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

A. Marroni [1-2-6], R. Cali Corleo [1-2-6], C. Balestra [1-3-6], P. Longobardi [4-6],

E. Voellm [5-6], M. Pieri [1-6], R. Pepoli [6-7]

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, Belgium. 4) Centro Iperbarico, Ravenna, Italy. 5) Uwatec AG, Hallwill, Swizterland. 6) DAN - UWATEC Diving Safety Laboratory. 7) Ravenna Sub, Ravenna, Italy

Introduction

The first results of the DAN Europe SAFE DIVE project, obtained from 1418 recreational dives fully monitored according to the original DAN Europe SAFE Dive Protocol (1, 2, 3) showed that post dive High Bubble Grades (HBG), as detected with a Doppler Ultrasound Bubble Detector (DAN Europe Design, 1,2), graded according to the Spencer Method (4), modified by DAN Europe for this particular field use (3), and correlated to the electronically downloaded dive profiles, are directly related to:

1) Fast to Medium Half Time Tissues according to the UWATEC ZH-L8 ADT model

2) Computed Nitrogen Venous Partial Pressure (PvenN$_2$) higher that 1100 mbar

3) Computed Leading Tissue Nitrogen Partial Pressure (PltN$_2$) higher than 80% of the allowed M Value for that tissue.

4) Total Decompression Debit expressed as computed residual No-D time or computed Time to Reach Surface.

5) Absolute Depth of the Dive

6) Repetitive Dives

7) The fact that no evident correlation could be found between HBG and the fractional speed of ascent at any given time of the ascent.

Materials and Methods

DAN Europe and UWATEC, within the common research project known under the name of DAN-UWATEC Diving Safety Laboratory, started a specific research protocol (DSL Special Project 01/2000), aimed at identifying bubble-safer dive profiles and based on the findings of DAN Europe Project SAFE DIVE.

Three relatively common square dive profiles were selected:

a single dive to 20 meters for 60 minutes bottom time (including 1' 40'' descent)

a single dive to 40 meters for 10 minutes bottom time (including 3' 01'' descent)

a series of three repetitive dives to 30 meters for 16 minutes bottom time (including 2' 40'' descent) with 75 Surface Interval between them.

The dives were made according to the original ZH-L8 ADT model an repeated one week after with the same group of divers and a modified algorhythm.

The new model was designed without changing the original fractional speed of ascent and was aimed at keeping the $PvenN_2$ below 1100 mbar and the $PltN_2$ below 80% of the allowed M Value.

The five dives – 2 single, 3 repetitive – were made by 3 groups of 3 volunteer divers of the Dive Club Ravenna Sub, who had been informed about the scopes and the modality of the test and knew that they would have dived according to standard tables on their first dive series and on experimental tables on the second dive series. All the divers signed and informed consent form, as requested by the Clinical Hyperbaric Facility and the DAN Europe Research Division.

The two series of dives were performed on two consecutive Saturdays, to allow for complete desaturation of the divers between the dives, and all the divers accepted not to dive on their own in the interval.

The dives were performed in the Multiplace Hyperbaric Chambers of the Centro Iperbarico di Ravenna, Italy. Three couples of Black Boxes – modified UWATEC computers as described in our previous work (1,2) - were kept in the chamber during each of the five different dives, and the same couples were used the following Saturday for the second dive series, assuring that the same computers were used for the same dive series. To assure that the Black Boxes worked properly, they were immersed in water all the time during the chamber dives.

Of the 9 volunteer divers, 3 – one for each dive series - were known "Bubblers" form previous SAFE DIVE Research Trips organized by the Dive Club Ravenna Sub.

Doppler Recording were performed by a member of the Research Team, every 15 minutes after the dives, up to 75 or 90 minutes, and evaluated subsequently in undisturbed laboratory conditions.

We graded the Doppler Bubble Signals according to the Spencer Scale (4) and also according to a Doppler Bubble Grading System that we designed, as a variant of the Spencer method, as follows:

♦ 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 higher than 2 in the Spencer scale.

Occasional very high DBG were rated HBG+ grading, when bubble signals reached grade 4 in the Spencer scale.

Results

Dive series 1 – 20 meters 60 minutes. Both dives clinically uneventful

Dive 1a

Depth	20	20 – 3	3	3 -0	Total Ascent
Time	60	2.05	15	0.25	17.30

Dive 1b

Depth	20	20 – 9	9	9 – 6	6	6 – 3	3	3 – 0	Tot. Asc.
Time	60	1.15	1	0.20	9	0.25	19	0.25	31.25

Doppler Readings Dive series 1

Dive 1a – 20 meters 60 minutes total ascent time 17,30 minutes							
Research Diver	"Bubbler"	DBG at 15 minutes	DBG at 30 minutes	DBG at 45 minutes	DBG at 60 minutes	DBG at 75 minutes	DBG at 90 minutes
RS31	Medium	1	2.5	2	2	2	2
RS32	High	2	2.5	2.5	2	2	2
RS33	Medium	1	1	0.5	3	2	1
Dive 1b – 20 meters 60 minutes total ascent time 31,25 minutes							
Research Diver	"Bubbler"	DBG at 15 minutes	DBG at 30 minutes	DBG at 45 minutes	DBG at 60 minutes	DBG at 75 minutes	DBG at 90 minutes
RS31	Medium	0	1	0	0	0	0
RS32	High	0	0,5	1	1	0	0
RS33	Medium	0	0	0	1	0	0
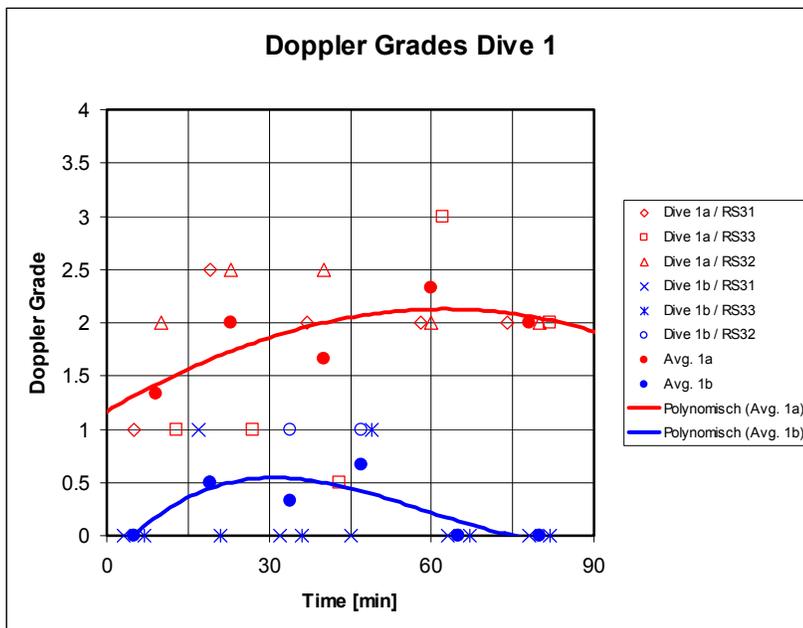
Graph 1. Doppler Bubble Grades after the 20 meter dive series for standard (upper curve) and modified profiles (lower curve).

Dive Series 2 – 40 meters 10 minutes. Dive 2a produced Skin DCI in diver RS34

Dive 2a

Depth	40	40 – 0	Total ascent
Time	10	4	4

Dive 2b

Depth	40	40-12	12	12 – 9	9	9 – 6	6	6 - 3	3	3 - 0	Tot Asc
Time	10	1.25	2	0.20	3	0.20	5	0.25	6	0.25	18.55

Doppler readings Dive Series 2

Dive 2a – 40 meters 10 minutes total ascent time 4 minutes							
Research Diver	"Bubbler"	DBG at 15 minutes	DBG at 30 minutes	DBG at 45 minutes	DBG at 60 minutes	DBG at 75 minutes	DBG at 90 minutes
RS34	High	1	2	3	3	2	2
RS35	Low	0	0	1.5	1.5	1.5	-
RS36	Low	0	1.5	1	1.5	1.5	-
Dive 2b – 40 meters 10 minutes total ascent time 18.55 minutes							
Research Diver	"Bubbler"	DBG at 15 minutes	DBG at 30 minutes	DBG at 45 minutes	DBG at 60 minutes	DBG at 75 minutes	DBG at 90 minutes
RS34	High	0	0	0	0.5	0	0
RS35	Low	0	0	0.5	0	0.5	0
RS36	Low	0	0.5	0.5	0.5	0.5	0.5
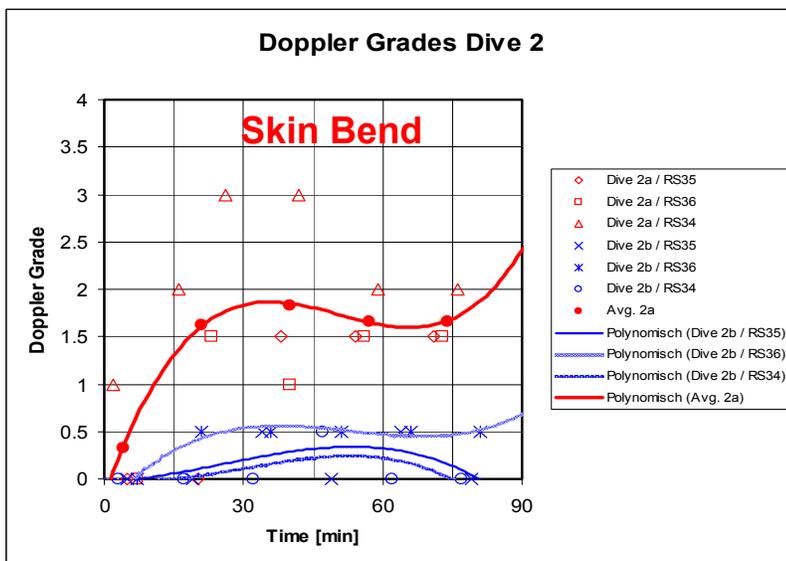
Graph 2. Doppler Bubble Grades after the 40 meter dive series for standard (upper curve) and modified profiles (lower curve).

Dive Series 3 – 30 meters 16 minutes. Three repetitive dives with 75 minutes surface interval. All Dives clinically uneventful.

Dive Series 3a

3.1a			
Depth	30	30 – 0	Total ascent
Time	16	3.25	3.25

3.2a					
Depth	30	30 – 3	3	3 – 0	Tot asc
Time	16	3	3	0.25	6.25

3.3a							
Depth	30	30 – 6	6	6 – 3	3	3 – 0	Tot asc
Time	16	2.30	1	0.25	7	0.25	11.20

Dive Series 3b

3.1b											
Depth	30	30–12	12	12-9	9	9-6	6	6-3	3	3-0	Tot asc
Time	16	1.25	2	0.20	3	0.20	5	0.25	6	0.25	18.55
3.2b	*75 minutes surface interval*										
Depth	30	30–12	12	12-9	9	9-6	6	6-3	3	3-0	Tot asc
Time	16	1.25	2	0.20	3	0.20	5	0.25	6	0.25	18.55
3.3b	*75 minutes surface interval*										
Depth	30	30–12	12	12-9	9	9-6	6	6-3	3	3-0	Tot asc
Time	16	1.25	2	0.20	3	0.20	5	0.25	6	0.25	18.55

Doppler Readings. Dive Series 3

First Dive

Dive 3.1a – 30 meters 16 minutes total ascent time 3.25 minutes							
Research Diver	"Bubbler"	DBG at 15 minutes	DBG at 30 minutes	DBG at 45 minutes	DBG at 60 minutes	DBG at 75 minutes	DBG at 90 minutes
RS37	Low	0	0.5	0.5	1	1	-
RS38	High	0	0.5	1.5	1.5	1.5	-
RS39	Medium	1.5	1	1.5	0.5	0.5	-
Dive 3.1b – 30 meters 16 minutes total ascent time 18.55 minutes							
Research Diver	"Bubbler"	DBG at 15 minutes	DBG at 30 minutes	DBG at 45 minutes	DBG at 60 minutes	DBG at 75 minutes	DBG at 90 minutes
RS37	Low	0	0	0	0	0	-
RS38	High	0	0.5	0	0	0	-
RS39	Medium	0	0	0	0.5	0.5	-

First Repetitive Dive

Dive 3.2a – 30 meters 16 minutes total ascent time 6.25 minutes							
Research Diver	"Bubbler"	DBG at 15 minutes	DBG at 30 minutes	DBG at 45 minutes	DBG at 60 minutes	DBG at 75 minutes	DBG at 90 minutes
RS37	Low	1.5	1.5	1.5	0.5	0.5	-
RS38	High	2	1	2.5	2	2	-
RS39	Medium	1.5	1.5	1	1.5	1	-
Dive 3.1b – 30 meters 16 minutes total ascent time 18.55 minutes							
Research Diver	"Bubbler"	DBG at 15 minutes	DBG at 30 minutes	DBG at 45 minutes	DBG at 60 minutes	DBG at 75 minutes	DBG at 90 minutes
RS37	Low	0	1	0	0	0	-
RS38	High	1	1	0	0	1	-
RS39	Medium	0	0	0	1	0	-

Second Repetitive Dive

Dive 3.3a – 30 meters 16 minutes total ascent time 11.20 minutes							
Research Diver	"Bubbler"	DBG at 15 minutes	DBG at 30 minutes	DBG at 45 minutes	DBG at 60 minutes	DBG at 75 minutes	DBG at 90 minutes
RS37	Low	1.5	2	1.5	1.5	1	-
RS38	High	2.5	2	2	1.5	2	-
RS39	Medium	1	1	1.5	2	1.5	-
Dive 3.3b – 30 meters 16 minutes total ascent time 18.55 minutes							
Research Diver	"Bubbler"	DBG at 15 minutes	DBG at 30 minutes	DBG at 45 minutes	DBG at 60 minutes	DBG at 75 minutes	DBG at 90 minutes
RS37	Low	0	1	0	1	0	0
RS38	High	1	1	1.5	1	1.5	1
RS39	Medium	1	1	0	1	1	0
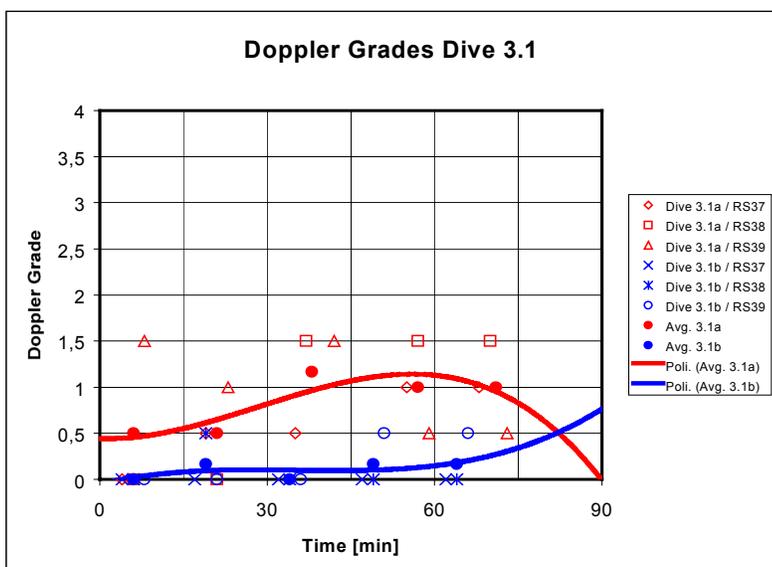
Graph 3.1. Doppler Bubble Grades after the first dive of the repetitive dive series for standard (upper curve) and modified profiles (lower curve).
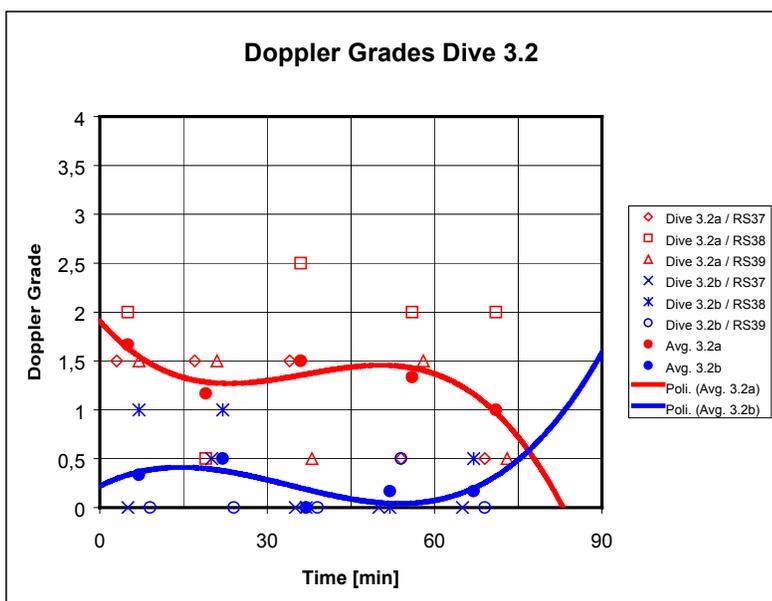
Graph 3.2. Doppler Bubble Grades after the second dive of the repetitive dive series for standard (upper curve) and modified profiles (lower curve).
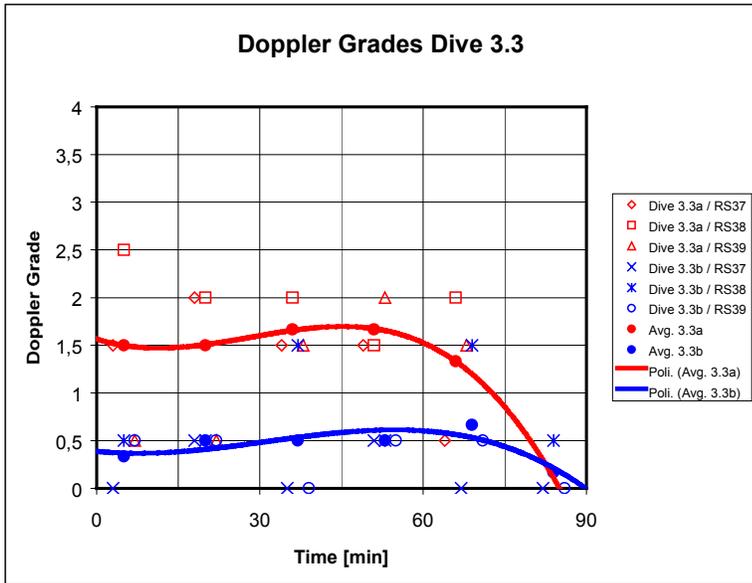
Graph 3.3. Doppler Bubble Grades after the third dive of the repetitive dive series for standard (upper curve) and modified profiles (lower curve).

General Results

During the series of 10 test dives (5 with a "regular" profile and 5 with the experimental profile), 184 Doppler Recordings were made on the 9 volunteer Divers. After Dive Series A - "Regular Profile" - 5 of the 9 Divers presented High Bubble Grades for extended time and 1 Diver suffered a mild episode of Skin Bend, which was promptly and successfully treated. After the Dive Series B - "Experimental Profile" - we could only monitor occasional Low Bubble Grades and all the dives were uneventful.

Dives A produced 6,3% DBG Zero, 58,2% LBG, 25,3% HBG and 10,2% HBG+. On the contrary Dives B produced 60,8% DBG Zero, 39,2% LBG and no incidence of HBG (See Table below).

Table I. Doppler Bubble Grades after "Regular" (A) and "Experimental" (B) Dive Profiles				
DBG	**Zero**	**LBG**	**HBG**	**HBG+**
DIVES A	6.3%	58.2%	25.3%	10.2%
DIVES B	60.8%	39.2%	--	--

Conclusions

The introduction of extra deep stops in the ascent profile from compressed air dives, without changing the fractional speed of ascent at any time, and keeping the computer-estimated $PvenN_2$ and $PltN_2$ levels within 1100 mbars and 80% of the allowed M Value, respectively, as suggested by the first results of DAN Europe Project SAFE DIVE, greatly reduced Doppler detected Bubble production in a sample of volunteer divers exposed to "regular" and "experimental" dive profiles and being their own control during the two consecutive chamber dive series.

Re-calculating the deep phases of decompression, through an alteration of the overall ascent slope, aimed at reducing the Pressure Differential imposed on the Fast to Medium Half Time Tissue Compartments (20 – 80 minutes according to the UWATEC ZH-L8 ADT Model) and to keep $PvenN_2$

and $PltN_2$ within the above indicated limits, may be effective in preventing gas nucleation during decompression from compressed air dives.

References

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