Incidence of Asymptomatic Circulating Venous Gas Emboli in unrestricted, uneventful Recreational Diving. DAN Europe's Project SAFE DIVE first results

A. Marroni [1-2], R. Cali Corleo [1-2], C. Balestra [1-3], E. Voellm [4], M. Pieri [1]

1) DAN Europe Foundation, Research Division . 2) Division of Baromedicine, University of Malta Medical School. 3) Haute Ecole Paul Henry Spaak, Human Biology Dept. Bruxelles. 4) Uwatec AG, Hallwill, Swizterland

INTRODUCTION

The requirements of medical research on recreational diving differs from those of military or commercial diving. This is principally due to the fact that recreational diving is not easily reproducible in a laboratory because of the wide variety of profiles and practices utilized by recreational divers world-wide. A recreational dive may vary from the relatively shallow, repetitive dive carried out in the Caribbean to the single deep daily dive usually practised in the Mediterranean.

Fitness standards in recreational diving are much less stringent than in professional diving and the age range of a recreational diver starts from pre-teenage with no defined upper limit, while professional diving is usually restricted to persons from young adult to early middle age.

This creates difficulties when designing a research protocol to examine and define the level of risk associated with recreational diving because of the large number of variables present. These variables and the fact that DCI is a very rare occurrence requires that the number of dives in the study has to be very large to produce results which can be statistically significant.

Project SAFE DIVE, an autonomous core study in the International DAN study DIVE SAFETY, was intended to eliminate the above mentioned problems by monitoring a very large and varied sample of European diving.

SCOPES OF THE PROJECT AND TRAINING OF THE RESEARCH FIELD OPERATORS

The type of diving being monitored is not restricted in any way, in fact, the protocol has been designed in such a way as to influence the subject divers minimally, allowing them to dive where, when and how they wish and normally do.

The size of dives sample planned is much too large to be monitored personally by the scientists forming part of DAN Europe's and International DAN's research teams. This problem has been eliminated with the creation of a special training scheme whereby the divers and instructors themselves are trained to act as data collectors in the field. Two levels of training are being given to the volunteers wishing to become part of DAN's research group. The course prepared by DAN Europe trains the participant in the use of the project software called Data Acquisition Software (DAS for short) and in the correct filling in of the project forms. They are also instructed how to monitor the divers they are accompanying in a discrete way and how to follow them up for the 48 hours following their last dive or altitude change.

The participants, who are normally diving instructors, were also taught how to monitor the subject divers for post dive vascular bubbles, using a specially designed Doppler recorder, and how to use a special dive monitoring device called the "Divers Black Box".

On completing the advanced course successfully the participants become Research Field Operators (RFO).

The core study SAFE DIVE aimed to define the true value of post-dive Doppler monitoring in predicting a clinical outcome following particular dive profiles and in particular diver types.

DAN Projects SAFE DIVE and DIVE SAFETY Worldwide – 1995 - 1999

Between 1995 and 1999, over 16.000 recreational, unrestricted dives were monitored worldwide and entered into the original DAN Data Acquisition Software (DAS) for statistical analysis.

The core project SAFE DIVE, conducted by DAN Europe, in the same period collected 2105 fully monitored recreational dives, during 75 Research Trips organized by 106 Research Field Operators and involving 575 volunteer Research Divers.

The Research Divers who elected to participate in a DAN Europe Research Trip carried a DAN-UWATEC Black Box during their monitored dives, and dedicated a few minutes to fill the project's questionnaires and for circulating Venous Gas Emboli (VGE) Precordial Doppler Monitoring, according to the protocol described in our earlier publications (1, 2).

The DAN Europe Black Box consists of a specially modified dive computer, where the data display is blank, whilst in diving mode and all the alarm functions and signals, in order to assure an objective recording of the diva data and profiles, without any possible influence on the divers' behavior underwater.

To date, 67% of the available data have been analyzed and the first results are presented in this study.

We evaluated 1418 electronically downloaded dive profiles, from 41 Research Trips. 2136 Doppler Recordings were effected by the Research Field Operators, only 409 of which were considered not interpretable and were rejected. The Doppler Recording Rejection rate was only 19%, to confirm the validity of the concept that recreational divers can effectively be trained to recover valid and useful post-dive Doppler Recordings, to be evaluated by specialists for the presence of bubble signals at a different time.

We could evaluate 1058 successfully "Dopplered" dives, 521 of which were Doppler monitored every 10-15 minutes, for 75 to 90 minutes post dive. This portion of dives was more intensively monitored with the scope to confirm that the standard monitoring interval of approximately 30 minutes after surfacing we adopted for the study was correct.

This interval was selected as it represented a logistically acceptable compromise for the recreational divers and the diving centers, allowing for effective monitoring in virtually all the recreational diving conditions we tested, without disturbing the normal post-dive operations and activities for both the divers and the dive centers or boats.

The distribution by depth of the monitored dives showed that the relative majority (33,15%) of the dives were made in the 20 to 30 meters depth range and the absolute majority (over 56%) in the 20 to 40 meters range. 23,42% of the dives were shallow, between 10 and 20 meters, 12,97% were made between 40 and 50 meters, while 4,65% were very shallow, within 10 meters and only 1,84% were deeper than 50 meters- The Overall depth range varied from 5 to 65 meters.

Table 1. Distribution by depth of the 1418 monitored dives

Depth	0-10	10-20	20-30	30-40	40-50	>50
Percent	4,65	23,42	33,15	23,97	12,97	1,84

Incidence of Doppler Bubble Signals and correlation to the different dive variables in the monitored dives sample

The Doppler recordings were evaluated by trained and expert independent evaluators, who listened to the recorded cassettes undisturbed, in laboratory conditions and were blinded as to what regarded the dive profiles, the answers to the questionnaires, and any medical problem, symptom or sign. The names of the divers were also unknown by the evaluators, who coded the recording using the Project's alphanumeric codes only.

The correlation between the evaluated Doppler Bubble Grades and the dive profiles was evaluated by a separate member of the team, by multiple regression statistical analysis of the electronically downloaded dive profiles, correlated with the Doppler Bubble Gradings.

Doppler Grades were assigned according to the Spencer Protocol, from Grade Zero to Grade Four, but an adaptation of the grading protocol was made, dividing the Doppler Bubble Grades (DBG) into two categories: Low Bubble Grades (LBG) - occasional bubble signals over the one minute recording (Spencer grades lower than 2), and High Bubble Grades (HBG) – frequent to continuous bubble signals (Spencer grades higher than 2).

Doppler detectable bubbles were observed in 37,4% of all the monitored dives, while 62,6% of the dives were bubble free. 25,4% of the dives produced LBG recordings only, while 12% produced High Bubble Grades and 2,4% produced Very High Bubble Grades (HBG+), between grade 3 and 4 according to the Spencer scale.

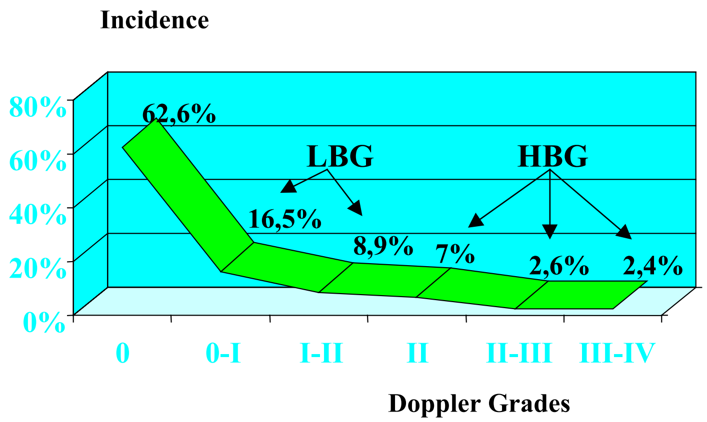

Table 2. Incidence of Doppler Bubble signals after all the 1418 monitored dives

We also performed a comparison test to assess the relative frequency of Doppler signals in all the dives and in the Repetitive Dives, considered per se, in the sample of 521 dives that were monitored for Doppler signals every 10-15 minutes. Not completely to our surprise, as the data are coherent with the DAN Diving Accidents Reports of the last 15 years, which showed a relatively higher frequency of DCI after repetitive and multiple dives, we observed that the LBG to HBG frequency ratio is inverted for the repetitive dives we monitored, and that VGE were detectable in the majority of the repetitive dives, while only 15% of them were bubble free.

Furthermore, the majority of the repetitive dives produced HBG recordings (67%), against 18% incidence of LBG.

Table 3. Incidence of Doppler Bubble Signals after all the dives and after the repetitive dives separately. Sample of 521 dives			
DBG	Zero	LBG	HBG
All Dives	55%	22%	23%
Rep Dives	15%	18%	67%

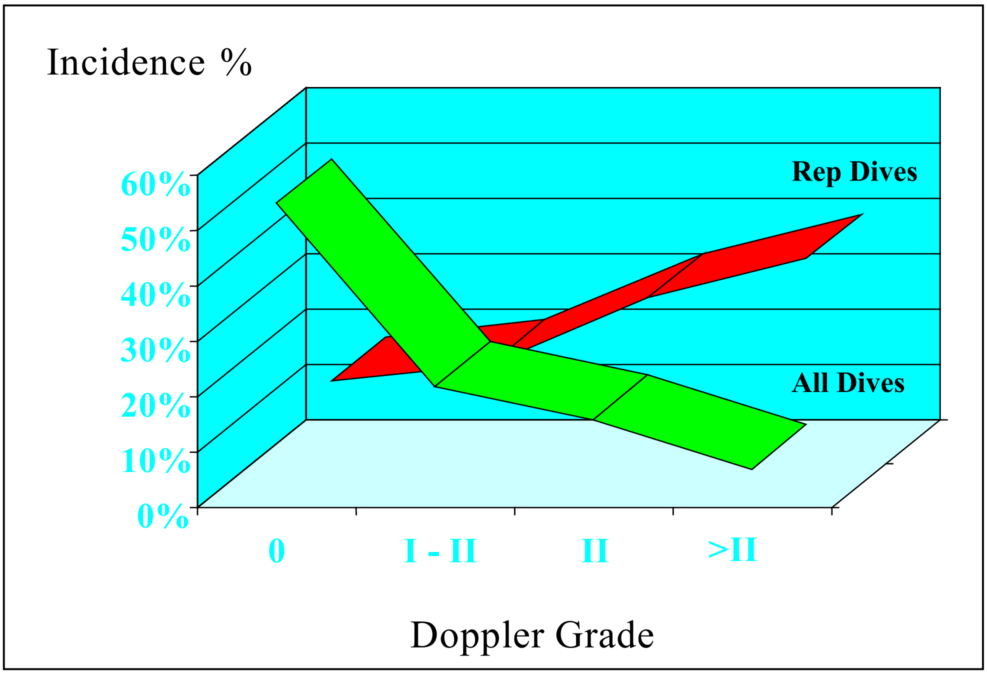

Table 3a. Incidence of Doppler Bubble Signals after all the dives and after the repetitive dives separately. Sample of 521 dives

The Depth of the dive appeared to influence the average Doppler Grade, with a tendency to higher Doppler Grades with the increase of the dive depth.

Table 4. Average Doppler Grades as a function of dive depth in meters.				
DBG	Zero	LBG	HBG	HBG+
Average Depth	25	28	31	33

Coherently, the higher the Decompression Debit, as indicated by the decrease of the remaining No-Decompression Time or by the increase of the Necessary Time to Surface, the higher the Doppler Bubble Grade observed .

Table 5. Average Doppler Grades as a function of the computed Decompression Debit expressed as average time to / for Deco – and range – in minutes				
DBG	Zero	LBG	HBG	HBG+
Deco Debit	-38 (-100 + 20)	-25 (-100 +20)	-18 (-40 +10)	-4 (-40 +20)

The ZH-L8 ADT UWATEC model we used for the calculation of the downloaded dive profiles, also allowed for other, more specific, calculations with regard to the variables normally considered in decompression calculations.

We specifically observed the computer-estimated levels of Nitrogen Venous Partial Pressure (Pven N_2), as a variable logically related to the occurrence of Venous Gas Emboli, and the Maximum Nitrogen Partial Pressure in any tissue compartment at any moment, which we called the Leading Tissue Nitrogen Partial Pressure ($PltN_2$), and which was confronted to the currently allowed Maximal Supersaturation Value (M Value) for that tissue compartment.

The Average DBG was observed to increase with the increase of Pven N_2 and $PltN_2$.

In particular Pven N_2 appeared to be directly related to the DBG. Our data suggest that no bubbles or LBG can be expected when Pven N_2 is kept under 1100 mbar, but HBG can be expected when Pven N_2 is allowed to be higher than 1100 mbar.

Table 6. Average Doppler Grades as a function of the computed Venous Nitrogen Partial Pressure in mbar.				
DBG	Zero	LBG	HBG	HBG+
Pven N_2	1080	1080	1200	1220

According to the UWATEC ZH-L8 ADT model the fast to medium Half Time tissues (HT 20 – 80 minutes) seem to be mainly responsible for bubble formation, with a trend to produce more bubbles when the Leading Tissue's Half Time is shorter.

The speed of ascent per se was also considered, in the attempt to evaluate if any period – if brief - of fast ascent, during the total ascent time had an influence on bubble formation. We could not find any correlation between the fractional speed of ascent and the monitored DBG.

The evaluation of the Average DBG as a function of the $PltN_2$ showed that the currently adopted M Values may be excessive and that Zero Bubbles or LBG can be expected only if the $PltN_2$ is kept under 80% of the allowed M Value, while HBG can be expected if the $PltN_2$ exceeds 80% of the M Value.

Table 7. Average Doppler Grades as a function of the computed Leading Tissue Nitrogen Partial Pressure, expressed as a fraction of the M Value.				
DBG	Zero	LBG	HBG	HBG+
$PltN_2$ / M Value	< 0,8	< 0,8	0,8 – 0,9	> 0,9

The time of maximal Bubble Grade after surfacing was found to be between 30 and 40 minutes, with a trend to be closer to 30 minutes for HBG, which appeared to peak earlier than LBG. This confirms that the 30 minute post dive interval we adopted as the standard Doppler Time in our field studies is correct, as well as logistically feasible.

Table 8. Peak Doppler Grades as a function of time interval after surfacing, in minutes				
DBG	Zero	LBG	HBG	HBG+
Interval	--	38	33	31

Summary of the results

Circulating venous gas bubbles have been found to be a common occurrence in the, otherwise uneventful, recreational dives monitored during the DAN Europe's Project SAFE DIVE between 1995 and 1999. Doppler monitored bubbles have been detected in 37,4% of all the monitored dives. 25,4% of the dives produced LBG recordings only, while 12% produced High Bubble Grades and 2,4% produced Very High Bubble Grades (HBG+), between grade 3 and 4 according to the Spencer scale.

Repetitive dives showed a different incidence of post dive VGE, with only 15% of the repetitive dives bubble free and an inverted LBG to HBG frequency ratio, with HBG recorded in 67% of the repetitive dives, and LBG in 18% of the repetitive dives only.

VGE were detected at any time until 90 minutes post dive, but peaked to the higher detected levels between 30 and 40 minutes after surfacing, with a tendency to peak earlier for higher Bubble Grades.

In general VGE were found more frequently and at different timings than expected according to the adopted algorhythm.

No clear correlation was found between any fractional fast ascent period during any phase of the total ascent and the DBG.

The fast to medium Half Time Tissues seem to be the ones mainly involved in the production of gas bubbles in the monitored recreational dives, with a trend to higher bubble grades when the leading tissue Half Time is faster.

A direct correlation between the Venous Nitrogen Partial Pressure and the DBG was observed, with Zero Bubbles or LBG only when the calculated $PvenN_2$ was lower than 1100 mbar , and HBG when the calculated $PvenN_2$ was higher than 1100 mbar.

The Leading Tissue calculated Nitrogen supersaturation was also found to be related to the DBG, with Zero Bubbles or LBG found when the $PltN_2$ was lower than 80% of the admitted M Value and HBG when it was higher than 80% of the M Value.

DBG were directly related to the Decompression Debit after any dive, calculated as residual No Decompression Time or Necessary Time To Surface, with higher DBG for increasing Decompression Debit.

These last three findings ($PvenN_2$, $PltN_2$ and Deco Debit) are coherently related.

Questions raised

Would a correction of the algothythm used to compute the ascent and decompression phase reduce the total incidence of VGE and the level of DBG?

Why is the DBG max occurring 30 – 40 minutes after the dive?

Why are there "High Grade Bubblers", "Low Grade Bubblers" and "Non Bubblers" after the very same dive?

Why not all "Bubblers" develop DCI? Where is the patho-physiological link between Bubbles and DCI?

The observed data showed high standard deviations and low correlation factors (around 0,3). What other factors capable of influencing VGE production and DBG are we ignoring?

Conclusion

It is hypothesized that a slowing down of the deep phases of the ascent, through the alteration of the ascent slope should reduce initial bubble generation at depth. Further studies to confirm this hypothesis are already underway.

References

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