas during critical phases of the decompression, resulting in the generation of bubbles and occurrence of DCS.

Many attempts to prevent DCS in the past have relied on the Haldane hypothesis (2). This based gas uptake or elimination from 5 so-called 'tissue' exponentials later increased to 6 by the U.S. Navy. These were the 'fast' half time exponentials of 5, 10 and 20 minutes and the 'slow' tissue exponentials of 40, 80 and 120 minutes. The premise was that excess gas retained in any of these tissues or compartments during ascent could lead to bubble formation and DCS.

As military diving experience suggested that slow tissues were responsible for decompression symptoms, the emphasis moved from preventing supersaturation in fast tissues to protecting the slow ones by adding longer tissue half times. Thus for example, the Bühlmann tables and computers were expanded to include 16 tissue half times (3) with the longest at 635 minutes.

Experience in recreational divers has shown that 65% of treated DCS cases are neurological. They usually involve the spinal cord which has a "tissue" half time of only 12.5 minutes (4). During a 30 m (100 fsw) dive of 25 minutes, the 5 and 10 minute tissues will attain a high degree of saturation. Even though current computer models de-emphasize the importance of these tissues, these may, in fact, be controlling factors. Significantly more ascent time may therefore be required to off-gas these critical fast tissues and avoid neurological DCS. Indeed, the original Haldane table (2) for a 30 m (100 fsw)/25 minute dive required decompression stops at 9, 6 and 3 m (30, 20 and 10 fsw) for a total decompression time of 19 minutes. Yet today, with an ascent of 9 m (30 fsw)/minute and a 'safety stop' at 5 m (15 fsw) for 3 minutes, the recreational scuba diver is on the surface in only 6 minutes. This may be far too short for adequate desaturation of a 5 minute tissue that has attained a high degree of saturation.

Haldane's original research in 1906 maintained that for a dive to an absolute pressure of P_1, the absolute pressure reduction during decompression to a P_2 should not be less than half the pressure of P_1. This 2:1 ratio concept of Haldane is widely quoted but was not actually used in his later decompression tables. Sir Leonard Hill (5), by contrast, believed in a slow linear ascent model. In testing with goats, Haldane found that the Hill method of a slow linear ascent was ineffective and resulted in significant DCS. Yet for many decades an empirical linear decompression ascent rate of 18 m/min (60 fsw/min) was recommended by the US Navy. More recently, the rate was reduced to a linear 9 m/min (30 ft/min), but when even this strategy did not eliminate DCS, a single brief safety stop at 5 m (15 fsw) was introduced for 3-5 minutes. From 5 m (15 fsw) the diver would then surface – usually rapidly. The modifications to the Haldane model by the US Navy thus eliminated the need for more decompression stops during the ascent and the so-called 'deep stop' was lost. However, experience in pearl divers, and more recently in technical divers, has led to empirical reintroduction of the deep stop with apparent success (6). The research described in this paper tested the hypothesis that a deep stop is efficacious in preventing neurological DCS in recreational scuba divers.

Marroni et al. (7) applied the above hypothesis to 1,418 normal recreational scuba dives monitored using so-called 'black box' depth-time recorders to predict tissue gas tensions while blinding the diver to the data collection. Precordial Doppler bubbles were measured at 15 minute intervals up to 90 minutes and again 48 hrs after the last dive or with an altitude change. Interestingly, as with other such Doppler studies, precordial bubbles did not appear until 30 or 40 minutes after surfacing. After repetitive diving, 85% of the dives produced bubbles, and though 18% were low grade (i.e., Spencer Scale of 1-2), 67% had high bubble grades (i.e., Spencer Scale of 3-4). By retrospectively applying the Bühlmann algorithm (3) to the data from the black box depth-time recorders, peak nitrogen tensions were determined in various tissue compartments during the ascent (i.e., the leading tissue nitrogen pressure (PltN2) or critical supersaturation). Consistent with the hypothesis, it was found that the presence of bubbles was directly related to critical supersaturation in faster (5 to 20 minute) rather than in slower tissues. Also consistent with the hypothesis was that the fast tissues controlled the ascent, the faster the leading tissue (i.e., 5 vs. 10 minute; 10 vs. 20 minute), the worse the bubbling became.

As a result of this research and recent theoretical discussions (1) of the effects of linear ascent rates (Hill) versus deep stops (Haldane), a matrix was developed for experimental dives to

25 m (82 fsw) by volunteer divers using ascent rates of 3, 10 or 18 m/minute (10, 33, or 60 fsw/minute) and stops at 6 m (20 fsw) or both 6 m and 15 m (20 fsw and 50 fsw). Blacked-out Uwatec depth-time recorders were again used to track predicted gas tensions for 5, 10, 20, 40 and 80 minute half time 'tissues'. The hypothesis was that by combining a deep and a shallow stop – to avoid critical supersaturation levels in the fast, leading tissues – decompression stress would be reduced as observed by Doppler-detectable bubbles and lower predicted gas tensions when compared to either a direct ascent, or direct ascent with only a shallow stop.

METHODS

The dives were carried out by 22 volunteer recreational divers. After reading and signing the informed consent form, which excluded pregnancy from the study, the divers were instructed to complete each of 8 possible combinations of ascent rate with or without decompression stops. The dives were undertaken over 8 separate weekends, with no dives in between, and involved a 25 m (82 ft) dive for 25 min followed by a repetitive dive to 25 m (82 fsw) for 20 minutes after a 3h30 minute surface interval. The prescribed ascent rates were 3, 10 and 18 m/minutes respectively, with or without 5 minute stops at 15 and 6 m. An 18 m/minute ascent profile without stops was excluded intentionally for safety reasons. Most subjects completed all 8 profiles. Two divers were excluded before completing the fifth profile, due to pregnancy. A few divers omitted the repetitive dive profile due to feeling too cold or due to adverse sea conditions. The following data were collected: 24 dives for profile 1-1R; 25 dives for profile 2-2R; 27 dives for profile 3-3R; 26 dives for profile 4-4R; 26 dives for profile 5-5R; 25 dives for profile 6-6R; 14 dives for profile 7-7R; and 14 dives for profile 8-8R. All in all, 181 dives were completed with 1086 Doppler readings.

Table 1 - Matrix of Experimental Dive Profiles

Profile (code no. for dives)	Depth (m)	Time (min)	Ascent Speed m/min	Stop @ 15 m	Stop @ 6 m	Total Ascent Time (min)
1 (13)	25	25	10	0	0	2.5
1R (11)	25	20	10	0	0	2.5
2 (13)	25	25	3	0	0	8
2R (12)	25	20	3	0	0	8
3 (15)	25	25	18	0	5	6.5
3R (12)	25	20	18	0	5	6.5
4 (16)	25	25	10	0	5	7.5
4R (10)	25	20	10	0	5	7.5
5 (13)	25	25	3	0	5	13
5R (13)	25	20	3	0	5	13
6 (13)	25	25	10	5	5	12.5
6R (12)	25	20	10	5	5	12.5
7 (7)	25	25	18	5	5	11.5
7R (7)	25	20	18	5	5	11.5
8 (7)	25	25	3	5	5	18
8R (7)	25	20	3	5	5	18

All dives were recorded for each time-depth profile as described previously (8, 9). Blacked out Uwatec computers were worn by the divers to assure objective dive profile recording and to allow subsequent mathematical calculation and analysis of the predicted tissue saturations. Doppler recordings were performed by specially trained members of the volunteer divers' group, using an Oxford Instruments 3.5 MHz probe with a digital recorder (8, 9). Recordings over the precordial area were made with the divers standing, at rest for thirty seconds, and again for thirty seconds after performing two deep knee bends. The highest bubble grade attained was used. A total of six one-min recordings were made at 15 minute intervals for a total of 90 minutes after the dives. The recordings were later analyzed by a blinded, experienced researcher. The Doppler bubble signals were scored according to three scales: The Spencer Scale (SS), our simplified Doppler Bubble Grading System (DBGS), and our modification of the Spencer Scale (called the Expanded Spencer Scale or ESS) defined as follows (10, 11, 12).

Simplified Doppler Bubble Grading System:

- LBG – Low Bubble Grade: occasional bubble signals, Doppler Bubble Grades (DBG) lower than 2 in the Spencer Scale
- HBG – High Bubble Grade: Frequent to continuous bubble signals, DBG 2 and higher in the Spencer scale.
- HBG+ – Very High Bubble Grade: Bubble signals reaching grade 3 in the SS and 2.5 in the Expanded Spencer Scale (see below).

Expanded Spencer Scale:

The original Spencer Scale was adapted by introducing "half grades" to allow a more incremental grading:

- Grade 0 = No Bubble Signals
- Grade 0.5 = 1-2 sporadic Bubble signals over the 1 min recording
- Grade 1 = up to 5 Bubble signals over the 1 min recording
- Grade 1.5 = up to 15 Bubble signals over the 1 min recording, with bubble showers
- Grade 2 = up to 30 Bubble signals over the 1 min recording
- Grade 2.5 = more than 30 Bubble signals over the 1 min recording, with bubble showers
- Grade 3 = virtually continuous Bubble signals over the 1 min recording
- Grade 3.5 = continuous Bubble signals over the 1 min recording, with numerous bubble showers
- Grade 4 = continuous Bubble signals over the 1 min recording, with continuous bubble showers

Table 2 provides a comparison between these scales. To determine the relative index of decompression stress, a "Bubble Score Index - BSI" was calculated for each "Dive plus Repetitive Dive" experimental profile. Peak Doppler readings from the participants were classified and recorded according to both SS and ESS systems. These were then added and divided by the number of participating volunteer divers for each profile to generate an average score. The individual incidence of BSI and various grades of Doppler detected bubbles were compared using a generalized estimating equation (GEE) (13, 14) to account for repeated observations from the same subject.

Table 2

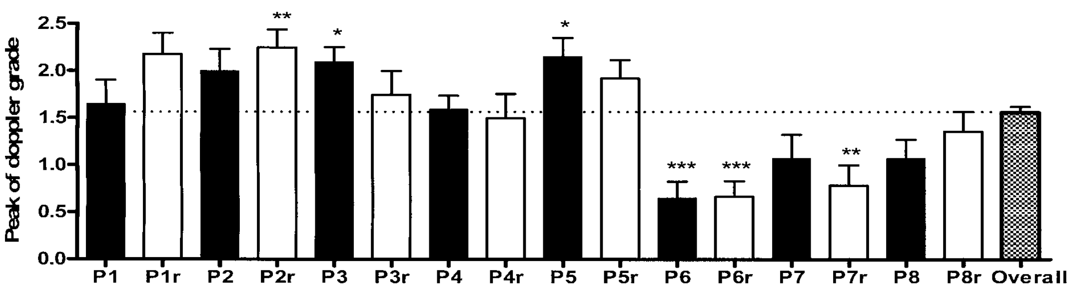
SS	SDBG	ESS
0	LBG	0
1	LBG	0.5
1	LBG	1
2	LBG	1.5
2	HBG	2
3	HBG+	2.5
3	HBG+	3
4	HBG+	3.5
4	HBG+	4

In order to correlate BSI to tissue saturations, all dive profile data were downloaded from the depth-time recorders and analyzed using the Bühlmann algorithm (3) to predict the supersaturation peaks for each of the 8 tissue compartments during the ascent. The changes in supersaturation were expressed as fractions of the respective M Values, and calculated from commencing the ascent until reaching the surface.

RESULTS

Figure 1 (a, b) summarizes the effect of the different profiles on ESS and SS Doppler bubble scores respectively. It shows the range of Doppler grade variation after each profile as expressed by the mean of the individual Doppler grade peak for each dive profile. Profile 2/2R (i.e., slow linear ascent) achieves the highest mean BSI, whereas profile 6/6R (i.e., deep and shallow stop with a 10 m/min ascent rate) is the lowest.

Fig. 1a: Doppler Grade Variation (ESS) after each dive profile



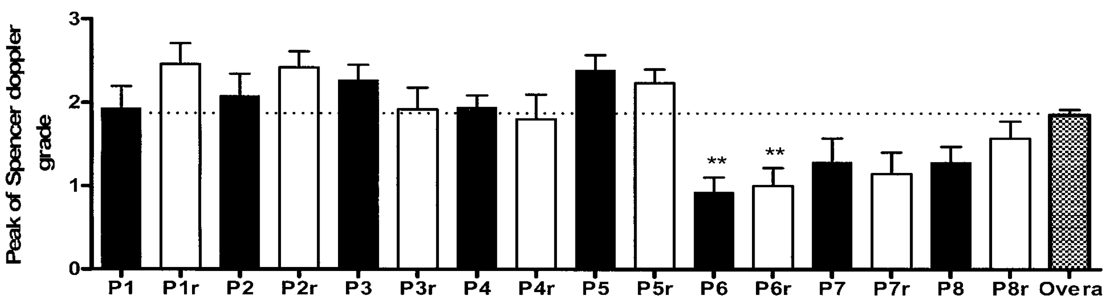
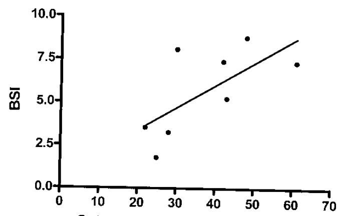


Fig. 1b: Doppler Grade Variations (SS) after each dive profile. The comparison of means has been done computing the peak Doppler scores for each individual after each dive profile according to the Expanded Spencer Scale (ESS) and Spencer Scale (SS). The means have been compared using parametric tests when possible after KS normality testing (ANOVA with Neuman-Keuls post tests) and Kruskal-Wallis and Dunn's post test when the normality testing does not allow parametric evaluation. By accepting a ESS score of 1.5 and an SS score of 2 as "safe", it can be seen that the deep stop appears "safer" using both ESS and SS scales, while repetitive profiles 1,2,3 and 5 are "unsafe".

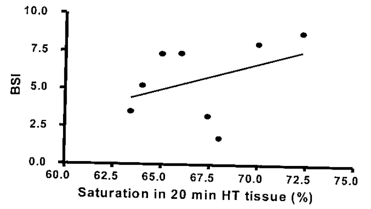
Figure 2 (a-d) shows the various regression analyses for BSI vs. saturation of the 5, 10, 20 and the 10 and 20-minute tissues combined as predicted by the Bühlmann algorithm. It can be seen that the correlation between the predicted saturation of the 10 minute tissue, and the 10 and 20-minute tissues combined, vs. BSI achieve statistical significance but not for the 5 or 20-minute tissues.

Fig. 2a. 5-min tissue saturation versus BSI



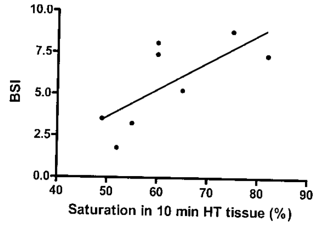
$r^2 = 0.46$; r = 0.67; p =0.66; y=0.1312 x + 0.76

Fig. 2b. 10-min tissue saturation versus BSI



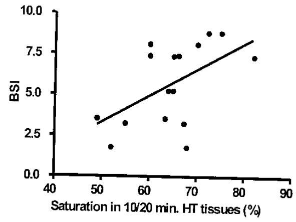
$r^2 = 0.17$; r = 0.41; p =0.17; y=0.35 x - 18

Fig. 2c. 20-min tissue saturation versus BSI



r^2=0.5173; r=0.72; p=0.044; y=0.1646x -4.581

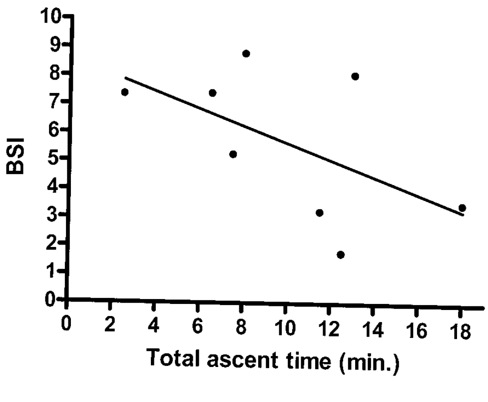
Fig. 2d. 10 and 20-min tissue saturation versus BSI



r^2 = 0.29; r = 0.54; p =0.03; y=0.16x - 4.8

Figure 3 shows a regression analysis of BSI vs. total ascent time. This shows the absence of a significant correlation between total ascent time and BSI.

Fig. 3. BSI vs. total ascent time



r^2=0.2935; r= 0.54; p=0.165; y=0.2945x+8.5885

This together with the significant correlation found between the 10 minute tissue saturation and the BSI supports our hypothesis that the level or supersaturation of the fast tissues determines the BSI, rather than the time it takes to reach the surface. The Highest Doppler scores were observed after linear ascents with no stops. Here predicted tissue saturations of the 5 and 10 minute tissue compartments exceeded 50 to 80% of the Bühlmann M Values (see Figure. 4a). The BSI for these dives reached values of 8.78 / 9.97 (ESS / SS) at an ascent rate of 3 m/min and 7.51 / 8.46 (ESS / SS) at an ascent rate of 10 m/minutes. For safety reasons the linear ascents at 18 m/minutes were not performed.

Fig. 4 a. Tracing of predicted tissue saturations for 5, 10 and 20-minute tissues according to the Bühlmann algorithm, vs. fraction of M-value achieved, during decompression from profile 2 (slow linear ascent of 3 m/min)

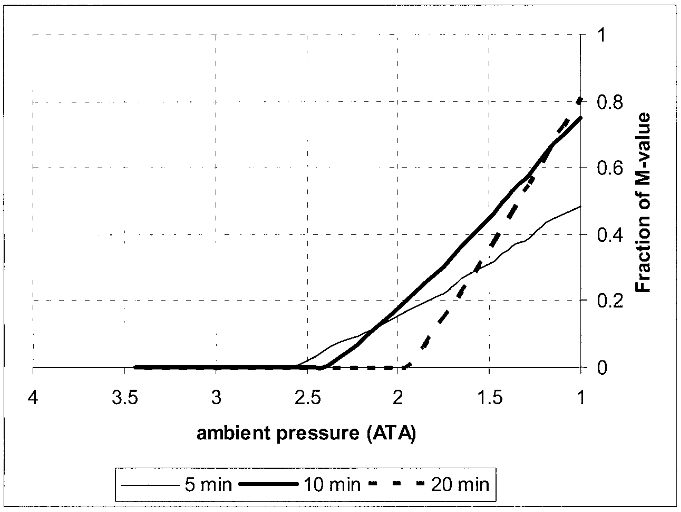
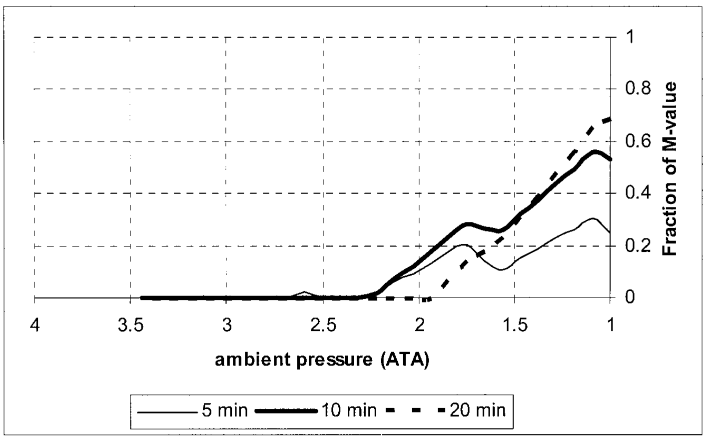


Fig. 4 b. Tracing of predicted tissue saturations for 5, 10 and 20-minute tissues according to the Bühlmann algorithm, vs. fraction of M-value achieved, during decompression from profile 6 (10 m/min ascent rate with deep and shallow stop)



High Bubble Grades (HBG) also were observed after dives with a stop only at 6 m for 5 minutes, with the predicted 5 and 10 minute tissues saturation exceeding 30% and 65% respectively. The BSI was 8.10 / 10.4 (ESS /SS) for the 3m/minute ascent rate; 7.41 / 8.78 (ESS / SS) for the 18 m/minute speed of ascent; and 5.39 / 7.07 (ESS / SS) for the 10 m/minute speed of ascent (Table 3). Finally, when a deep stop was also added, the predicted 5 and 10 minutes tissue tensions dropped to between 22 and 28%, and 49 to 55% respectively (see Figure 4b). The observed Doppler BSI reached minimum values of 3.25 / 4.64 (ESS / SS) for the 18m/minute speed of ascent, only 1.79 / 2.50 (ESS / SS) for the 10-m/minute speed of ascent, and 3.50 / 4.53 (ESS / SS) for the 3-m / minute speed of ascent.

Table 3 – Fast tissue saturation and bubble scores after the different dive profiles

Ascent Rate	Stops	Average surfacing saturation (%): 5 min Tissue	Average surfacing saturation (%): 10 min Tissue	BSI (ESS/SS)	Total Time to Surface minutes
3 m/min (Profile 2)	No Stop	48	75	8.78 / 9.97	8
3 m/min (Profile 5)	6 m / 5 min	30	60	8.10 / 10.04	13
3 m/min (Profile 8)	15 + 6 m / 5 min	22	49	3.50 / 4.53	18
10 m/min (Profile 1)	No Stop	61	82	7.51 / 8.46	2.5
10 m/min (Profile 4)	6 m / 5 min	43	65	5.39 / 7.07	7.5
10m/min (Profile 6)	15 + 6 m / 5 min	25	52	1.79 / 2.50	12.5
18 m/min (Profile 3)	6 m / 5 min	42	60	7.41 / 8.78	6.5
18 m/min (Profile 7)	15 + 6 m / 5 min	28	55	3.25 / 4.64	11.5

Although variations in the rate of ascent and the inclusion of a safety stop all affected the BSI and individual diver ESS scores (see Table 4) the lowest scores (1.79/2.50) were obtained by the addition of a 5 minute deep stop at 15 m (profile 6). Conversely, the highest BSI and ESS scores were associated with a linear, direct ascent to the surface at an ascent rate of 3 m/minutes with no stops (profile 2). Such high grade scores have, in previous studies by others, been associated with a higher risk of DCS (10, 16, 18).

DISCUSSION

In spite of gradual reductions in bottom time over the past decades, ascent rate and the addition of an arbitrary shallow safety stop at 5 m (15 ft) for 3-5 minutes, neurological decompression sickness remains a significant problem in recreational diving. A primary target for DCS appears to be the spinal cord with its 12.5 min half-time (4). This research with human divers produced two primary findings: (1) Slow ascents (3m/min) produced greater bubble grades than faster ascents (see Figure 5); and (2) the inclusion of a deep stop together with a shallow stop yielded the lowest bubble grades (see Figure 6). Therefore, contrary to popular belief, this study has indicated that a slow, linear ascent may produce significantly more bubbles than a more rapid ascent rate with a deep and shallow stop. Further, the optimal method for reducing post-dive bubble production is the combination of an ascent rate of 10 m/min (30 fsw/min) with a deep stop at about half the depth of the dive and a stop at 15 fsw (5 m) for 3-5 minutes.

Table 4 – Incidence of Doppler detected bubbles after the different dive profiles

Dive Profile	BSI (ESS / SS)	Grade 0 %	Low Grade %	High Grade %	Very High Grade %
1 – 1R	7.51 / 8.46	9.7	63.9	17.4	9.0
2 – 2R (worst)	**8.78 / 9.97**	**10.0**	**50.6**	**19.4**	**20.0**
3 – 3R	7.41 / 8.78	16.0	56.2	19.8	8.0
4 – 4R	5.39 / 7.07	18.6	62.8	10.9	5.7
5 – 5R	8.10 / 10.04	5.1	65.4	19.2	10.9
6 – 6R (best)	**1.79 / 2.50**	**64.7**	**33.3**	**2.0**	**0.0**
7–7R (2nd best)	*3.25 / 4.64*	***34.5***	***64.3***	***1.2***	***0.0***
8 – 8R *(3rd best)*	*3.50 / 4.53*	***33.3***	***63.1***	***3.6***	***0.0***

These observations suggest that it is necessary to re-examine strategies for gradual decompression of the fast tissue compartment to improve diving safety. By using the known dive data collection methodologies employed in Divers Alert Network Project Dive Safety; Project Safe Dive; and recently Project Dive Exploration and the Diving Safety Laboratory in America and Europe respectively, the effect of varying ascent rate and decompression may be evaluated. The present research with recreational divers was able to show, in accordance with our hypothesis, that the introduction of a 'deep stop' greatly reduced decompression stress as observed by Doppler-detectable bubbles. The regression analyses indicate that the 10 min tissue is most closely related to BSI scores for this type of diving. Therefore decompression profiles may need to focus more closely on the this 'tissue' as not only being a critical factor in the production of bubbles, but also possibly reflecting supersaturation within the spinal cord.

These observations also confirm a prior hypothesis of the authors (15) that the Delta-P imposed on the leading tissue (i.e., the depth of the first stop) may be a critical factor for the production of precordially detectable bubbles, and, possibly, for the development of neurological DCI in recreational dives.

While this study did not use DCS as an endpoint, there is previous research to support that high grades of bubbles do correlate with an increased incidence of DCS (10, 16-18). This study also indicates an improved gas elimination due to the inclusion of a deep stop which is the probable reason for the significant bubble reduction.

CONCLUSIONS

The introduction of a deep stop during decompression ascent appears to significantly decrease Doppler recorded bubbles and predicted gas tensions in the fast 'tissues' which may relate to actual gas exchange within the spinal cord. The authors conclude that such a deep stop may therefore significantly reduce the incidence of spinal cord related decompression sickness.

Further studies are planned to prove the direct correlation between this reduction in precordial bubbles and tissue gas tensions in the so-called fast tissues and the appearance of DCS. These observations and conclusions are relevant only to the types of recreational dives studied. They should not be extrapolated to deeper and longer decompression dives without additional research and analysis.

Fig. 5. Ascent Rate vs. % high & very high bubble grades for all profiles

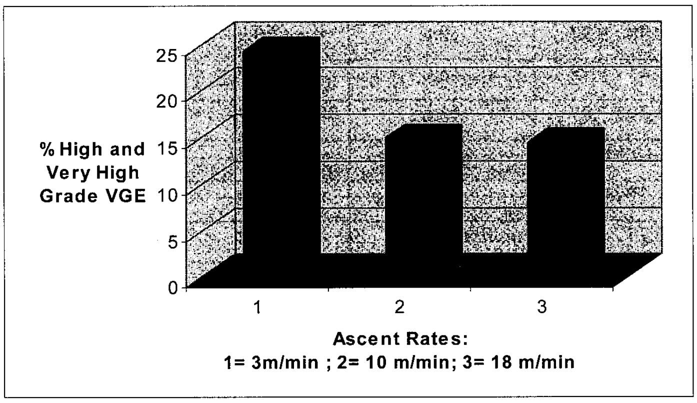
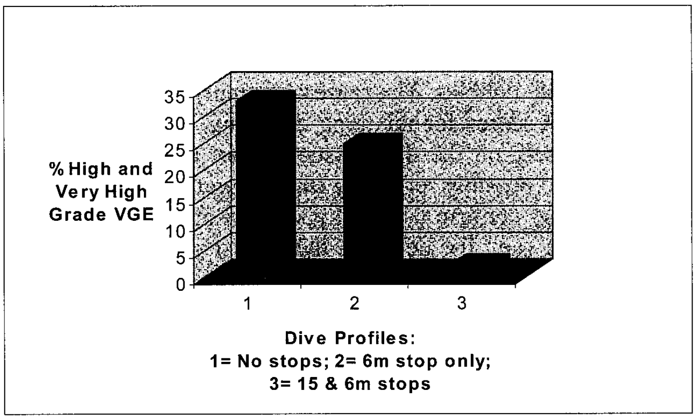


Fig 6. Percentage high and very high bubble grades versus stops (all ascent rates)



ACKNOWLEDGEMENT

This work would not have been possible without the enthusiasm and professional dedication of the divers of the Italian Dive Clubs – "Ravenna Sub" and "Sub Novara Laghi" led respectively by Riccardo Pepoli and Daniele Pes. The data they provided – which include the dive profiles and Doppler recordings of excellent quality – have made an invaluable contribution to the advancement of recreational dive safety.

References

1. Bennett PB, Marroni A, Balestra C, Cali-Corleo R, Germonpre P, Pieri M, Bonuccelli C. What ascent profile for the prevention of decompression sickness? I – Recent research on the Hill/Haldane ascent controversy. Proceedings of

the 28th Annual Scientific Meeting of the European Underwater and Biomedical Society, pp 35-38:2002. September 4-8. Brugge, Belgium.

2. Hempleman HV. History of decompression disorders. In The Physiology and Medicine of Diving, 4th edition. Eds PB Bennett and DH Elliott, pp 342-375:1993. Saunders, London.
3. Bühlmann AA. Decompression theory: Swiss practice. In The Physiology and Medicine of Diving, 2nd edition. Eds PB Bennett and DH Elliott, pp 348-365:1975. Williams and Wilkins, Baltimore.
4. Edmonds C, Lowry C and Pennefather J. Historical and physiological concepts of decompression. In Diving and Subaquatic Medicine, pp 40-158:1992. Butterworth-Heinemann.
5. Valentine R. Physiologists, Fathometers and Menfish. Proceeding 10th Conference Historical Diving Society. Plymouth UK Historical Diving Times, pp 26:10-14:2000.
6. Wong RM. Empirical diving techniques. In Bennett and Elliott's Physiology and Medicine of Diving, 5th edition. Eds AO Brubakk and TO Neuman, pp 64-76:2003. Saunders, London.
7. Marroni A, Bennett PB, Balestra C, Cali-Corleo R, Germonpre P, Pieri M, Bonuccelli C. What ascent profile for the prevention of decompression sickness? II – A field model comparing Hill and Haldane ascent modalities, with an eye to the development of a bubble-safe decompression algorithm. Proceedings of the 28th Annual Scientific Meeting of the European Underwater and Biomedical Society, pp 44-48:2002. September 4-8. Brugge, Belgium.
8. Marroni A, Cali-Corleo R, Denoble P. Understanding the safety of recreational diving. DAN Europe's Project SAFE DIVE Phase I: Fine tuning of the field research engine and methods Proceedings of the International Joint Meeting on Hyperbaric and Underwater Medicine, EUBS, ECHM, ICHM, DAN., p. 279-284:1996 September 4-8 Milano, Italy.
9. Marroni A, Cali Corleo R, Balestra C, Voellm E, Pieri M. Incidence of Asymptomatic Circulating Venous Gas Emboli in Unrestricted, Uneventful Recreational Diving. DAN Europe's Project SAFE DIVE first results. EUBS 2000 Proceedings. Diving and Hyperbaric Medicine, Proceedings of the XXVI Annual Scientific Meeting of the European Underwater and Baromedical Society, R Cali Corleo ed., p 9-15:2000, September 14-17 Malta.
10. Spencer MP, Johanson DC. Investigation of new principles for human decompression schedules using the Doppler ultrasonic blood bubble detector. Tech. Report to ONR on contract N00014-73-C-0094, Institute for Environmental Medicine and Physiology, Seattle, Wash. USA. 1974.
11. Marroni A, Cali Corleo R, Balestra C, Longobardi P, Voellm E, Pieri M, Pepoli R. Effects of the Variation of Ascent Speed and Profile on the Production of Circulating Venous Gas Emboli and the Incidence of DCI in Compressed Air Diving. Phase 1. Introduction of extra deep stops in the ascent profile without changing the original ascent rates. DSL Special Project 01/2000. EUBS 2000 Proceedings. Diving and Hyperbaric Medicine, Proceedings of the XXVI Annual Scientific Meeting of the European Underwater and Baromedical Society, R. Cali Corleo ed., 2000: p 1-8: 2000, September 14-17 Malta.
12. Marroni A, Cali Corleo R, Balestra C, Longobardi P, Voellm E, Pieri M, Pepoli R. The Use of a "Proportional M-Value Reduction Concept" (PMRC) Changing the Ascent Profile with the Introduction of Extra Deep Stops Reduces the Production of Circulating Venous Gas Emboli after Compressed Air Diving. DSL Special Project 01/2001. EUBS 2001 Proceedings of the 27th Annual Meeting. U van Laak ed.,: p 69-73: 2001, September 12-16, Hamburg, Germany
13. Diggle P, Liang KY, Zeger SL. 1995. Analysis of Longitudinal Data. Oxford Science Publications, Clarendon Press: Oxford.
14. Zeger SL, Liang K-Y, Albert PS. Models for longitudinal data: a generalized estimating equation approach. Biometrics 44, 1049-1060; 1988.
15. Marroni A, Cali Corleo R, Balestra C, Longobardi P, Voellm E, Pieri M, Pepoli R. The Use of a "Proportional M-Value Reduction Concept" (PMRC) The Speed of Ascent Dilemma: "Instant Speed of Ascent" or "Time to Surface" – which one really matters? Instant speed of ascent vs Delta-P in the leading tissue and post dive Doppler Bubble production.. DSL Special Project 02/2001. EUBS 2001 Proceedings of the 27th Annual Meeting. U van Laak ed.: p 74-78: 2001, September 12-16, Hamburg, Germany
16. Nashimoto I, Gotoh Y. Relationship Between Precordial Doppler Ultrasound Records and Decompression Sickness. In: CW Shilling, MW Beckett (eds) Underwater Physiology VI. Undersea Medical Society, Bethesda 1978:497-501.
17. Marroni A, Zannini D. Effetti della variazione della velocità di risalita sulla produzione di bolle gassose circolanti dopo immersioni ad aria compressa. *Min Med* 1981(Dec):3567-3572.
18. Nishi RY, Brubakk AO, Eftedal OS. Bubble detection. In: Bennett and Elliott's Physiology and Medicine of Diving. AA Brubakk, T Newman (eds) 5th edition. WB Saunders Company, London 2003:501-529.