Effect of oxygen flow on inspired oxygen and carbon dioxide concentrations and patient comfort in the Amron™ oxygen hood

Gretel Davidson and Michael H Bennett

Key words

Hyperbaric oxygen, equipment, oxygen, carbon dioxide, performance, research

Abstract

(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.)

The Amron™ Oxygen Treatment Hood was tested to determine the effect of altering oxygen flow on conditions within the hood. Inspired oxygen percentage, and inspired and end tidal carbon dioxide pressures were measured as fresh oxygen flow was reduced. Temperature within the hood was also measured. Discomfort was scored by the subjects for noise, temperature and respiratory effort. Inspired oxygen percentage was well maintained at flows of greater than 20 l.min^{-1}. As oxygen flows fell, inspired carbon dioxide pressure increased, although there was little clinically relevant change until flows were reduced below 30 l.min^{-1}. End tidal carbon dioxide did not change significantly. Temperature was higher at low flows, but did not fall significantly further with flows above 20 l.min^{-1}. Patient discomfort scores did not change significantly, but there was a positive correlation between flow and noise, and a negative correlation between both temperature and respiratory effort and flow. We conclude that, with healthy volunteers at one atmosphere absolute ambient pressure, an oxygen flow of 30 l.min^{-1} into the Amron™ Oxygen Treatment Hood provides adequate inspired oxygen concentration, with minimal rebreathing of carbon dioxide, and maintains acceptable conditions of noise and temperature.

Introduction

Hyperbaric oxygen therapy (HBOT) is used in the management of medical and surgical conditions including carbon monoxide poisoning, diabetic and ischaemic ulcers, necrotising infections and decompression illness. In multi-place hyperbaric chambers pressurised using air, administration of 100% oxygen to patients and removal of exhaled gas, without contaminating the chamber atmosphere, is achieved using either a mask fitted over the nose and mouth to supply oxygen on demand, or a hood enclosing the head and supplied with a constant flow of oxygen. Such a device may be used, for example, for patients who have undergone head or neck surgery and to whom a tight mask cannot be fitted, patients with tracheostomies, or persons who are unable to tolerate a tight-fitting mask for any other reason.

The Amron™ Oxygen Treatment Hood (Amron, California, USA) is commonly used by hyperbaric medicine units both in Australia and elsewhere. The device consists of a clear vinyl hood fitted to a plastic ring with a soft dam fitting around the neck. Oxygen is supplied through an inlet hose and the hood is exhausted through a separate outlet hose (Figure 1).

The manufacturers' advice is to supply oxygen at a rate of 25–50 l.min^{-1}. In our facility, patients receiving oxygen at high flows often report being disturbed by the high level of noise within the hood, and communication between the chamber attendant and the patient may be impaired by this noise. Some patients are also disturbed by the high temperature and 'stuffiness' within the hood during the treatment period. Additionally, if flows at the upper end of this range are not in fact required to safely conduct therapy and provide patient comfort, this would represent a considerable waste of oxygen.

A preliminary, unpublished study conducted in our facility determined that reducing fresh oxygen flow had little effect on inspired carbon dioxide concentration down to a flow of 20 l.min^{-1}. Currently in our facility, oxygen is routinely administered at 30 l.min^{-1}. Around Australia, of those centres using oxygen hoods, higher flows are used in most – up to 60–70 l.min^{-1} in one centre.

The manufacturers were unable to provide evidence to support their recommendations, and a search of relevant literature yielded no previously published study assessing the effects of varying oxygen flow into the hood. The aim of our study was to determine the effect of reducing oxygen flow on concentrations of inspired carbon dioxide (P_ICO_2), end tidal carbon dioxide ($P_{ET}CO_2$), inspired oxygen fraction (F_IO_2) and temperature within the Amron hood. In addition, subjective information was gathered about aspects of patient discomfort regarding noise levels, temperature and dyspnoea. We aimed to determine the optimal fresh gas flow rate to ensure administration of 100% oxygen, while ensuring acceptable carbon dioxide elimination and patient comfort.

Figure 1. The Amron™ Oxygen Treatment Hood

Methods

Following approval by the South Eastern Sydney Area Health Service Eastern Section Research Ethics Committee, healthy volunteers were recruited for the study. Prior to fitting the hood, sampling nasal cannulae (Salter Labs, California, USA) were placed on each subject for end tidal gas sampling. A temperature probe (Mallinckrodt Mon-a-Therm, Mallinckrodt Chihuahua, Mexico) was attached to the inner surface of the hood. Subjects were fitted with an appropriately sized neck seal and the sampling line and temperature probe were passed under the neck seal to exit the hood (Figure 1). The gas-sampling line was connected to the gas-sampling inlet of a Datex AS/3 anaesthetic monitor (Datex-Ohmeda, Helsinki). Oxygen was administered via 22 mm tubing from a high-flow oxygen flowmeter to the inlet port, and gases were exhausted via 22 mm tubing from the outlet port via a wall-mounted suction outlet (Clemens, Australia). These arrangements mimicked the equipment used during hyperbaric exposure. Exhaust pressure was titrated against flow to maintain constant hood inflation, just as during treatment.

Subjects were requested to breathe through the nose and encouraged to read in order to reduce their awareness of their respiratory pattern. Commencing at an oxygen flow

of 50 l.min^{-1}, tidal ventilation was monitored from the nasal sampling line for a five-minute period. Flow was sequentially reduced through 40, 35, 30, 25, 20, 15, and 10 l.min^{-1}. Concentrations of inspired oxygen, and inspired and end tidal carbon dioxide were recorded at the end of each five-minute period. Temperature within the hood was continually monitored with the AS/3 monitor and recorded at five-minute intervals.

Subjects were provided with a questionnaire and asked to complete each section following the five-minute period at each flow setting. Subjects were asked to record their level of discomfort on a scale of one (comfortable) to five (distressing) with regard to noise level, temperature within the hood and difficulty breathing. Space was also available on the questionnaire for freehand recording of relevant comments.

In order to confirm the observation that a steady state for the measured gas concentrations was reached within the five-minute period, a second study was completed. Further healthy volunteers were recruited and prepared as above. In this series of subjects, fresh gas flows were altered in random order. Measurements of inspired oxygen and carbon dioxide concentrations were recorded at one-minute intervals for ten minutes if a steady state was observed. If the parameters had not achieved a steady state at that time, observations were to be continued for fifteen or twenty minutes as required.

Data were assessed using Stats Direct Statistical Software Version 1.9.8 (Iain Buchan, 2001). Shapiro-Wilk W test for non-normality suggested it would be reasonable to use parametric tests to analyse data from gas and temperature measurements. Comparisons were thus made using ANOVA with Tukey correction for multiple comparisons and simple linear regression where appropriate. Non-parametric data were analysed using Kendall Rank Correlation. Comparisons were considered to be statistically significant when the p-value was < 0.05. Results are expressed as the mean with 95% confidence intervals.

Results

Nineteen subjects were enrolled in the sequential flow phase of the study. Complete data were available on 17 subjects and partial data on the other two. Twelve of the subjects were male, and the range of body mass indices (BMI) was 21.6 to 31.7 (median 24.7). Five subjects were enrolled in the random flow phase of the study (four male), and the BMI ranged from 19.9 to 31.4 (median 24.4). Results from the random flow phase are included only in the 'steady state' analysis.

INSPIRED OXYGEN

Inspired oxygen concentration decreased with decreasing oxygen flow (Figure 2). On examination of the corrected

Figure 2. Mean F_IO_2 (%) with 95% CI at different fresh gas flows
Indicates significantly lower concentration than at 50 l.min^{-1}
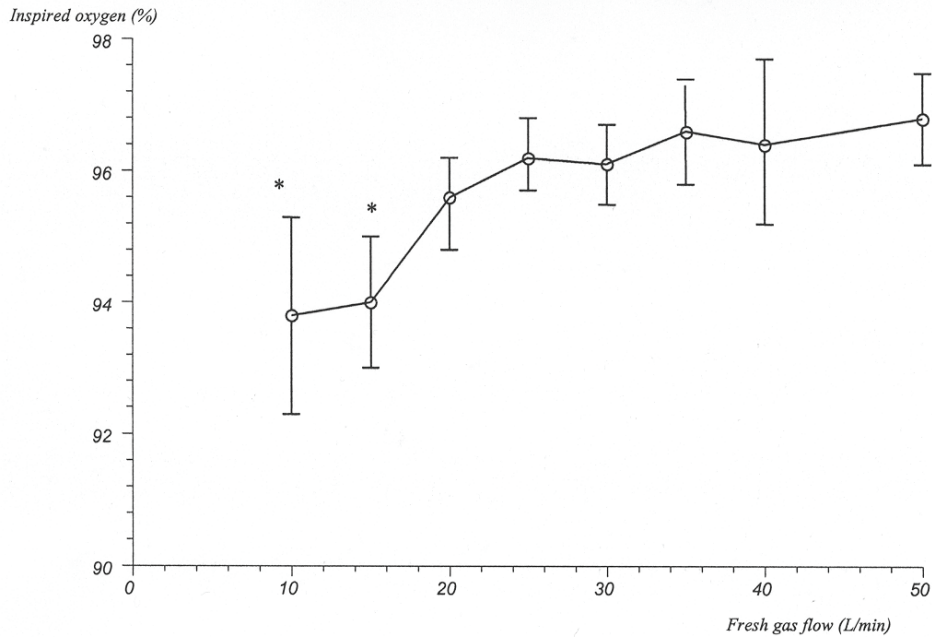
multiple comparisons by ANOVA, there were significant differences between low flows (10 and 15 l.min^{-1}) and 50 l.min^{-1}, but no further significant differences when flow was 20 l.min^{-1} or above. The mean difference in oxygen concentration at 50 l.min^{-1} flow compared with 10 l.min^{-1} flow is 3.0% (95% CI 1.0 to 5.1), p = 0.0003.

INSPIRED CARBON DIOXIDE

P_ICO_2 increased in a non-linear way with reducing oxygen flow although there was no significant difference in P_ICO_2 for flows less than 30 l.min^{-1} when compared with 50 l.min^{-1}. Using a regression of $\log_{10}P_ICO_2$ against flow, this relationship is highly significant (p = 0.0007), and most of the variability in P_ICO_2 is accounted for by varying flow ($r^2 = 0.87$). P_ICO_2 values were never zero, even at 50 l.min^{-1} (mean 5.9 mmHg, 95% CI 5.5–6.4) (Figure 3).

At most flows, P_ICO_2 increased significantly with increasing BMI. For example, at 30 l.min^{-1} there was a significant relationship by linear regression (p = 0.002), with changes in BMI accounting for 40% of the variability in P_ICO_2

Figure 3. Mean P_ICO_2 (mmHg) with 95% CI at different fresh gas flows
Indicates significantly higher concentration than at 50 l.min^{-1}
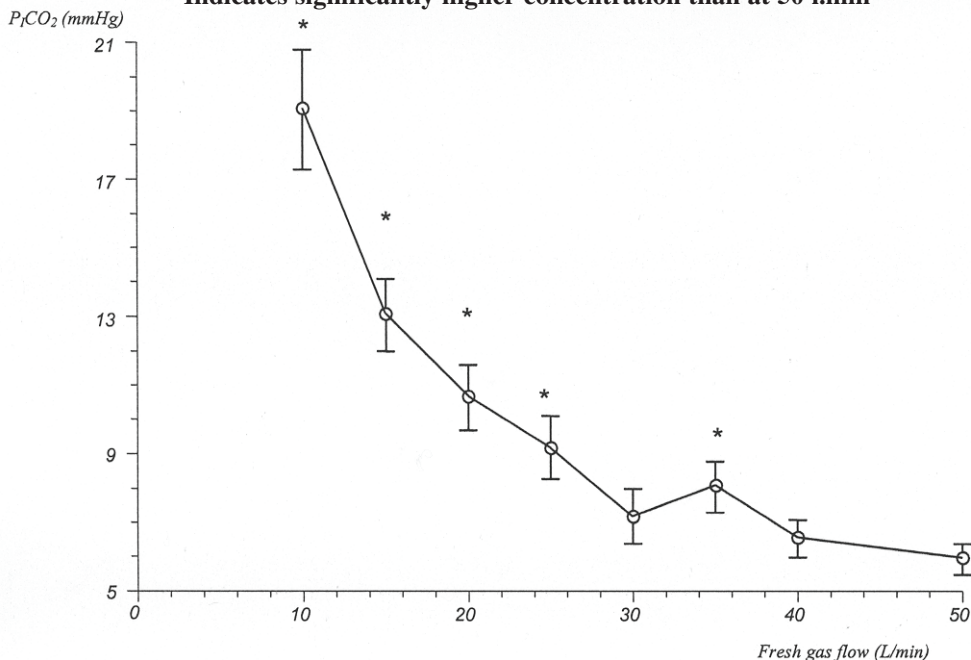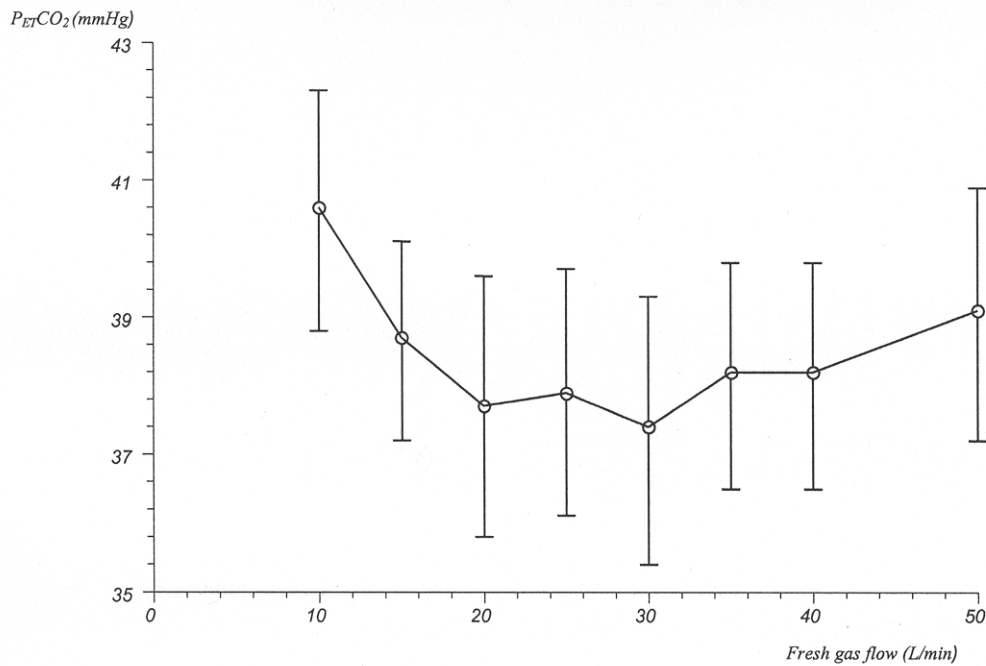
Figure 4. Mean $P_{ET}CO_2$ (mmHg) with 95% CI at different fresh gas flows

$(r^2 = 0.4)$. Regression suggests that P_ICO_2 will increase by 0.36 mmHg with each unit increase in BMI (P_ICO_2 mmHg = 0.36 x BMI – 1.80).

END-TIDAL CARBON DIOXIDE

$P_{ET}CO_2$ was lowest at a flow of 30 l.min^{-1} (mean 37.4 mmHg, 95% CI 35.4 to 39.3), increasing at both higher and lower flows (Figure 4). ANOVA suggests, however, that there was no significant difference in mean $P_{ET}CO_2$ at any of the flows measured (F = 1.93, 6 degrees of freedom, p = 0.06).

TEMPERATURE

Temperature measured within the hood increased significantly with reducing flows ($r^2 = 1.0$, $p < 0.0001$). Regression suggests that temperature decreases 0.07 ºC for every litre of oxygen flow (hood temperature ºC = 27.3 – 0.07 x oxygen flow l.min^{-1}). On examination of the corrected multiple comparisons, there were significant differences in hood temperature between low flows and 50 l.min^{-1}, but no further differences on comparison of flows of 20 l.min^{-1} or greater with 50 l.min^{-1} (Figure 5).

Figure 5. Mean temperature within hood (ºC) with 95% CI at different fresh gas flows
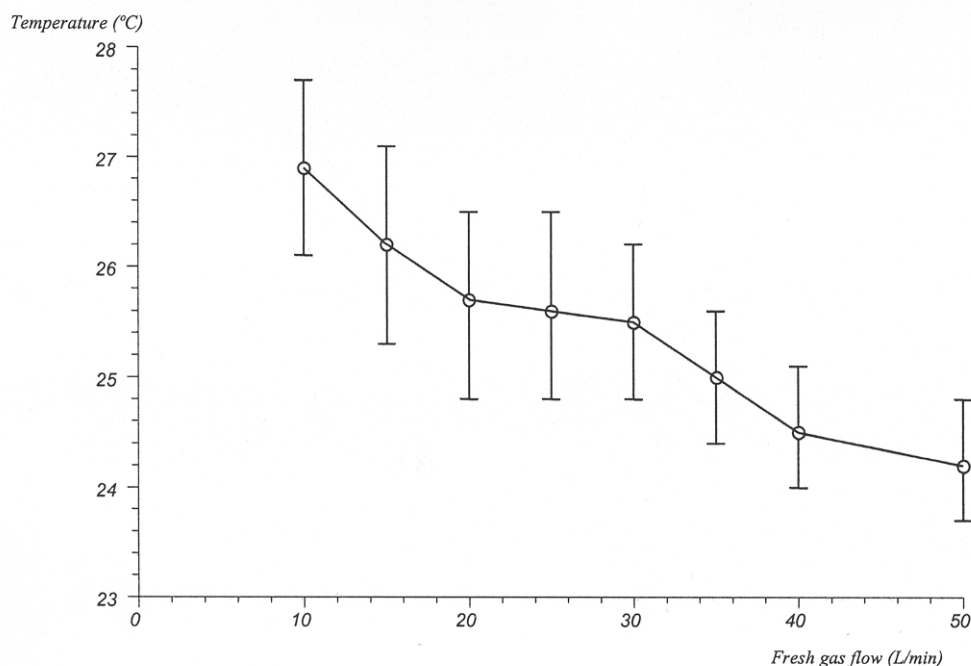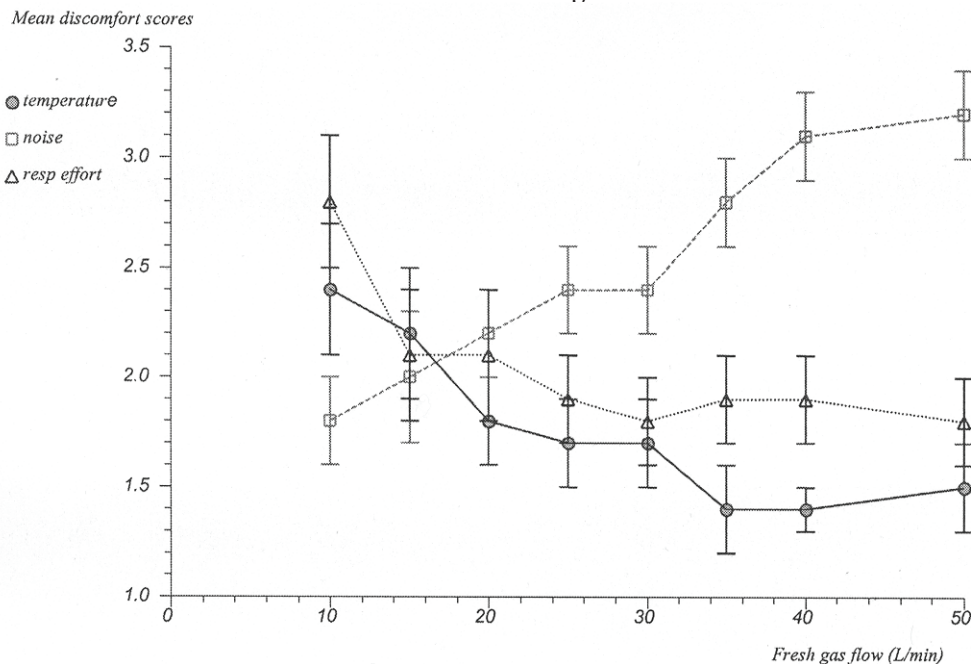
Figure 6. Patient discomfort values (with standard error) for noise, temperature and respiratory effort at different fresh gas flows

PATIENT DISCOMFORT VALUES

Over the range of oxygen flows there were no statistically significant differences in patient discomfort values for noise (p = 0.11), temperature (p = 0.23), or respiratory effort (p = 0.48). However, mean patient discomfort scores for noise correlated positively with oxygen flow (p < 0.0001), and scores for temperature and respiratory effort correlated negatively with oxygen flow (p = 0.0002 and p = 0.002 respectively) (Figure 6).

STEADY STATE

In this study, there was a statistically significant difference in the mean values for oxygen fraction at one minute compared with all other times at a flow of 20 l.min^{-1}. There were no significant differences in the mean values for oxygen fraction at any other times or at other flows (Figure 7). There were no significant differences in the mean values for P_ICO_2 at any of the flows tested over the ten-minute period (Figure 8).

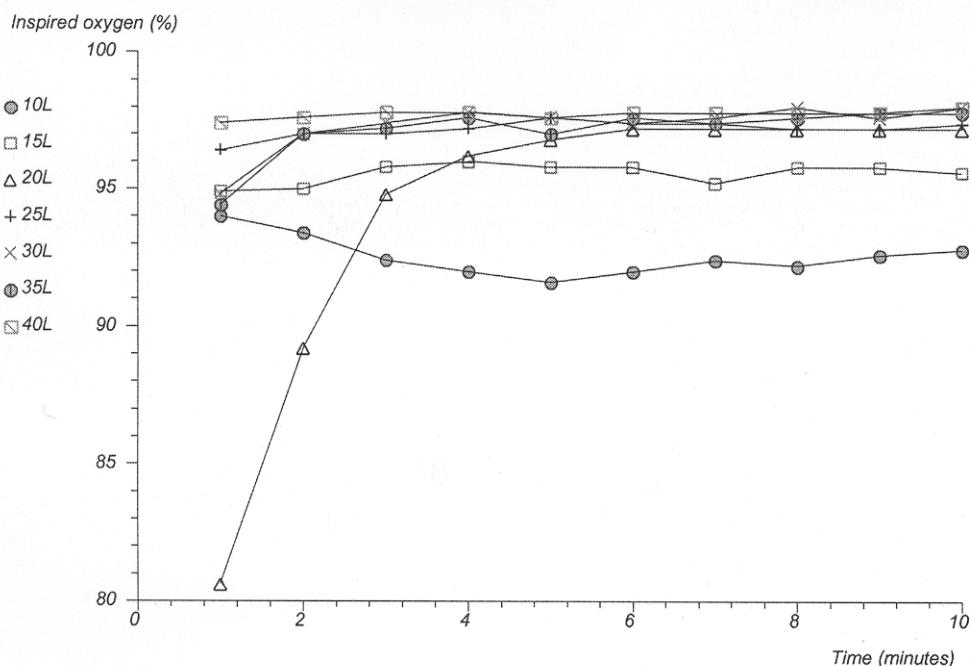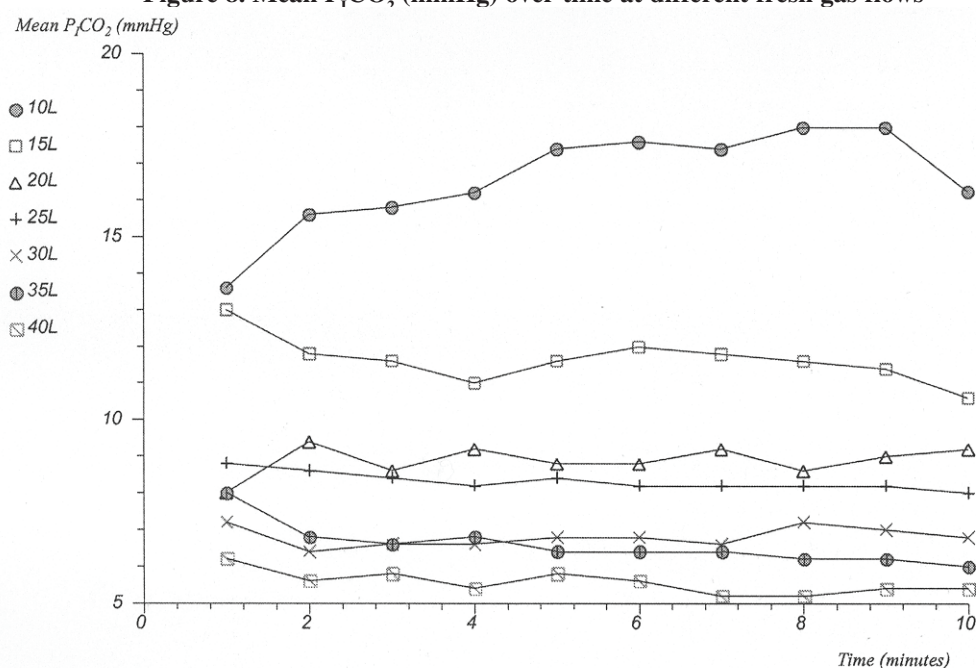**Figure 7. Mean F_IO_2 (%) over time at different fresh gas flows**

Figure 8. Mean P_ICO_2 (mmHg) over time at different fresh gas flows

Discussion

The respiratory equipment tested in this study is designed to deliver high concentrations of oxygen at elevated ambient pressure while avoiding hypercapnia. The primary purpose of this study was to test the ability of the Amron™ hood to achieve these aims at flows acceptable to patients. The manufacturers recommend oxygen flows of 25–50 l.min⁻¹, and although the operating procedures manual states that *"flow rates will vary with chamber, delivery system, patient tidal volume and breathing rate"*,[1] this represents a wide range of possible values. A gas flow of 50 l.min⁻¹ at sea level (101 kPa) equates to 120 l.min⁻¹ at 242 kPa (14 metres of sea water), a pressure commonly employed in hyperbaric oxygen therapy. Over 90 minutes of treatment time this may considerably contribute to an institution's total consumption of medical oxygen.

Our study confirms our clinical impression that a fresh oxygen flow of 30 l.min⁻¹ into the Amron™ hood provides adequate inspired oxygen concentration, with minimal accumulation and rebreathing of carbon dioxide. In addition, temperatures and noise levels within the hood are maintained at reasonably comfortable levels.

A previous study found $F_IO_2 > 0.9$ in all subjects to whom oxygen was delivered via hood, as compared with oxygen delivered via oral-nasal masks.[2] Our study has confirmed this finding, with no values lower than 90% recorded at any flow, and no clinically important difference in inspired oxygen concentration for flows above 25 l.min⁻¹. Inspection of graphical data suggests little clinically significant difference in inspired oxygen concentration at any of the flows employed, as compared with 50 l.min⁻¹.

While there is a significant correlation between oxygen flow and inspired carbon dioxide concentration, at flows less than 30 l.min⁻¹ there is little clinically significant difference in P_ICO_2. None of our experimental conditions achieved a P_ICO_2 of zero. This finding accords with similar investigations in other clinical scenarios. For example, carbon dioxide levels have been shown to increase significantly under surgical drapes throughout the duration of ophthalmological surgery, with or without insufflation of oxygen and suction to remove carbon dioxide.[3,4] It remains to be determined what concentration of inspired carbon dioxide may be considered acceptable. One author suggests a concentration of 10 mmHg, although it is accepted that a significantly increased minute volume is required to maintain normocarbia with this level of inspired carbon dioxide.[5]

In our group of healthy subjects, increased inspired partial pressure of carbon dioxide was not associated with significantly increased end tidal (and presumably arterial) carbon dioxide tension. While these individuals were able to regulate their ventilation to maintain normocarbia, it cannot be assumed that patients with impaired respiratory reserve or at risk of carbon dioxide retention would be able to compensate.

Temperatures measured in the hood increased with reducing flows in our study and achieved a steady state after five minutes at each step. Given that HBOT treatment times are usually 90–120 minutes, however, we cannot confidently assert that temperatures will remain acceptable over a full treatment period at low flows. In clinical practice at our facility, patients rarely complain of feeling hot during treatment with an oxygen flow of 30 l.min⁻¹.

Inspection of Figure 6 suggests there is a point of compromise between noise, temperature and respiratory effort at an oxygen flow of approximately 15 l.min^{-1}. At flows of less than 15 l.min^{-1}, discomfort scores for temperature and respiratory effort increased rapidly. At a flow of 10 l.min^{-1}, subjects reported significant discomfort. At flows of 40 or 50 l.min^{-1}, however, subjects were disturbed by the levels of noise. Some subjects reported that enduring such levels of noise throughout a treatment period of 90 minutes could become distressing.

We recognise our study has two potential methodological flaws. Firstly, it was conducted at an ambient pressure of 101 kPa (sea level) rather than at a treatment pressure. This was primarily because of our inability to monitor gas concentrations in the chamber at pressure. We believe, however, that the relationships between flows and gas concentrations are unlikely to change at the modest hyperbaric pressures used therapeutically. Further investigation to confirm this assumption should be undertaken, and we plan to do this when suitable equipment is available to us.

Secondly, we measured outcomes following a step-wise reduction in flow, rather than randomly altering flow, on the assumption that values after five minutes at each flow would not be influenced by the previous flow setting. The finding that steady state was achieved after one minute when flows were randomly varied suggests this is a valid assumption. Given that rates of oxygen consumption and carbon dioxide production should not be significantly different under hyperbaric conditions, it is probably reasonable to extrapolate these results for application to clinical usage.

In conclusion, we recommend that an oxygen flow of 30 l.min^{-1} into the Amron™ Oxygen Treatment Hood is appropriate and can be expected to provide acceptable oxygen delivery and carbon dioxide elimination while providing reasonable patient comfort. Further studies are required to determine whether flows should be adjusted for individuals at risk of retaining carbon dioxide.

Acknowledgement

References

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Gretel Davidson, MB, BS, is a Provisional Fellow in Anaesthesia, Prince of Wales Hospital,
Randwick, NSW 2031,
Australia.
Phone: *+61-(0)2-9382-2222*
E-mail: *<gretelie@yahoo.com>*

Michael H Bennett is Medical Director, Department of Diving and Hyperbaric Medicine, at the Prince of Wales Hospital.

Erratum

In the editorial by Dr Carl Edmonds on diving and inner ear damage (*SPUMS J.* 2004; 34: 2-4.) the meaning of the fourth paragraph, left-hand column, on page 3 regarding the treatment of inner ear barotrauma (IEBt) was substantially changed by a typographical error. The term MEBt (middle ear barotrauma) appeared in the first sentence rather than IEBt. The first sentence of that paragraph should read:

   "*The pathophysiology guides the treatment of IEBt.*"
The advice given in that paragraph does *not* pertain to MEBt. Dr Edmonds hopes that no one ever quotes this as treatment for MEBt. The Editor apologises for this error.

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