RESTING METABOLIC GAS EXCHANGE WITHIN THE ENCLOSED HOOD OF THE MK10 SUBMARINE ESCAPE AND IMMERSION EQUIPMENT (SEIE) SUIT AT DEPTH

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INTRODUCTION

The MK10 SEIE suit is designed to enable free ascent from a stricken submarine. It incorporates an enclosed ascent hood for buoyancy and breathable air during escape. With the introduction of *Virginia* class submarines into the U.S. submarine fleet mass escape for up to 22 submariners at a time may be possible by pressurizing and flooding the *Virginia* lockout trunk. While the CONOPS for *Virginia* class submarine mass escape is currently being developed, it is possible that during an actual escape some escapees may not have convenient access to the built-in breathing system and may be required to rebreathe from the hood volume prior to escape. Furthermore, once submariners reach the surface following an escape they may keep the hood zipped up while floating in the SEIE raft to avoid inhaling sea water during high sea states. Prolonged breathing from the enclosed volume of the hood could lead to dangerous levels of hypercapnia or hypoxia that may compromise escape or survival.

Previously we showed that resting submariners breathing from the enclosed volume of the SEIE suit hood while partially immersed at 1 ATA will approach unsafe hypoxia levels after 2 to 3 minutes of rebreathing (Fothergill & Horn, UHM **34:** 254-55, 2007). As the study by Fothergill & Horn (2007) did not address the effects of exercise or pressurized escape depth on safe rebreathing times we repeated the study with subjects conducting mild exercise at 2 ATA (33 fsw) and 4 ATA (99 fsw).

OBJECTIVES

To describe the rate of build up of CO_2 and rate of O_2 use in the MK10 SEIE suit hood volume at escape depths of 2 and 4 ATA with escapee subjects immersed in water at a level just above the hood vent while performing moderate single arm isometric exercise simulating the exertion required during an escape. These data will be used to formulate guidance for the safe time limits for rebreathing the enclosed volume within the MK 10 SEIE suit hood during escape procedures when direct access to the BIBS air supply is limited.

METHODS

Subjects

12 U.S. Navy trained divers.

Age (mean ± SD):	31.6 ± 10.2 yrs,
Height (H):	1.80 ± 0.05 m,
Weight (W):	87.1 ± 10.5 kg,

Procedures

Each subject donned the MK10 SEIE suit and performed four gas exchange measurement trials with the hood fully closed while immersed in a water tank with the water level 2 inches above the hood vent. The test conditions were:

1) 2 ATA at rest,
2) 2 ATA with moderate one arm lift isometric exercise (holding a 6.66 Kg weight at 90° of elbow flexion).
3) 4 ATA at rest, and
4) 4 ATA with moderate one arm lift isometric exercise.

The rest and exercise conditions at a given dive depth were conducted on the same dive in a counter balanced order with a minimum 5 minute rest interval between the conditions. The 2 and 4 ATA conditions were conducted on separate dives with the order counter balanced among the subject population. All compression and decompression rates were conducted in accordance with the US Navy Dive Manual. The experiments were conducted in a water tank located in the main lock of NSMRLs Genesis hyperbaric chamber (Fig 1).

Subjects re-breathed from the suit volume until one of the following termination criteria was reached:

- FiO_2 reaches 13% SEV (PiO_2 = 100 mmHg).
- $FetCO_2$ reaches 9% SEV ($PetCO_2$ = 68 mmHg).
- The subject prematurely aborts the trial due to discomfort.
- PI or dive tender aborts the trial due to excessive subject distress.

Minute ventilation was monitored continuously using a K.L Engineering pneumoscan Spirometric module attached to the expired port of a Gentex oxygen mask (see Fig 1). Inspired and end tidal measurements of O_2 and CO_2 were continuously monitored via an MGA 1100 mass spectrometer from a gas sample line connected to the oral nasal mask. The volume of air removed from the hood for sampling was 60 ml/min. Analogue output from the mass spectrometer and spirometric module was passed to a BIOPAC A/D system to permit the CO_2 and O_2 fraction to be continuously displayed on a monitor and stored on computer hard disc for later analysis.

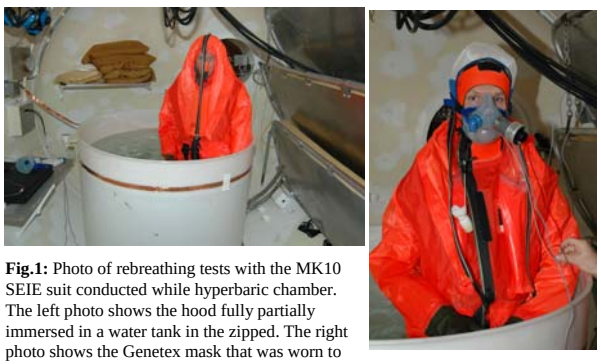

Fig.1: Photo of rebreathing tests with the MK10 SEIE suit conducted while hyperbaric chamber. The left photo shows the hood fully partially immersed in a water tank in the zipped. The right photo shows the Genetex mask that was worn to permit measurement of metabolic gas exchange.

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RESULTS & DISCUSSION

The mean time to reach the abort criteria for each condition is shown in Table 1. Although all the subjects except one tolerated the brief high hypercapnic levels well, many subjects reported significant CO_2 toxicity and narcotic symptoms. For operational safety concerns, guidance for the safe time limits of rebreathing were based on a more conservative maximum allowable $PetCO_2$ of 60 mmHg recommended by Walkander et al., (UBR.**19**: 427-445, 1992) for underwater breathing apparatus. The mean times for $PetCO_2$ to reach the 60 mmHg this safety limit is shown in Table 2 and was similar at 2 and 4 ATA ($F_{1,11}$= 1.21, p=0.294), but was reduced from 301 s at rest to 263 s [data averaged across the two depths] when forearm isometric exercise was performed ($F_{1,11}$ = 5.80, p=0.034).

Table 1: Mean ± standard deviations for the rebreathing time (s) to reach the abort criteria at 2 ATA and 4 ATA under rest and exercise conditions. Note that two subjects achieved the maximum 10 minute rebreathing time limit during the resting trials at 4 ATA and one also achieved the maximum 10 minute time limit during the exercise trial at 4 ATA. The data from these subjects are included in the mean data shown in red by assigning a time limit of 600 s to their trials. The means in normal text omit the data from these latter subjects.

	Rest	n	Single arm isometric exercise	n
Depth = 2 ATA (33 fsw)	415 ± 70	12	361 ± 96	12
Depth = 4 ATA (99 fsw)	406 ± 117 438 ± 130	10 12	359 ± 103 380 ± 120	11 12

Table 2: Mean ± standard deviations and minimum and maximum time (s) to reach 60 mmHg $PetCO_2$ at 2 and 4 ATA under rests and exercise conditions. n = 12

Conditions	Rest			Single arm isometric exercise		
	Mean±SD	Min	Max	Mean±SD	Min	Max
Depth = 2 ATA (33 fsw)	275±59	179	388	258±75	148	383
Depth = 4 ATA (99 fsw)	326±149	154	600*	267±111	160	537

*During this condition, one subject did not reach 60 mmHg P_aCO_2 during the 10 minute rebreathing period. For the purpose of analysis this subject was assigned the maximum rebreathing time of 10 minutes (600 s).

Calculation of guidance for safe rebreathing times

The most conservative approach to setting guidance for the depth trials is to consider the variance expected over the entire population and set the guidance to ensure that the majority of submariners will not exceed the chosen physiological safety limit. For the surface trails described in Fothergill & Horn (2007) guidance was set at 2 SD below the mean rebreathing time for subjects to reach the maximum allowable FiO_2 criteria of 13.0%. Using a similar approach to ensure that the majority of the population does not exceed the 60 mmHg $PetCO_2$ limit, the safe rebreathing time for the most conservative exercise condition in Table 2 (i.e. the lowest mean, min, and max time = the 2 ATA trials) =

Mean rebreathing Time – (2 x SD)

= 258 – (2 x 75) = 108 s

As the above safe rebreathing time at depth is very close to the 100 s guidance provided in Fothergill and Horn (2007) for 1 ATA conditions it is recommended that the guidance for the safe rebreathing time for escapes up to 4 ATA be also set at 100 s. Assuming that the current study provides an accurate estimation of the population mean and SD for safe rebreathing times at depth it is predicted that less than 2% of the submariners will attain a $PetCO_2$ >60 mmHg when rebreathing from the hood volume of the MK10 SEIE for durations up to 100 s. This guidance assumes that the starting ambient PCO_2 in the hood is below 10 mmHg and that the physical activity of the submariner is limited to similar levels as that tested in the current study.

CONCLUSIONS

The safe time limit for rebreathing the enclosed volume of air in the MK10 SEIE suit at depth is:

- Limited by hypercapnia.
- Reduced by performing single arm isometric exercise.
- Unaffected by ambient pressure for pressures up to 4 ATA (99fsw).

The recommended maximum safe time limit for rebreathing from the enclosed volume of the MK10 SEIE suit at depth is 100 s providing that the starting ambient PCO_2 is below 10 mmHg (1.3% SEV).