

APPARATUS

Improving the efficiency of the drawover anaesthetic breathing system

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Summary

We investigated modifications to the reservoir tube usually used in drawover anaesthetic breathing systems as a method of improving its efficiency and performance. The resulting oxygen concentration was recorded at different oxygen flow rates whilst an artificial lung was being ventilated over a range of minute volumes. Addition of a reservoir bag and valves significantly increased the measured percentage of oxygen at the common gas outlet when compared to a 300-ml reservoir tube. There was no difference in the percentage of oxygen when comparing a reservoir bag and a 600-ml reservoir tube.

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Drawover anaesthesia is used extensively in the developing world and among the military to provide general anaesthesia in situations where compressed gases are expensive, scarce or even completely unavailable. In this system, atmospheric air is utilised as the carrier gas, usually supplemented by oxygen delivered via a side port into an open ended tube (Fig. 1). This acts as a reservoir for the oxygen until it is included in the next breath. The mixture of oxygen and air in the reservoir tube is drawn over a vaporiser by the patient's own inspiratory efforts or by the expansion of bellows or a self-inflating bag.

Although it is extremely safe and effective, disadvantages of the conventional reservoir tube include difficulty in delivering high inspired oxygen concentrations, absence of a means of observing the rate and depth of respiration, and potential wastage of oxygen if it spills out of the open end of the reservoir tube into the atmosphere.

The $F_{I}O_2$ delivered to the patient is determined by three factors: the flow rate of added oxygen; the patient's respiratory minute volume; and the volume of the reservoir. A previous study concluded that a reservoir tube of at least 1 m in length and volume 415 ml makes optimal use of 4 l.min⁻¹ oxygen flow [1]. However, increasing the length of the reservoir tube beyond this to

accommodate the demands of a high minute volume makes the arrangement cumbersome and potentially increases the resistance to flow. In an attempt to improve the efficiency of the drawover system and overcome these disadvantages, a modification of the reservoir tube was designed and its performance compared with the conventional reservoir tube. A similar modification has recently been recommended for use with the Triservice apparatus [2].

Methods

The modified reservoir consisted of a shortened reservoir tube incorporating a one-way valve at the open end of the tube to prevent spillage of oxygen when high flow rates are used, a reservoir bag to increase the volume of the system, and an adjustable pressure limiting (APL) valve (5-cmH₂O continuous positive airway pressure valve, Vital Signs Inc., Totowa, NJ, USA) to prevent excessive pressure developing (Fig. 2). The one-way valve consists of a latex flutter valve designed to be used with spontaneous breathing. The APL valve offers minimal resistance to flow and opens to prevent the bag becoming distended.

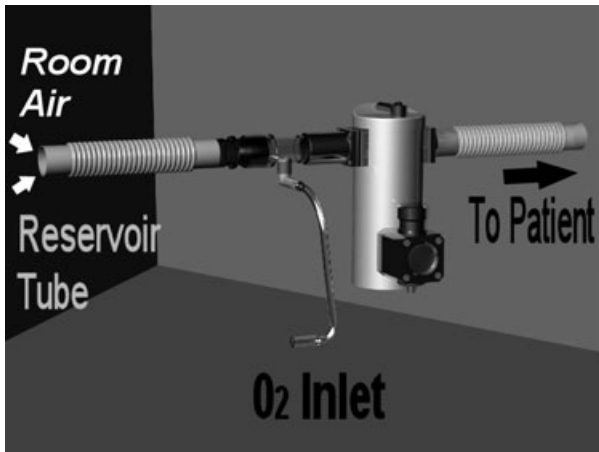


Figure 1 Drawover anaesthetic breathing system with standard reservoir tube.

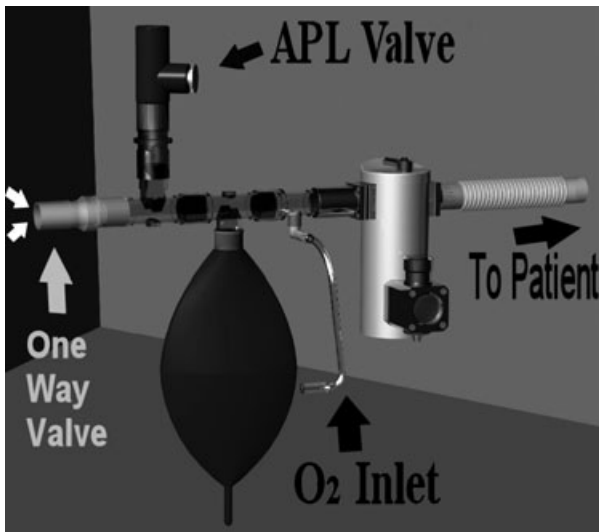


Figure 2 Drawover anaesthetic breathing system with modified reservoir tube.

The performances of the two types of reservoir were studied after attachment to a Glostavent anaesthetic machine [3] which was used to ventilate a set of artificial lungs (Siemens, Erlangen, Germany) at tidal volumes varying from 125 ml to 1000 ml. The resulting percentage of oxygen delivered by different flow rates of added oxygen was compared between the two systems over a range of minute volumes. The oxygen was delivered from a recently calibrated Aestiva 5 anaesthetic machine (Ohmeda, Madison, WI, USA) allowing accurate and reproducible flows. The I : E ratio was maintained at 1 : 2 throughout. The respiratory rate was kept at 10 breaths. min⁻¹ and the tidal volume was altered to achieve the

required minute volume, measured using a Metron QA-VTM ventilator tester (Metron, Trondheim, Norway). Reservoir tubes of 22 mm diameter (aerosol hose tubing, Intersurgical Ltd, Wokingham, UK) with volumes of 300 ml and 600 ml using the standard drawover system were compared with the modified system incorporating either 1000-ml or 2000-ml reservoir bags (Intersurgical). The percentage of oxygen was measured at the common gas outlet using an Ohmeda 5120 oxygen analyser. After 5 min for equilibration for each new set of parameters the percentage of oxygen was measured each minute for the next 3 min. The mean of these three measurements was taken as the result.

Data were analysed using ANOVA with posthoc analysis using the Scheffé method. A p value of 0.05 was taken to denote statistical significance.

Results

The percentages of oxygen for increasing flow rates of oxygen and minute volumes are shown in Table 1. With

Table 1 Percentages of oxygen resulting from increasing flow rates of oxygen and minute volumes using a drawover anaesthetic breathing system with a standard 300-ml (a) or 600-ml (b) reservoir tube, or with a reservoir tube modified with a 1000-ml (c) or 2000-ml (d) bag. Values are mean (SD).

		Oxygen flow rates; l.min ⁻¹				
		0.5	1.0	2.5	5.0	10.0
(a) 300-ml tube						
Minute volume; ml						
1250	47 (1.0)	76 (0.6)	97 (1.7)	98 (0)	99 (0.6)	
2500	36 (0.6)	50 (0.6)	89 (0)	98 (0.6)	98 (0.6)	
5000	29 (0.6)	36 (0)	58 (0.6)	78 (1.0)	85 (0)	
7500	27 (0.6)	32 (1.0)	47 (0.6)	63 (0)	71 (0.6)	
10 000	26 (0)	29 (0.6)	42 (0)	57 (0)	67 (0.6)	
(b) 600-ml tube						
Minute volume; ml						
1250	48 (0.6)	76 (0.6)	97 (0)	98 (0)	99 (0.6)	
2500	36 (1.5)	51 (0)	93 (0.6)	98 (0.6)	98 (0)	
5000	29 (0)	36 (0.6)	58 (0)	96 (1.0)	99 (0.6)	
7500	27 (0.6)	32 (0.6)	48 (0.6)	75 (0.6)	96 (0)	
10 000	26 (0)	29 (0.6)	42 (0.6)	63 (0.6)	89 (0.6)	
(c) 1000-ml bag						
Minute volume; ml						
1250	51 (0)	78 (0.6)	99 (0)	99 (0)	99 (0.6)	
2500	38 (0.6)	52 (1.5)	92 (0)	98 (0.6)	98 (0.6)	
5000	29 (0.6)	36 (0)	59 (0.6)	98 (0.6)	99 (0)	
7500	27 (0)	33 (1.0)	48 (0.6)	74 (0.6)	99 (0.6)	
10 000	26 (0.6)	30 (0.6)	42 (0.6)	63 (0.6)	99 (0.6)	
(d) 2000-ml bag						
Minute volume; ml						
1250	51 (0.6)	78 (1.0)	99 (0)	99 (0.6)	99 (0)	
2500	37 (0.6)	52 (0)	94 (0.6)	98 (0)	99 (0)	
5000	29 (1.6)	37 (0.6)	60 (1.0)	98 (0.6)	99 (0.6)	
7500	27 (0)	32 (0)	48 (0.6)	75 (0.6)	99 (0.6)	
10 000	26 (0.6)	30 (0.6)	42 (0)	63 (1.0)	99 (0.6)	

the standard drawover system incorporating a 300-ml reservoir tube (a) the percentage of oxygen increased in proportion to the supplementary oxygen flow rates, tailing off at higher flow rates. When the larger reservoir tube was used (600 ml (b)) the same pattern was observed for the lower flow rates and minute volumes. However, at higher minute volumes and flow rates, the resulting percentage of oxygen was comparatively higher. When the same flow rates were used with the modified system, the resulting percentages of oxygen equalled those found with the large reservoir tube group, regardless of whether a 1000-ml (c) or a 2000-ml (d) reservoir bag was used.

The separate effects on the percentage oxygen of increasing minute volumes and flow rates of added oxygen are illustrated graphically in Figs 3 and 4. In Fig. 3 the percentage of oxygen is shown to fall as the minute volume increases above 2500 ml. This effect is most noticeable with the 300-ml reservoir tube. In Fig. 4 the percentage of oxygen is seen to rise with increasing flow rates of added oxygen, reaching 100% with the 600-ml reservoir tube and both reservoir bags but only 80% with the 300-ml reservoir tube.

Statistical analysis showed that flow rate, minute volume and reservoir volume accounted for 99% of the variability in the readings ($r^2 = 0.99$), each factor separately having a significant ($p < 0.001$) effect on outcome. The 300-ml reservoir tube was associated with a significantly lower percentage of oxygen than the other systems, and there was no statistical difference between the other three systems.

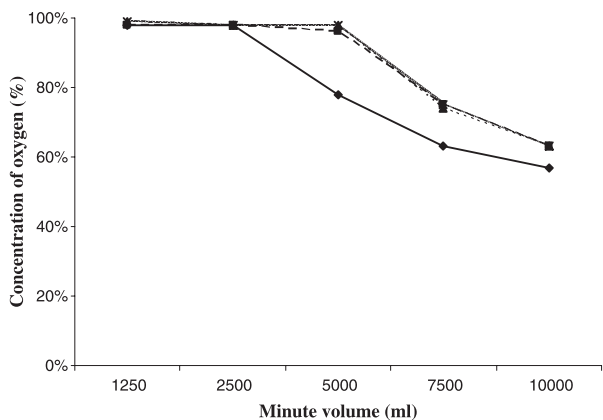


Figure 3 Percentage of oxygen delivered when ventilating a model lung at various minute volumes, at an oxygen flow rate of 5 l.min⁻¹, using a drawover anaesthetic breathing system with a standard 300-ml (◆) or 600-ml (■) reservoir tube, or with a reservoir tube modified with a 1000-ml (▲) or 2000-ml (×) bag.

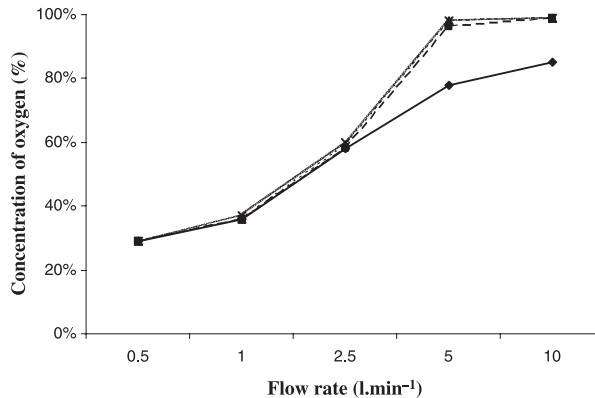


Figure 4 Percentage of oxygen delivered when ventilating a model lung at various oxygen flow rates, using a minute volume of 5000 ml, using a drawover anaesthetic breathing system with a standard 300-ml (◆) or 600-ml (■) reservoir tube, or with a reservoir tube modified with a 1000-ml (▲) or 2000-ml (×) bag.

Discussion

The study confirms that at high respiratory minute volumes, use of the modified reservoir tube results in a more efficient system of oxygen delivery than the commonly used size of reservoir tube. When the flow rate equalled or exceeded the patient’s minute volume, very little air entrainment occurred resulting in delivery of high percentages of oxygen. For example, our results suggest that for intermittent positive pressure ventilation (IPPV) for an adult requiring a respiratory minute volume of 5 l.min⁻¹, 30–40% oxygen can be achieved with all the set-ups we studied using an oxygen flow rate of only 1 l.min⁻¹. Indeed, reservoir tubes of varying sizes have been used successfully in this way for many years. However, when a high $F_{I}O_2$ is required in combination with large minute volumes, as in pre-oxygenation or when flushing the system, then the degree of air entrainment makes this difficult to achieve when the smaller volume reservoir is used. In this situation, use of the larger volume reservoir tube or bag arrangement is required. In the past this problem has been overcome by increasing the flow rate of added oxygen; however, this may require an additional supply of oxygen, which, in the developing world, is seldom available. The open-ended reservoir tube with side oxygen port is traditionally used in drawover anaesthetic practice because it is inexpensive and simple. However, the modified system adds little in the way of expense or complexity, being assembled from simple commercially available components.

The volumes of reservoir tube tested were chosen because 300 ml (measuring 82 cm of 22-mm diameter corrugated tubing) is very similar to the volume recom-

mended in the original description of the Triservice apparatus [4] and is still commonly used in drawover anaesthesia throughout the developing world, including on the Glostavent machine. In theory, 600 ml, being equal to or greater than the typical tidal volume, should minimise spillage of oxygen and entrainment of room air at higher oxygen flow rates. In practice, however, using a reservoir tube of volume 600 ml (160 cm of 22-mm tubing) is impractical because of its size, whereas the modified tube is a small, discrete unit that can conveniently sit at the back of the anaesthetic machine.

The pressure in the reservoir bag is limited to 5 cmH₂O by the APL valve. By observing the degree of filling of the reservoir bag, an optimal oxygen flow rate can be chosen to produce maximum efficiency during hyperventilation. If the flow rate is too high, the reservoir bag becomes distended, and oxygen escapes through the APL valve and is wasted. If the flow rate is too low, the reservoir bag collapses, a negative pressure is created and air is sucked in through the one-way valve, diluting the oxygen. Movements of the reservoir bag are determined by the pressure within the reservoir and provide an indication of respiratory rate and depth that is not available with the standard drawover system. This is especially important in the developing world where electronic tidal volume measurement and capnography are seldom available.

In normal clinical practice, a degree of dilution of oxygen with room air is acceptable and even desirable. However, during pre-oxygenation before rapid sequence induction, the highest possible $F_{I}O_2$ is required at a time when a degree of hyperventilation is normally seen. The same applies in an emergency situation when it becomes necessary to flush the breathing system with a high percentage of oxygen. Using the conventional type of reservoir tube, difficulties have been found achieving a

high $F_{I}O_2$ in these settings [5–7]. However, the modified tube can prevent dilution with air provided the oxygen flow rate equals or exceeds the minute volume. If this cannot be achieved by the volume of oxygen available from the concentrator alone, a small supplement of oxygen from a cylinder can be added.

All the theoretical advantages suggested in the letter by Birt [2] have been confirmed in this study. We have shown that the size of the reservoir tube can be limited to 1000 ml, enabling respiratory movements to be more easily observed. Birt also suggested that the use of such a system be limited to patients breathing spontaneously; however, this study has shown that the modified tube is also effective during IPPV and may therefore improve the efficiency of all forms of drawover anaesthesia.

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