DOMICILIARY OXYGEN CONCENTRATORS IN ANAESTHESIA: PREOXYGENATION TECHNIQUES AND INSPIRED OXYGEN CONCENTRATIONS

I. H. WILSON, P. V. VAN HEERDEN AND J. LEIGH

SUMMARY

A conventional preoxygenation technique was compared in two volunteers with two techniques based on a drawover breathing system supplied with oxygen enriched air from a Devilbiss Mini VO2 domiciliary oxygen concentrator. Breathing from a 20-litre bag, filled previously at 2 litre min⁻¹ from the concentrator was as effective as the conventional technique (PaO₂ 73.2 kPa). Supplying 4 litre min⁻¹ to a drawover system was less effective (PaO₂ 35.5 kPa). We present a simple method for determining the inspired oxygen concentration obtained under conditions of drawover anaesthesia using an oxygen concentrator.

KEY WORDS

Oxygen concentrators are capable of separating oxygen from other atmospheric gases by filtration through zeolite columns which act as molecular sieves [1]. Concentrators of varying capacity are available, the most common being the electrically powered "domiciliary oxygen concentrator" used for oxygen therapy at home. The use of these devices has been investigated for oxygen supplementation during drawover anaesthesia [2-4]. Small size and portability make them an ideal oxygen source for use in situations in which there are shortages of compressed gases, such as military and disaster situations or developing countries [5, 6]. In addition, considerable financial savings may result from reduced cylinder hire and transportation costs, as has been shown recently in Malawi, where all government hospitals use concentrators in theatres as the main supply of oxygen [6].

The oxygen concentration delivered by a concentrator depends on the model used and on the flowmeter setting. At low flow rates, the oxygen is highly concentrated, but at higher flow rates the oxygen is less concentrated, as the nitrogen absorption by zeolite becomes less efficient. A typical domiciliary oxygen concentrator produces approximately 2 litre min⁻¹ of 95% oxygen or 4 litre min⁻¹ of 70-80% oxygen, the balance being nitrogen and argon [1].

During anaesthesia there are times when a high flow of oxygen is required, most commonly for preoxygenation [7]. This process is difficult when a domiciliary oxygen concentrator is used as the oxygen source in a drawover circuit, as the limited flow of oxygen provided allows air to be drawn into the circuit, diluting the oxygen. This results in inefficient preoxygenation, particularly in patients who are hyperventilating.

Two methods may be used for preoxygenation when using an oxygen concentrator. The method practised most commonly involves breathing through a standard drawover circuit [8] with a flow of 4 litre min⁻¹ of concentrator "oxygen" added to the circuit via a T-piece. Some workers recommend adding to the circuit a larger reservoir which has been pre-filled with concentrator "oxygen" [9].

During use of the concentrator, the inspired oxygen concentration depends on concentrator flow and ventilatory volume. We studied the effect of these variables on the inspired concentration of oxygen and assessed the efficiency of preoxygenation under conditions of drawover anaesthesia.
SUBJECTS AND METHODS
A Devilbiss Mini VO2 oxygen concentrator, the output of which had been confirmed to be within manufacturer's recommendations using a calibrated gas analyser (Datex Normocap), was used. Between experiments using different concentrator flow rates, adequate time was allowed for the output of the concentrator to stabilize as judged by gas analysis.

Two techniques of preoxygenation using an oxygen concentrator were compared with a standard method using a Magill circuit in two of the authors (ASA 1, age 29 and 33 yr, weight 78 and 73 kg) who had been subjected to arterial cannulation to facilitate blood-gas analysis. During each of the techniques of preoxygenation, blood was drawn during the final 5 s and was analysed immediately using an Instrumentation Laboratories 1312 blood-gas analyser. Subjects breathed atmospheric air between experiments for at least 10 min, to allow alveolar gases to normalize. Three baseline blood-gas samples were obtained with the subject breathing air and analysed for comparison. Three techniques were evaluated:

**Magill technique.** The subject breathed for 3 min from a Boyle's machine via a standard Magill circuit with a flow of oxygen 6 litre min⁻¹. The reservoir bag was filled with oxygen at the start of the experiment.

**Standard drawover technique.** Using the circuit illustrated in figure 1, 4 litre min⁻¹ of concentrator "oxygen" was added to a standard drawover circuit which comprised an Ambu E valve, T-piece for oxygen addition and a 1-litre reservoir tube. We assessed the efficacy of preoxygenation at a minute ventilation of 10 litre min⁻¹. To facilitate this we added air 6 litre min⁻¹ via a 2-litre reservoir bag which was connected to the circuit as shown in figure 1. At the start of preoxygenation, the reservoir tubing was filled with concentrator gas, the reservoir bag was empty and the air flow was started as the subject was connected to the circuit. After 3 min of preoxygenation, blood was drawn for analysis during the final 5 s. During the experiment the subject breathed so as to keep the reservoir bag between empty and half full.

**Drawover technique with a 20-litre reservoir.** A 20-litre reservoir bag (made from a disposable plastic bag), pre-filled from the output of the concentrator at 2 litre min⁻¹, was connected directly to the inlet port of the Ambu E valve. The subject breathed from the reservoir until it was empty and a blood sample was taken during the last breath. The time taken to empty the bag was noted.

Each subject performed the three techniques on three separate occasions.

We calculated the inspired oxygen concentration during drawover anaesthesia in relation to patient ventilation when a domiciliary oxygen concentrator is used, applying the formula:

$$F_{Io_2} = \frac{0.21(\dot{V}_E - \dot{V}_C) + (\dot{V}_C \times F_{Co_2})}{\dot{V}_E}$$

where $F_{Io_2} =$ fractional inspired oxygen concentration; $F_{Co_2} =$ fractional oxygen delivered by concentrator; $\dot{V}_E =$ minute ventilation (litre min⁻¹); $\dot{V}_C =$ concentrator flow (litre min⁻¹).

Data were subjected to analysis of variance using the Genstat statistical package, version

---

**Fig. 1.** Circuit for standard drawover technique.
TABLE I. Mean blood-gas tensions (kPa) for each treatment

<table>
<thead>
<tr>
<th>Variable</th>
<th>Air baseline</th>
<th>Magill system</th>
<th>Drawover standard</th>
<th>Drawover reservoir</th>
<th>se of diff. between treatments</th>
<th>95% CI of each mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\log P_{A_O_2}$</td>
<td>1.136</td>
<td>1.825</td>
<td>1.550</td>
<td>1.864</td>
<td>0.0065</td>
<td>±0.0146</td>
</tr>
<tr>
<td>Corresponding $P_{A_O_2}$</td>
<td>13.7</td>
<td>66.8</td>
<td>35.5</td>
<td>73.1</td>
<td>±3.4%</td>
<td></td>
</tr>
<tr>
<td>$P_{A_C_O_2}$</td>
<td>4.82</td>
<td>4.68</td>
<td>4.65</td>
<td>4.74</td>
<td>0.092</td>
<td>±0.29</td>
</tr>
</tbody>
</table>

4.04B (Numerical Algorithms Group Ltd), on a Honeywell mainframe computer running under Multics release 11.0. As the basic “experimental unit” was the subject, the mean of the three values for each treatment in each subject was calculated and the analysis performed on the resulting eight means (four techniques in each of two subjects). This was done for both the $P_{A_O_2}$ and the $P_{A_C_O_2}$ data. Analysis was made directly on the $P_{A_C_O_2}$ values, but on the logarithms of the $P_{A_O_2}$ data, in order to make the residuals independent of the fitted values. The means for each treatment are shown in table I for $\log P_{A_O_2}$ and the corresponding values of $P_{A_O_2}$, and for $P_{A_C_O_2}$, together with the standard errors of the differences.

RESULTS

The time taken to empty the 20-litre reservoir bag ranged from 2 to 2.5 min, equivalent to a minute volume of 8–10 litre min$^{-1}$.

The differences between treatments in terms of $\log P_{A_O_2}$ were all highly significant: even the small difference between Magill and Drawover–reservoir was six times the se of the differences between means (table I). The 95% confidence limits for each treatment were ±3.4% of the estimated value (table I). The mean values of $P_{A_C_O_2}$ were similar for all treatments: even the largest difference (between baseline and drawover-standard) was only 1.8 times the se of the differences (table I).

FIG. 2. Predicted inspired oxygen concentrations.

The output of the concentrator used in the study is shown in table II. Figure 2 allows the inspired oxygen concentrations from a drawover anaesthetic system to be determined for different ventilation rates and concentrator flow settings.

DISCUSSION

Preoxygenation increases the safety of anaesthesia, particularly around the time of tracheal intubation and extubation, by increasing pulmonary oxygen stores. The immediate administration of a high concentration of oxygen may be lifesaving when severe hypoxia occurs such as during cardiac arrest. Although oxygen concentrators of the domestic type are revolutionizing oxygen supply in rural hospitals in developing countries, they are limited by inability to produce a high flow of oxygen. Our results show that the standard technique used for preoxygenation with an oxygen concentrator and a standard drawover anaesthetic circuit is relatively ineffective compared with a
method using a prefilled reservoir bag [9]. When the standard drawover technique of preoxygenation is in use, the $F_{1O_2}$ which is inspired may be read from figure 2. In our experiment we chose to examine a minute ventilation ($V$) of 10 litre min$^{-1}$ so as to simulate the mild hyperventilation of preoxygenation, a common occurrence, particularly with obstetric patients. At this $V$, the $F_{1O_2}$ was about 45% and the resulting $P_{aO_2}$ (and therefore denitrogenation) 50% of that achieved by the other methods. More pronounced hyperventilation would have reduced $F_{1O_2}$ further, making denitrogenation even less effective.

The technique of preoxygenation using a 20-litre reservoir was as effective as the Magill technique with 100% oxygen. The reservoir bag was constructed from materials which would be available in any part of the world: in our case we used a plastic disposable bin liner. The size was reduced to 20 litre (measured by the time to fill with a Boyle's machine rotameter set at 5 litre min$^{-1}$) by the application of tape around the neck of the bag, which was attached to a standard connector. Previously a 40-litre reservoir has been recommended [9], but our results indicate that a 20-litre reservoir is an effective volume for preoxygenation. When used in anaesthesia, this bag should be filled from the concentrator running at 2 litre min$^{-1}$ and left ready for emergency use. In urgent situations a higher rate of filling from the concentrator would be effective. It would provide an immediate supply of 95% oxygen for preoxygenation, emergency administration of oxygen, or even during neonatal resuscitation, when it could be connected to a paediatric self-inflating bag. Previous studies [2–4] have shown that oxygen concentrators take 5–10 min to reach their full oxygen output. It is likely that the use of a prefilled reservoir would facilitate induction in emergency patients.

We note that the Triservice apparatus (Penlon U.K. Ltd) is supplied with the Houtonox oxygen valve, which is an oxygen pressure reducing valve providing a choice of oxygen flows of 1 or 4 litre min$^{-1}$, with the recommendation that the greater flow is used for preoxygenation [10]. For preoxygenation, a flow of 4 litre min$^{-1}$ is likely to be inadequate for full denitrogenation and the 20-litre reservoir is likely to be of benefit [9].

When an oxygen concentrator is used as an oxygen source for anaesthesia or for a ventilator, the graph shown in figure 2 may be used to predict the $F_{1O_2}$ by relating the concentrator "oxygen" flow and the total ventilation. The value could be checked if an oxygen analyser was available. Although our results refer specifically to the Devilbiss concentrator studied, we feel that they may be applied to the majority of domiciliary concentrators, as most models in this flow range perform to a similar specification [2–4].

ACKNOWLEDGEMENTS

The authors thank Professor W. W. Mapleson for his assistance with statistical analysis, Mrs C. Childs of Devilbiss Health Care U.K. for supplying the oxygen concentrator, and Mr C. Dolman, Operating Department Assistant.

REFERENCES