Conclusions

Many experienced scuba divers take a variety of medications for chronic conditions. These medications are likely to be markers of the chronic medical conditions with which the divers dive. These conditions may impact adversely on divers’ fitness to dive. In addition, many experienced divers take medications to assist with diving. Further research is required to evaluate the impact of these medications on divers’ fitness to dive.

Acknowledgments

We thank the Pittsburgh Emergency Medicine Foundation, Pittsburgh, PA, USA, which partially funded this study.

References

2 Abraini JH. Inert gas and raised pressure: evidence that motor decrements are due to pressure per se and cognitive decrements due to narcotic action. Eur J Physiol 1997; 433: 788-791
3 Taylor DMcD, O’Toole KS, Auble TE, Ryan CM, Sherman DR. The psychometric and cardiac effects of dimenhydrinate in the hyperbaric environment. Pharmacotherapy 2000; 20: 1051-1054
4 Taylor DMcD, O’Toole KS, Auble TE, Ryan CM, Sherman DR. The psychometric and cardiac effects of pseudoephedrine in the hyperbaric environment. Pharmacotherapy 2000; 20: 1045-1050
5 Taylor DMcD, O’Toole KS, Ryan CM. Experienced, recreational scuba divers in Australia continue to dive despite medical contra-indications. WEM 2002; 13: 187-193
6 Walsh JM. Interaction of Drugs in the hyperbaric environment. The 21st Undersea Medical Society Workshop. Bethesda: Undersea Medical Society Inc; 1979
continuous positive airway pressure (CPAP) under hyperbaric conditions.

Respiratory changes during hyperbaric therapy

Changes to the respiratory system during HBOT can cause problems. A number of physiologic responses may alter gas exchange and the patient’s ventilatory capacity in the chamber may be inadequate. A critically ill patient may have pre-existing pulmonary pathology due to the primary disease process or even ventilator-associated barotrauma. Treatment with high-inspired oxygen can increase sensitivity to the toxic effects of oxygen on the lung under pressure. Barotrauma must be excluded, or managed, prior to compression to avoid disastrous consequences.

Aside from these possible adverse effects to the lung and risks of barotrauma, there are other effects of HBOT:

• suppression of afferent carotid and aortic chemoreceptor activity may result in initial respiratory depression in patients who are not mechanically ventilated;
• later, during treatment, hyperventilation may occur due to raised mixed venous carbon dioxide (CO₂) secondary to decreased binding of CO₂ to reduced haemoglobin;
• increase in oxygen tension resulting in depression of hypoxic ventilatory drive;
• washout of nitrogen leading to absorption atelectasis.

There remains controversy over the amount of alveolar-arterial (A-a) ratio change that occurs. There is evidence that the A-a ratio remains constant, independent of inspired oxygen concentration even at increased barometric pressure. However, other uncontrolled human evidence suggests that patients with lung disease seem to have arterial oxygen tensions (PₐO₂) greater then predicted, whilst patients with normal lungs have PₐO₂'s that are lower than predicted when exposed to hyperbaric oxygen.

Animal studies have demonstrated increases in pulmonary vascular resistance as well as blunting of hypoxic vasoconstriction. Both may have implications in patients with significant lung pathology. Often areas of ventilation/perfusion mismatch are already present and may worsen during HBOT, resulting in marked increases in the A-a gradient. Some data suggest that, in patients requiring inspired oxygen concentrations of more than 50% for adequate oxygenation in normobaric conditions, the tissue oxygen levels achieved in the hyperbaric environment are inadequate for therapeutic effects.

In patients who are not mechanically ventilated but have limited respiratory reserve, the changes above may contribute to respiratory insufficiency at increased pressure.

Physiologic effects of IPPV

The effects of IPPV have been extensively studied under normobaric conditions. Unfortunately this does not appear to be the case in the hyperbaric environment. Respiratory changes induced by IPPV include increased physiological dead space, decreased functional residual capacity and increased intrathoracic pressure. Cardiovascular changes include decreased cardiac output (decreased preload), increased right ventricular pressures and increased systemic and pulmonary vascular resistance. Endocrine changes include an increase in ADH release.

It is reasonable to extrapolate that the effects of IPPV and HBOT may be additive. In particular, HBOT may cause increased vascular resistance and decreased cardiac output.

Positive end expiratory pressure (PEEP)

Positive end expiratory pressure is the application of greater than ambient pressure, measured in cm of H2O, applied during the expiratory phase of positive pressure ventilation. PEEP is often required as a method of recruiting and stabilising alveoli in the critically ill and is an important part of ventilatory strategy in the intensive care unit (ICU) setting. In the hyperbaric environment, there is evidence that significant variations in the level of PEEP may occur.

Depending on the amount of pressure and the PEEP valve used, an increase in preset PEEP by up to 4 cm of water at depth has been demonstrated. Two major problems may occur as a result – cardiovascular compromise (by reducing preload), and barotrauma. Recommendations include monitoring of proximal airway pressure, use of adjustable PEEP valves and checking PEEP and readjusting after any change in pressure. There may also be a problem to maintain PEEP with less sophisticated ventilators.

Despite these potential problems, there are a number of physiological reasons why PEEP should be maintained during HBOT. Most particularly, PEEP recruits and stabilises alveoli, preventing areas of collapse, which are potential areas of gas trapping. PEEP also splints open airways to allow more even gas flow and again lessens the likelihood of barotrauma. It has been demonstrated that even short periods without optimal ventilation may result in deterioration that takes up to 24 hours to resolve.

Continuous positive airway pressure (CPAP)

Constant positive airway pressure, which is used with spontaneously breathing patients, is easy to apply in the hyperbaric environment. The physiologic effects are similar to those seen with PEEP. A number of circuits have been tested. A simple system with a high compliance and high volume reservoir coupled with a water valve is easy to achieve. The only precaution necessary is to ensure that air from the compressors is not contaminated with oil, which may cause an adult respiratory distress syndrome (ARDS).

Ventilators

A number of studies have examined the function of various ventilators under hyperbaric conditions. Blanch et al tested
19 ventilators under hyperbaric conditions to assess their function. Adequate mechanical ventilation in the chamber requires a ventilator capable of functioning predictably and safely under hyperbaric conditions.

Changes that occur with increasing pressure affect ventilator function. An increase in chamber pressure may result in reduction in inspiratory flow unless the supply pressure is increased. If this happens, inadequate flow to the ventilator will not maintain adequate ventilation. An increase in pressure also increases the density and viscosity of gases, which decreases the compressibility of gases and decreases the flow rate for a given pressure.

In addition to these changes, one has to consider fire prevention and maintenance of normal oxygen percentage in the chamber atmosphere. Table 1 lists the ideal requirements of a ventilator for use in a hyperbaric chamber.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>DESIRABLE FEATURES OF THE HYPERBARIC VENTILATOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Small and compact</td>
<td></td>
</tr>
<tr>
<td>• No electrical requirement</td>
<td></td>
</tr>
<tr>
<td>• No flammable lubricants</td>
<td></td>
</tr>
<tr>
<td>• Powered by compressed air or chamber environment gas</td>
<td></td>
</tr>
<tr>
<td>• Minimum work of breathing with low gas consumption</td>
<td></td>
</tr>
<tr>
<td>• Low oxygen bleed into the chamber to prevent contamination of the atmosphere</td>
<td></td>
</tr>
<tr>
<td>• Multiple ventilatory modes</td>
<td></td>
</tr>
<tr>
<td>• Stable tidal volume and rate changes with pressure</td>
<td></td>
</tr>
<tr>
<td>• Constant PEEP</td>
<td></td>
</tr>
<tr>
<td>• Continuous monitoring of tidal volume, frequency, minute volume, peak and mean airway pressure, PEEP, I-E ratio</td>
<td></td>
</tr>
</tbody>
</table>

VOLUME CYCLED VENTILATORS

Regulation from inspiratory to expiratory phase is by tidal volume (Vt). Once the set Vt is reached, the ventilator cycles from inspiratory to expiratory mode. During HBOT the increase in viscosity and resistance results in a decrease in flow, therefore longer time is needed for the desired Vt to be reached. As a result, respiratory rate decreases.

PRESSURE CYCLED VENTILATORS

Inspiratory to expiratory timing is determined by the set pressure being reached. During HBOT at the same passage pressures, the flow is decreased due to increased resistance resulting in a longer time to reach the set pressure. This increases the inspiratory time and again decreases the respiratory rate.

TIME CYCLED VENTILATORS

Time cycling is now the most common form of inspiratory to expiratory cycling used. Unfortunately, it is also the most affected by hyperbaric conditions. After compression, the circuit senses decreased compressibility of the gases and tends to fill and empty in a shorter time, resulting in increased frequency and decreased inspiratory and expiratory time. Decreased inspiratory time and reduced flow cause a decrease in tidal volume. In addition, a decreased expiratory time may result in auto PEEP from ‘breath stacking’ with a significant risk of barotrauma.

Ventilators in chambers

As a general rule, ventilators used in the chamber are not as sophisticated as those used in the ICU. Ventilation modes such as pressure support, pressure-controlled volume assist, and bilevel positive airway pressure are not readily available outside the ICU. Unfortunately, chambers are usually relatively small in size and space is at a premium. The experience in our unit with the Campbell EV 500 ventilator has recently been reported.

Intensive care patients who are breathing spontaneously with ventilator support may have high airway pressures and/or high levels of PEEP, and are often difficult to manage. In addition, any move from the intensive care environment and its sophisticated ventilatory strategies may result in significant changes to respiratory parameters. Unfortunately, the deterioration in respiratory function due to any disturbance may last up to 24 hours after transfer back to the intensive care unit.

As a result of the difficulties associated with the transfer of patients from the ICU to other environments at the Prince of Wales Hospital, we have devised a transport apparatus that brings the ICU ventilator, on the patient’s bed, with the patient to the chamber. This minimizes the time in which a patient’s ventilation is altered. In view of these problems and the changes that may occur, an important adjunct to treatment of the ventilated patient is regular arterial blood gas sampling. The safety of the patient depends on close monitoring, especially during the compression and decompression phases of the treatment when there are large changes in pressure.

References

3 Weaver LK, Howe S. Arterial oxygen tension of patients
with abnormal lungs treated with hyperbaric oxygen is greater than predicted. *Chest* 1994; 106: 1134-1139


5 Weaver LK and Larson-Lohr V. Hypoxemia during hyperbaric oxygen therapy. *Chest* 1994; 105: 1270-1271


---

**Does hyperbaric oxygen affect blood sugar levels in diabetics? (Abstract only)**

**Barbara Trytko**

**Introduction:** Diabetic patients constitute a major proportion of the patients treated in our hyperbaric unit. The effect of hyperbaric oxygen therapy (HBOT) on diabetic control is still unclear. A number of papers suggest an increase in insulin production or modification of metabolism favourable to the diabetic resulting in lower blood sugar. However, the numbers are small and all studies have involved insulin dependent (IDDM) diabetics exclusively.1-3 The effect in non-insulin dependent (NIDDM) diabetics is unknown. We have conducted an observational study over 12 months of blood sugar levels (BSL) before and after treatment in all diabetics presenting for HBOT.

**Methods:** Following ethical approval, 27 patients were consented, resulting in 237 episodes included for analysis. BSL was measured pre- and post-treatment for between three and 15 consecutive treatments. Glycosylated haemoglobin was measured from patients having more than 10 treatments. In addition, a daily diet plan, medication chart, and activity log were completed for each patient.

**Results:** The mean change in BSL over a single HBOT was a drop of 2.0 mmol.l\(^{-1}\) (SD +/- 2.5 mmol). Patients with IDDM accounted for 133 (56%) of treatment episodes. Of these, a reduction in BSL was recorded in 112 (84%) episodes. Seventy one (63%) of these reductions were > 2 mmol.l\(^{-1}\). Twenty one (19%) were > 4 mmol.l\(^{-1}\) with the majority requiring treatment. Eighty (77%) of the treatments in the NIDDM group were associated with a drop in BSL but none required intervention.

**Conclusion:** Our results show that on average diabetics having HBOT will drop their BSL by 2 mmol.l\(^{-1}\) during each treatment. There is however, considerable variability in this response. Non-insulin dependent diabetics appear to be more predictable in their response than insulin dependent diabetics and are unlikely to drop their BSL sufficiently to require treatment. We recommend that all diabetics eat a meal within two hours of their HBOT if possible and have a BSL prior to treatment. Significant hypoglycaemia is likely to be avoided if patients with IDDM and a BSL < 8.0 mmol.l\(^{-1}\), and with NIDDM and a BSL < 6.0 mmol.l\(^{-1}\), are given oral glucose before treatment. Larger numbers of patients should be studied to confirm this recommendation.

**References**

1 Ekanayake L, Doolette D. Effects of hyperbaric oxygen treatment on blood sugar levels and insulin levels in diabetics. *SPUMS J* 2001; 31: 16-20


*For author details see article above*