THE EFFECT OF ASCENT RATE ON CIRCULATING VENOUS GAS EMBOLI (VGE) FOLLOWING TRIMIX DIVES WITH SURFACE DECOMPRESSION

DEFENCE R&D DÉFENSE

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BACKGROUND

Fast ascent rates have generally been associated with an increased risk of DCS. An ascent rate of 9 or 10 meter seawater (msw)/min rather than the traditional 18 msw/min is now widely specified or recommended by a number of organizations. A slow ascent rate may possibly reduce post-dive VGE activity and decompression stress, thus reducing the risk of DCS.

DRDC Toronto has been tasked by the Canadian Forces (CF) to develop a full suite of TRIMIX decompression Tables, with 50%-50% He-N2 diluent, for use with the Canadian Underwater Mine Countermeasures Apparatus (CUMA), a semi-closed circuit breathing apparatus (***Figure 1***). Phase 2 of the research program has led to the development of a CUMA surface decompression (SurD) TRIMIX Table which is being validated for use as a potential replacement for the current CUMA HELIOX Tables.

All current CF decompression tables use a standard ascent rate of 18 msw/min. However, a pilot study appeared to indicate that an ascent rate of 10 msw/min might be beneficial for reducing VGE and a comparative study was performed using the two ascent rates.

Figure 1- *Four CUMA divers breathing trimix: 2 wet-working divers on underwater bicycle ergometers (electrically braked: 50 W; 5 min cycling-5 min rest) wearing dry suits in 6-8°C water, one standby diver (partially wet, resting), and a team leader (dry, lightly working).*

METHODS

The investigation was approved by the DRDC Toronto Human Research Ethics Committee and conducted in both the water-filled and dry portions of DRDC Toronto Diving Research Facility.

1. Subjects: 45 male military rebreather-qualified divers (ages of 20 to 49) from the Canadian Forces, Royal Australian Navy, Royal New Zealand Navy and the US Navy participated in the study. They all signed their written informed consent before participation.

2. Procedure** (see Figure 1):* Divers performed 174 TRIMIX dives with SurD O_2, at depths between 30 and 81 msw (Figure 2***). The minimum time between the start of successive experimental dives was 48 hours.

Descent rate: 12 msw/min from the surface to 6 msw and then 18 msw/min to the target depth.
Ascent rate: either 10 or 18 msw/min.

3. Measurement: The delivered PO_2, inhaled PO_2 and inhaled PCO_2 were continuously monitored for each subject. O_2 content was measured using a furnace type O_2 analyzer while CO_2 content was measured using an infrared analyzer.

Bubble monitoring and evaluation: VGE were monitored post-dive with Doppler ultrasound (Kisman-Masurel [KM] method) at the precordium and the right & left subclavian veins. The monitoring was conducted at approximately 20, 60, 100 and 140 min following decompression.

***KM code* main features:**
- **3-digit code** (from 0 to 4) and **64** possible combinations (from a minimum of "*111*" to a maximum of "*444*").
- Used to generate **bubble grades** (BG) ranging from I to IV (many many bubbles) with 0 indicating no perceptible bubbles.
- **Stress Severity** value ***(Z score)*** are computed at specific times (**t**, each observation) using an empirical mathematical model derived by Kisman.

$$Z\,score(t) = 1/2 \times [(Z_a)_{min} \times (Z_b)_{min} \times c^2]^{1/3} + 1/2 \times [(Z_a)_{max} \times (Z_b)_{max} \times c^2]^{1/3}$$

Where: Z_a : based on the frequency of bubbles per cardiac cycle
Z_b : associated with the percentage grade or the duration
c : amplitude of the bubble signal

- 0.4 (for "*111*") ≤ ***Z score*** ≤ 35.14 (for "*444*"), allowing a ***finer breakdown*** of bubble activity.

Bubble Severity Index (BSI): An estimate of the **total** bubble activity at *rest* and *movement*
1. Obtain ***ΣZ score*** by **integrating** "*Z score(t)*" over time at both the precordium and subclavian vein sites for both rest and movement
2. **BSI =** $\Sigma Z\,score_{\mathbf{Prec}} + \Sigma Z\,score_{\mathbf{SubR}} + \Sigma Z\,score_{\mathbf{SubL}}$

Depth (msw)	Bottom Time (min)	Ascent rate (msw/min)	Stop Times (min) at Different Depths (msw)																	TDT (min)
			In-Water Stops										SI	SurD Stops in RCC					
			Trimix									O_2		O_2	Air Break	O_2	Air Break	O_2	
			36	33	30	27	24	21	18	15	12	9	0	12	12	12	12	12	
81	20	**10**	-	-	-	7	3	3	3	4	5	14	7	30	5	30	5	5	122
		18	-	4	2	3	3	4	4	4	6	13	7	30	5	30	5	17	138

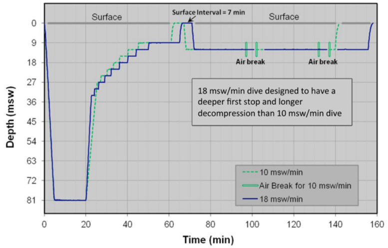

Figure 2- *Example of a SurD O_2 dive profile carried out. Divers switch to O_2 breathing at 9 msw in-water and at 12 msw after the surface interval (SI). Divers breathe air for 7 min max on the surface during SI and for 5 min after every 30 min O_2 breathing at 12 msw.*

4. Statistical Analyses: The effect of ascent rate was analyzed by comparing the Time Weighted Average (TWA) of the inhaled PO_2 and the BSI values at rest and movement in the slow ascent vs. fast ascent, using an unpaired t-test, or a Mann-Whitney U test when the normality test failed. A p-value < 0.05 was considered significant.

RESULTS

None of the subjects had DCS.
This poster covers the results of the two most stressful dive profiles: 69 and 81 msw, for a bottom time of 20 min.

- ***Effect of Ascent rate on Bubble Kinetics***
The analysis of the VGE data revealed that the effects of wet and dry conditions were not significantly different from each other. Therefore all wet and dry divers' data were pooled in each dive profile.

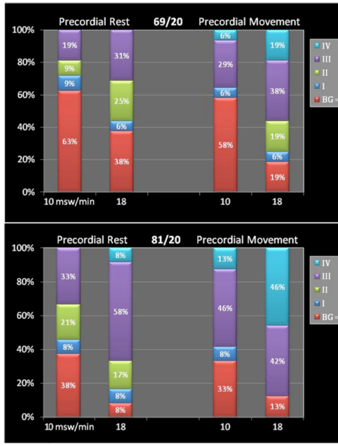

Figure 3 – Percentage of subjects with BG=0 (no observable bubbles), I, II, III and IV (many bubbles) in the precordium for both Rest (left) and Movement (right). High VGE for 18 msw/min and Movement

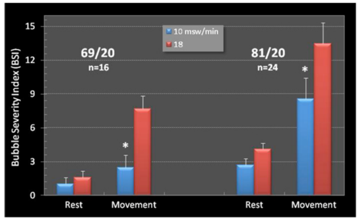

Figure 4 – *Mean and SEM for the Bubble Severity Index for both Rest and Movement. (*) indicates significance (69/20 p=.007; 81/20 p=.028).*

- ***Effect of Ascent rate on PO2 (for semi-closed circuit breathing apparatus)***

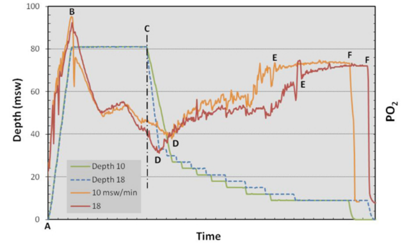

Figure 5 – Typical observed PO_2 for a wet working diver on CUMA. **A**: PO_2 increases when divers leave the surface; **B**: PO_2 maximum value observed on reaching bottom. PO_2 decreases due to (1) more diluent gas (He/N_2) is being delivered, and (2) the diver starts working following a work cycle of 5 min on-5 min off; **C**: Start of the decompression phase; **D**: PO_2 minimum value observed upon arrival to the **first decompression stop**; E: start of the O_2 decompression stop.

Table I **-** Indication of Significant Differences between Ascent rates for different Time-weighted average (TWA) PO_2 of wet divers computed at different dive phases – Profile 81 msw/20 min. The ascent rate appears to have a significant effect on the level of inhaled O_2 during the decompression phase.

Dependant variable	Dive Phase	Dive Phase on Fig. 5	Significance 10 msw/min vs. 18	p value
TWA PO_2 bottom	Start of dive to end of bottom time	A-C	NS	-
PO_2 min	**Decompression phase**	**D**	**S**	**<0.001**
TWA PO_2 9	All dive to the start of the 9 msw Stop	A-E	S	0.018
TWA PO_2 9All	All dive including the 9 msw Stop	A-F	S	0.002

DISCUSSION & SUMMARY

- The relationship between the decrease of decompression speed and the reduction of venous bubbles production has already been demonstrated in previous studies (Carturan *et al.*, 2002). However, most of these studies used the same decompression schedule to compare ascent rates, resulting in a longer total decompression time in the slower ascent rate dives, which may have caused the low observed VGE activity.
- Although the 18 msw/min dives in the current study were designed to have a deeper first stop and longer decompression times than the 10 msw/min dives, the bubble activity for the slower ascent rate dives was lower.
- Two concomitant mechanisms (breathing gas delivery and physiological) may have played a role in the decreased venous bubbles production and low maximum BG in the 10 msw/min dives:
  1. ***Breathing apparatus:*** CUMA is a re-circulating semi-closed circuit breathing apparatus providing a breathing mixture with a constant PO_2. This is achieved by combining a depth-dependant variable flow of diluent gas with a constant flow of O_2. During the ascent, the PO_2 in the counterlung decreases as the pressure decreases, reaching a minimum at the first stop when travel stops. With a slower ascent rate, the breathing set can maintain a higher PO_2 during travel ***(Figure 5)***. Thus, the divers in the slow ascent group received more O_2 during the initial stages of the decompression.
  2. For comparable decompression ascending at 18 msw/min with CUMA, a significant increase in decompression time would probably be required.

References:

Carturan D., Boussuges A., Vanuxem P., Bar-Hen A., Burnet H. & Gardette B. (2002). Ascent rate, age, maximal oxygen uptake, adiposity, and circulating venous bubbles after diving. J. Appl. Physiol 93: 1349-1356.

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