EVALUATION OF THE MBS 2000 CLOSED-CIRCUIT OXYGEN REBREATHER FOR PROVIDING HYPERBARIC OXYGEN AT 60 FSW

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INTRODUCTION

The MBS-2000 is a closed-circuit oxygen rebreather designed to provide oxygen for supporting on-scene decompression of submarine survivors. Previously we have reported the results of 1 ATA testing of the MBS-2000 (UHM 32: p45; 2005). The current study evaluates the performance of the modified MBS-2000 at 60 fsw. The main modification to the unit from that previously tested included the addition of a purge slide valve in the expired side of the rebreathing circuit to improve purge efficiency.

OBJECTIVES

Since all previous testing had been performed at 1 ATA, the main objective for this study was to evaluate the performance of the modified MBS 2000 rebreather (Fig 1) at 60 fsw in a hyperbaric chamber. Specifically, data on purge frequency and oxygen consumption at depth was sought to provide more accurate calculations of the total volume of oxygen needed to support an operation.

METHODS

Subjects

11 U.S. Navy trained divers,
Age: 37.0 ± 10.8 yrs,
FVC: 5.5 ± 0.7 L BTPS

MBS 2000 Modifications

The design modifications made to the MBS 2000 following 1 ATA testing that underwent human performance testing at 60 fsw are given below.

1. Incorporation of a purge slide valve on the exhaled side of the MBS 2000 main body. (Fig 2)
2. Elimination of the overpressure relief valve on the main body.
3. Incorporation of four hose clamps/breathing hose retainers for maintenance of a gas tight seal between the breathing hoses and main body and valve assembly. (Fig 3)
4. Replacement of the old rubber facemask with a silicone face mask and head net made by SEA-LONG (Series 700, SEA-LONG Medical Systems Inc., Louisville, KT). (Fig 3)
5. Incorporation of a removable T-bit mouthpiece in the breathing valve T-assembly. (Fig. 3)
6. Incorporation of the R10-DN oxygen sensor into the end cap of the inhalation side of the MBS 2000 valve main body.
7. Removal of the flow restrictor in the pressure oxygen supply whip.

Fig. 1: Photo of the modified MBS 2000 closed circuit oxygen rebreather. During the dive trials oxygen was provided from D size (425 l) capacity cylinders attached to the high pressure supply whip with the over bottom pressure set at 125 psi.

Apparatus

All dives were conducted in the Genesis hyperbaric chamber at NSMRL. The volume of O_2 used for each MBS 2000 was calculated from changes in bottle pressure measured using a DP15-64 pressure transducer (Validyne Engineering, Northridge, CA). Output from the pressure transducers were passed through chamber penetrators and amplified before being sampled by a BIOPAC analogue to digital (A/D) recording system. Gas samples lines were connected to each MBS 2000 gas sample port and passed through the chamber wall to flow meters located outside the chamber. The micrometer valves on the external flow meters were set to provide a flow rate of 130 cc/min (sample line 1) and 180 cc/min (sample line 2) following volume expansion of the gas sample at 1 ATA. Low volume capillary lines connected to a "T" pipe-coupling that was attached to the output port of each flow meter permitted FiO_2 and $FiCO_2$ to be monitored continuously by a MGA 1100 Mass Spectrometer (sample line 1) or S-3A O_2 analyzer (Applied Electrochemistry) and CD-3A CO_2 analyzer (Applied Electrochemistry) (sample line 2). Gas samples measured by the Mass Spectrometer were automatically corrected to dry fractions. For the O_2 and CO_2 analyzer, gas samples were dried by passing the gas sample through a length of Nafion® membrane tubing. The small volume of gas drawn from the closed circuit breathing loop for gas sampling was not subtracted from the total O_2 use reported in the individual or group data.

Procedures

The dive profile involved 60 minutes breathing chamber air at 60 fsw followed by two 20-minute O_2 breathing periods. A five minute air break separated the two 20 minute O_2 breathing periods. Subject's purged the MBS-2000 at the start of each O_2 breathing period and then again only if their FiO_2 dropped below 0.80. The first purge on the system involved a 10-breath purge; all subsequent purges were 5-breath purges. Purge efficiency for the 5 and 10 breath purge procedures was determined by comparing the volume of O_2 used for the purge with the point sample FiO_2 achieved after 30 s of rebreathing.

Purge Procedure

The initial purge procedure involved the subject donning the mask with T-bit and then conducting 10 medium to large breaths with the slide valve in the open circuit position. After exhaling the 10th breath, the subject moved the slide valve to the closed circuit position, inhaled a large breath and began closed-circuit breathing. Additional purges after the initial purge were performed in the same manner as that described above except that 5 large open circuit breaths instead of 10 breaths were conducted prior to beginning closed-circuit breathing.

Analysis

Paired t-tests were used to assess differences in purge efficiency and purge volume between the 10 and 5 breath purge procedures at 60 fsw. Wilcoxon Matched Pairs Test was used to compare purge frequency between the two O_2 breathing periods. Significance was set at $p<0.05$ for all tests.

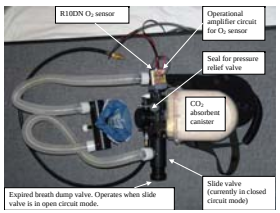

Fig. 2: A photo of the modified MBS 2000 without the breathing bags showing the new slide valve attached to the main body on the expired side of the circuit. When the slide valve is placed in the open circuit position (slide valve pushed out to the full lateral position [i.e. downwards toward the expired end cap in the above picture]) expired breath is directed out of the closed circuit through a one way valve in the end cap of the slide valve.

Fig 3: Close up of the SEA-LONG oral nasal mask and insert T-bit mouthpiece. The new hose clamps are also shown connecting the breathing hoses to the inspired (green dot) and expired (red dot) ports of the "T" valve.

RESULTS

The amount of oxygen used during the second 20 min O_2 period was approximately 44% lower than that used during the first 20 min O_2 period ($p<0.001$). This predominantly reflects the smaller volume of O_2 used for the 5-breath purge during the initial purge for the second O_2 period compared with the 10-breath purge used at the start of the first O_2 period. Both the 10 breath purge and 5 breath purge were able to achieve a starting FiO_2 >95%. and maintain a mean dry FiO_2 >0.90 over a 20 minute O_2 period (see Table 1).

Table 1: Comparison of performance for the modified MBS 2000 between the first and second O_2 breathing trials at 60 fsw. Data are mean ± SD (n=11) * = Significant at $p<0.05$ (paired t-test).

Variable	First O_2 Period	Second O_2 period	p
Purge volume (10 breath vs 5 breath) (liters)	81.5 ± 17.9	44.8 ± 9.7	<0.001*
Starting FiO_2 x 100 (%)[1]	97.8 ± 1.2	95.6 ± 2.4	0.002*
Oxygen usage over 20 min inclusive of initial purge (liters)	110.2 ± 39.6	62.1 ± 13.9	<0.001*
Oxygen usage over 20 min exclusive of initial purge (liters)	28.9 ± 28.0	17.3 ± 10.8	0.092
Mean FiO_2 x 100 over 20 min (%)[1]	93.4 ± 2.1	92.5 ± 2.8	0.203
Mean number of additional purges	0.45 ± 0.69	0.18 ± 0.40	0.109

[1] FiO_2 values are given as dry fractions x 100

CONCLUSION

When the mean O_2 volume used during the 60 fsw trails are converted to equivalent surface pressure volumes and presented as rates the first 20 minute O_2 period used approximately 2.0 liters/min/man and the second O_2 period used 1.1 liters/min/man. In comparison an open circuit breathing system that provides 100% oxygen at a normal resting minute ventilation uses approximately 10 l/min/man of O_2 at 1 ATA.

The results show that the MBS-2000 can provide acceptable hyperbaric treatment concentrations of oxygen while using less than 20% of the oxygen volume requirements needed to operate an open circuit oxygen system at 60 fsw.

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