Short communication

Medical standards for the use of 'Scubadoo' – a discussion paper

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Recreational diving, diving, safety, respiratory, Scubadoo, risk management

Abstract
(Simpson G, Ferns J, Knight T, Heron ML. Medical standards for the use of 'Scubadoo' – a discussion paper. *Diving and Hyperbaric Medicine*. 2006; 36: 9-11.)
'Scubadoo' is a novel recreational diving device which operates at a fixed depth of three metres' sea water (msw). The diver is free to move in an air-filled dome replenished by continuous air flow from a scuba tank which is an integral part of the device. Calculations show that the equilibrium concentration of carbon dioxide and oxygen in the dome depend on the volumetric air flow from the compressed-air cylinder. Experiments carried out with an air flow of 20 l.min^{-1} gave gas mixtures consistent with the calculations. This provides the basis of safe design for the air supply to the dome. The medical issues that may arise in the use of the Scubadoo device are discussed. Most of the medical issues which apply to scuba diving are minimised here because of the rigid three msw depth limit. Pulmonary barotrauma and also bronchospasm for asthmatics are theoretically possible but are considered to be low-risk conditions in the context of the use of the device. Epilepsy and other conditions likely to cause sudden loss of consciousness are the only contra-indications to use of the device. It is concluded that Scubadoo should not be subjected to the same medical restrictions as scuba diving.

Introduction

The 'Scubadoo' is an underwater recreational device, relatively new to the dive industry. The device consists of a submersible scooter-like vessel that is steerable and powered by an electric motor. The passenger sits astride the seat and an acrylic dome fits over the whole upper body of the passenger (Figure 1). The dome is air filled so that the passenger's shoulders and head are above the water level. Air is replenished at a constant rate from an integral scuba tank. The vessel is maintained in an upright position partly by the weight of the battery and motor at the base, and also by the buoyancy of the air in the acrylic dome, with the additional safety device of a line to a surface buoy attached to the dome. The vessel is operated at a fixed depth of three metres' sea water (msw). The electric motor and propeller provide slow forward motion and the vessel can be steered by the passenger.

Normal practice is to have a diving instructor wearing scuba gear supervising each Scubadoo device. The device is steered around a short tour underwater for approximately 20 minutes. The question has been raised as to what medical standards should apply to potential users of this device. We have undertaken some simple calculations and some in-water testing of the device to try to clarify the situation.

Potential medical problems

Users of the Scubadoo are breathing compressed air at the ambient pressure of one atmosphere plus three msw. There is no second-stage regulator and the user's head is in the dome surrounded by approximately 25 l of air. Fresh air is supplied to the dome from a compressed-air scuba cylinder at a constant flow rate of 20 l.min^{-1}. Potential problems, therefore, are:

1. decompression sickness
2. hypoxia because of inadequate air replacement
3. carbon dioxide retention because of inadequate flushing of the dome
4. barotrauma to the ears and/or sinuses
5. pulmonary barotrauma
6. exacerbations of pre-existing medical conditions, particularly asthma
7. panic.

Theoretical calculations

To investigate some of these problems further, calculations were undertaken regarding the expected alteration of gas composition in the dome using expected oxygen (O_2) consumption rates and carbon dioxide (CO_2) production rates for an adult at rest. It was assumed that oxygen removal rate would be 300 ml.min^{-1} and carbon dioxide production would be 250 ml.min^{-1}. The approximate volume of the airspace is 25 l. Calculations were performed for three different inflow rates from the compressed-air bottle of 20, 10 and 5 l.min^{-1}. In summary, it was shown that the volume of air in the dome does not influence the final levels of oxygen and carbon dioxide, although the smaller the volume, the more rapidly these equilibrium levels are approached. The calculated equilibrium values using the O_2 and CO_2 figures for an adult at rest given above and the flow rate of 20 l.min^{-1} are: equilibrium O_2 concentration

Table 1
Changes in temperature, humidity and CO_2 over time in a just-submerged Scubadoo, using a continuous 20 l.min^{-1} fresh-air flow rate

Time (min)	Temperature (°C)	Relative humidity (%)	CO_2 (%)*
0	33.3	60.5	0
1	33.9	73.8	0.82
3	34.9	78.0	1.09
5	36.4	84.0	1.24
8	35.9	87.0	1.24
11	36.7	92.4	1.52
13	37.2	88.0	1.66
16	37.2	87.0	2.07
19	37.9	83.6	2.22
22	38.7	79.8	2.08
25	41.3	76.6	2.07
27	41.4	79.4	2.35

*corrected for relative humidity, temperature and saturated vapour pressure of water

19.49%, equilibrium CO_2 concentration 1.29%. If it is assumed that, perhaps because of psychological stress or the minor physical exertion involved, the CO_2 production is doubled these figures change only slightly, with equilibrium CO_2 level rising to 2.51%. The critical factor determining the equilibration levels was the gas inflow rate. A flow of 10 l.min^{-1} approximately doubled the equilibrium CO_2 level but remained safe; however, flow levels below this could cause problems. Using 20 l.min^{-1}, 90% of the equilibration levels were reached in less than 12 minutes and values at the end of the 20-minute dive would be very close to the calculated equilibration levels. For a further explanation see *Bennett and Elliott's physiology and medicine of diving.*[1]

Figure 1
Artist's impression of Scubadoo™ device

Methods

Experiments were undertaken with a Scubadoo in a swimming pool with a volunteer. An air replenishment flow rate of 20 l.min^{-1} was used. Measurements were made of CO_2 levels in the dome air using an end tidal CO_2 meter (BCI International Capnocheck Model 20600A1) and of the temperature and relative humidity of air within the bell using a Centre 311 humidity and temperature meter Model RS-232. Measurements were made throughout a 27-minute 'dive'. Because of limitations of the monitoring equipment the Scubadoo dome actually remained at the surface rather than being completely submerged to 3 msw. The CO_2 levels were corrected for the alterations in temperature and relative humidity to allow for the vapour pressure of water under changing conditions.

Results

The results are shown in Table 1. The observed changes in CO_2 show close agreement with the calculated results, with a final CO_2 concentration of about 2.3%. The temperature in the dome rose significantly whilst relative humidity remained at approximately 80%.

Discussion

The final carbon dioxide concentration of about 2.3% would suggest that CO_2 production in the subject was greater than the basal assumed rate of 250 ml.min^{-1} but did not exceed 500 ml.min^{-1}. The calculated oxygen content of the dome atmosphere would thus be over 19%. The rise in temperature is explained by the fact that the experiment was performed at the surface on a sunny day. It would be anticipated that temperature would not rise so much with the dome completely submerged. Of interest is that the relative humidity of the air in the bell remained around 80% despite its constant replenishment with drier air from the scuba tank.

ISSUES

We are now able to address some of the potential medical problems related to operation of a Scubadoo device.

Decompression sickness
Exposure to nitrogen at a pressure of three msw for 20 minutes is insufficient to produce decompression sickness.

Barotrauma
Descent of three msw is unlikely to cause significant ear or sinus squeeze even without equalisation. Nevertheless, we would recommend that the participants be instructed in equalising techniques. The accompanying diver can easily signal through the transparent dome that equalisation should be done and check that the occupant is not distressed.

Pulmonary barotrauma
Pulmonary barotrauma is a theoretical possibility in a rapid ascent from three msw. However, it seems difficult to envisage a situation where this could occur with a Scubadoo, which is essentially hanging on a surface buoy at this depth and is negatively buoyant. The only way that this would be a problem is if the occupant exited the dome suddenly and ascended rapidly holding his or her breath. In a one-to-one supervision situation this would seem to be extremely unlikely to occur.

Hypoxia and carbon dioxide retention
Both calculation and direct experimental evidence based on a flow rate of 20 $l.min^{-1}$ (less than that used in practice, 25 $l.min^{-1}$) show that the air replenishment rate is adequate to keep O_2 levels in excess of 19%. Allowing for the fact that this in practice would be in a slightly increased pressure of three msw the partial pressure of O_2 in inspired gas would be effectively unaltered. CO_2 levels do rise, but not to the level where any symptoms would be anticipated or to a level where there would be respiratory stimulation by hyperventilation. A recent study of head hoods under hyperbaric conditions supports these conclusions.[2]

Medical conditions
The medical condition that causes the most debate regarding scuba diving is, of course, asthma. The theoretical objection to asthmatics scuba diving is of precipitation of an attack of bronchospasm by the scuba diving environment. Precipitants usually mentioned include exercise, inhalation of cold, dry air and the possibility of inhalation of an aerolised mist of sea water caused by a faulty regulator. Though considered spurious by some, this last point clearly is irrelevant in relation to the Scubadoo as there is no second-stage regulator and the occupant's head and shoulders are well clear of water and breathing is normal. Scubadoo does not involve significant exertion and our experiment has shown that the air in the dome is both warm and moist. Therefore, there seems no reason for asthma to be regarded as a contra-indication to use of the device. As far as other medical conditions go, the lack of an important exertional component and the close supervision provided would seem to render the device safe for almost anyone with the exception of patients suffering from epilepsy or other conditions likely to cause sudden loss of consciousness.

Panic
The underwater environment can produce panic and this seems to be the main potential problem of the Scubadoo. This would need to be dealt with by adequate instruction and supervision of Scubadoo users.

Conclusions

For the reasons outlined above, it is our opinion that the Scubadoo should not be subjected to the same medical restrictions as scuba diving. Assuming adequate instruction and supervision, the device should be available to anyone of adequate size to use it, and medical conditions, with the exception of epilepsy, should not be regarded as a contra-indication.

References

1 Camporesi EM, Bosco G. Ventilation, gas exchange and exercise under pressure. In: Brubakk AO, Neuman TS, editors. *Bennett and Elliott's physiology and medicine of diving*. 5th ed. Philadelphia: Saunders; 2003. p. 81.
2 Davidson G, Bennett MH. Effect of oxygen flow on inspired oxygen and carbon dioxide concentrations and patient comfort in the Amron™ oxygen hood. *SPUMS J*. 2004; 34: 68-74.

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