COMPARISON OF END-TIDAL VERSUS ARTERIAL MEASURES OF CARBON DIOXIDE DURING IMMERSED EXERCISE AT SURFACE AND DEPTH

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Introduction

- Arterial CO_2 (P_aCO_2) is typically estimated through non-invasive measures of expired gases
- The relationship between end-tidal CO_2 ($P_{ET}CO_2$) and P_aCO_2 has been characterized during dry exercise, but not during underwater exercise
- The integrated effects of hydrostatic pressure, increased gas density, underwater breathing apparatus resistance (inspiratory and/or expiratory), and increased respiratory deadspace may alter the relationship
- Our purpose was to compare simultaneous measures of $P_{ET}CO_2$ and P_aCO_2 during underwater exercise near the surface and at depth

Methods

- A system was designed and constructed to study fully immersed subjects exercising at various depths (Figure 1)
- Breathing gas, static lung load and inspired and expired breathing resistance could all be manipulated
- A radial artery catheter was placed prior to the experimental trial for blood collection
- A mass spectrometer (Perkins-Elmer MGA1100) was used for breath-by-breath analysis
    - 10.4 m sample tube, 0.86 mm ID; system rise time (10-90%) 230 msec
- Subjects completed six minute bouts of fully submerged, prone exercise at surface and at chamber pressure equivalent to 122 fsw
- Blood and expired gas samples were collected during steady rate exercise at up to near-maximal effort with varying PO_2, static lung load and imposed inspiratory and expiratory resistances
- Paired $P_{ET}CO_2$ & P_aCO_2 measures analyzed for Pearson correlation
- Differences in $P_{ET}CO_2$ & P_aCO_2 on data pooled by condition were analyzed with ANOVA; post hoc testing with Tukey HSD
    - significance for all statistical tests accepted at $p<0.05$

Table 1: Subject descriptive characteristics (mean±SD [range])

Subjects	Age (y)	Weight (kg)	Height (m)	Body Fat (%)	$VO_{2\,max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)
Male (29)	31±7 (20-46)	80±11 (65-98)	1.79±0.06 (1.73-1.93)	13±6 (4-27)	54±12 (32-73)
Female (5)	33±6 (25-36)	74±12 (62-95)	1.68±0.07 (1.60-1.73)	24±7 (18-35)	50±15 (38-72)

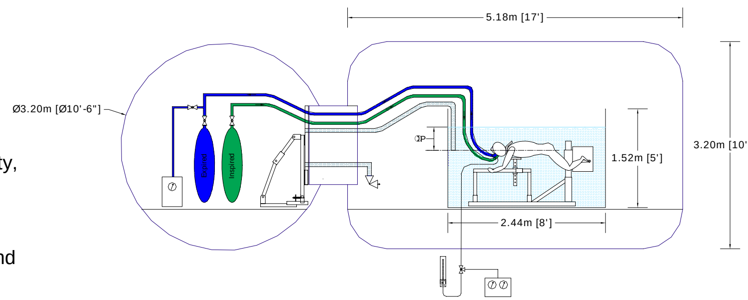

Figure 1: Experimental setup of chamber immersion study

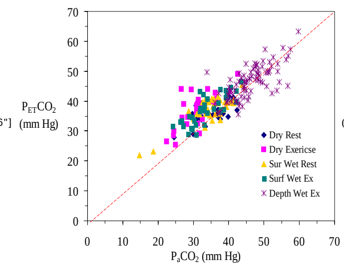

Figure 2: P_aCO_2 vs. $P_{ET}CO_2$; all conditions

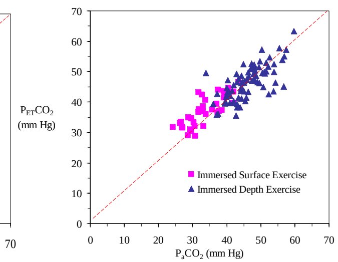

Figure 3: Immersed exercise

Results

- Paired measures were available from 34 subject-trials (Table 2)
    - dry rest and exercise
    - immersed rest and exercise submerged just beneath the surface
    - immersed exercise at a pressure equivalent to 122 fsw
- P_aCO_2 and $P_{ET}CO_2$ were strongly correlated in all conditions (Table 2)
- Resting P_aCO_2 and $P_{ET}CO_2$ did not differ between dry and immersed surface conditions
    - resting measures were not completed at depth
- P_aCO_2 was increased with exercise under both dry and surface immersed conditions
- P_aCO_2 was higher with immersed surface exercise than with dry exercise

Table 2: Correlations and regressions (mean±SD; * = p<0.05)

Condition	n	$P_{ET}CO_2$ (mm Hg)	P_aCO_2 (mm Hg)	r	Regression
All Data	218	40.5±6.8	38.5±8.0	0.855*	y = 0.7288x + 12.462
Dry Rest	32	36.3±3.2	34.9±4.1	0.578*	y = 0.4561x + 20.403
Dry Exercise	28	36.9±5.9	30.9±4.8	0.720*	y = 0.6603x + 13.946
Immersed Surface Rest	38	37.1±4.4	35.1±5.6	0.828*	y = 0.8846x + 9.4899
Immersed Surface Exercise	37	36.9±4.8	33.4±5.0	0.786*	y = 0.7556x + 11.609
Immersed Depth Exercise	83	46.6±5.5	46.3±5.4	0.700*	y = 0.7087x + 13.781

- P_aCO_2 and $P_{ET}CO_2$ were significantly elevated during immersed exercise at depth in comparison to surface immersed exercise
    - maximum paired values
        - surface - 43.5 and 46.6 mm Hg, respectively
        - depth - 59.7 and 63.3 mm Hg, respectively
    - exercise intensity similar at both depths

Conclusions

- Simultaneous measurement of P_aCO_2 and $P_{ET}CO_2$ during immersion indicated a generally high degree of correlation despite manipulations in exercise intensity, PO_2, static lung load and imposed inspiratory and expiratory resistance
- Immersion alone was not seen to alter P_aCO_2 or $P_{ET}CO_2$
- Immersed exercise at depth was associated with significant increases in P_aCO_2 and $P_{ET}CO_2$ compared to surface immersed exercise at similar intensities

Future Investigations

- Future investigations will consider the effect of thermal stress

Acknowledgments

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