FIELD DIVE MONITORING: BUBBLE PRESENTATION IN RECREATIONAL-TECHNICAL CLOSED-CIRCUIT REBREATHER TRIMIX DIVING

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Introduction

- Recreational-technical diving has grown markedly over the past 20 years, particularly with closed-circuit rebreather (CCR) use.
- Divers increasingly rely on mathematical algorithms incorporated into dive computers to manage their decompression profiles, many of these promising to control bubble formation.
  - There is often little or no human testing of such extended range exposures.
- We evaluated decompression stress in recreational-technical CCR dives conducted beyond 40 msw (130 fsw).
  - Left heart bubbles were of special interest; while serving as a test termination criterion in our laboratory flying after diving and high altitude decompression studies, their presence and natural history in operational diving is not well known.

Methods

- Observational studies were conducted on multi-day, deep recreational CCR trips organized as group charters or commercial events.
  - Divers controlled all of their own diving activity.
- Subject monitoring included dive profile capture, daily health surveys, and high resolution two-dimensional transthoracic echocardiographic (TTE) imaging (GE Vivid q) at 20 min intervals for 120 min post-dive.
  - Intravascular bubble loads scored on a semi-quantitative ordinal scale:

0	- no observable bubbles
I	- occasional bubbles
II	- at least one new bubble every four cardiac cycles
IIIa	- at least one new bubble every cardiac cycle
b	- at least six new bubbles every cardiac cycle
IVa	- at least one bubble • cm^{-2}
b	- at least three bubbles • cm^{-2}
c	- near whiteout; individual bubbles still discerned
V	- whiteout; individual bubbles cannot be discerned

- Scores were recorded for right and left heart, each in three conditions:
  - rest
  - immediately following three full engagement, single arm movements
  - immediately following three full engagement, single leg movements
- Bubble grades are reported as the highest of the three conditions for a given scan (typically observed after movement).
  - Data are presented as mean±SD with ranges, as appropriate.

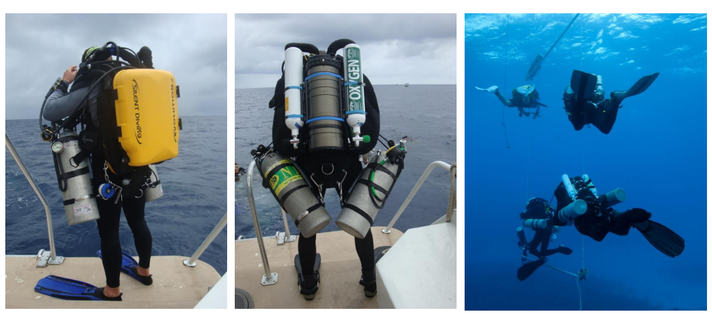


Figure 1: Subjects conducting self-determined technical dives.

Results

- We summarize five research trips; capturing a total of 287 open water CCR dives conducted by 55 individuals (75% male; Table 1).
  - Maximum dive depth was 73±17 (40-157) msw (238±56 [131-515] fsw) and total run time was 103±32 (11-258) min (Table 2).
- Right ventricular gas emboli (RVGE) were observed in all but one individual.
  - Peak non-0 grades following 80% of dives (Figures 2 and 3).
  - Peak IIIa-V grades following 39% of dives.
- Left ventricular gas emboli (LVGE) were observed in 33% of all subjects and on 13% of all dives, peaking at grades IIIa-IIIb in five cases.
- Decompression sickness (DCS) symptoms were noted in two cases.
  - Ambiguous symptoms were reported in three other cases.

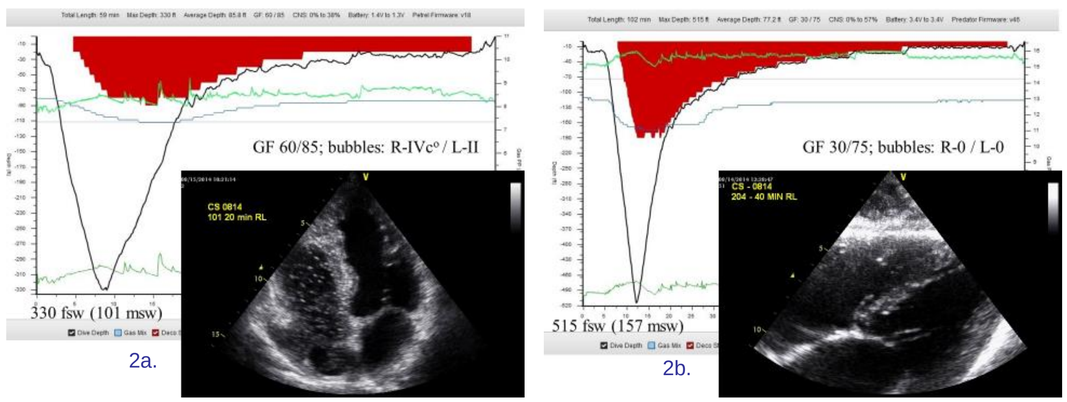
Table 1: Subject anthropometrics.

Parameter	Overall	Male	Female
Count	55	41	14
Age (y)	48±8	47±10	50±3
Weight (kg)	85±15	90±13	69±9
BMI[1] ($kg \cdot m^{-2}$)	27.2±4.0	27.9±4.1	25.5±3.0
Waist-Hip Ratio	0.86±0.08	0.90±0.06	0.76±0.04
Body fat[2] (%)	21±8	18±5	31±6

[1] body mass index; [2] body fat estimated by 7-site skinfold measures.

Table 2: Maximum dive depth and total run time.

Parameter	Overall	Male	Female
Max dive depth (msw)	73±17	74±17	71±16
Max dive depth (fsw)	238±56	241±57	231±52
Total run time (min)	103±32	105±34	100±26



2a. 2b.

Figure 2a&b: Dive profiles shown with superimposed stills from TTE imaging. The dive profile is indicated (black line) along with the decompression obligation/ceiling (red blocks). The decompression ceilings are influenced by the gradient factors (GF) selected by the diver. GF are commonly used with a Buhlmann algorithm to control decompression stress by limiting the percentage of the M-value (theoretically maximum allowable supersaturation) achieved during ascent. The first of the pair of numbers defines the first stop; the second defines the maximum percentage achieved during surfacing. **2a** - still shows a high bubble load in the right heart (left side as viewed); the left heart bubbles evident in the scan are not visible in the still image. **2b** - still reflects the absence of bubbles visible throughout the scan, despite a deep exposure depth.

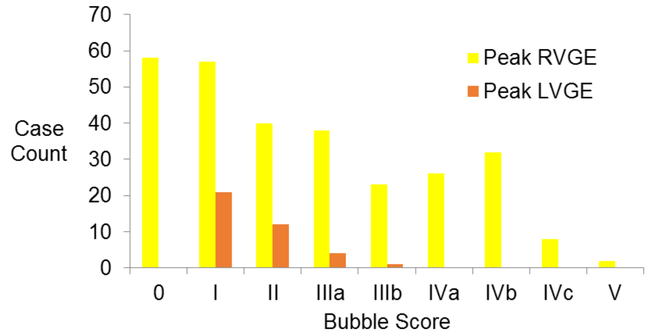


Figure 3: Distribution of peak bubble grades for all exposures; all RVGE (n=287) and all non-0 LVGE (n=38).

Discussion

- Recreational-technical divers are extending their diving range, increasingly beyond the zone where decompression algorithms have been adequately tested.
  - While a number of procedures are promoted and implemented, the absolute level of decompression safety may be overestimated.
- The frequency of LVGE in normal diving is likely underestimated; improvements in ultrasound technology almost certainly explain the recent increase in observations.

Conclusions

- Reflecting substantial decompression stress, the presentation of LVGE, high grade RVGE, and symptomatic DCS indicate that further evaluation of decompression procedures employed by recreational-technical divers is warranted.

Limitations

- As an observational study, divers controlled their own exposures and decompression procedures.
  - Aware of the results of ultrasonic monitoring as it was conducted, subjects were able to alter their exposures in response to findings.
  - The frequent increase in conservatism seen in divers presenting with high bubble grades suggest that these results could underestimate the typical severity of unmonitored exposures.

Future Work

- Continued efforts are required to promote understanding and critical evaluation of available procedures.

Acknowledgments

- We thank Divetech and Spree Expeditions Inc. for provision of facilities enabling our research.