CONTROLLED VENTILATION WITH A MAPLESON A (MAGILL) BREATHING SYSTEM: REASSESSMENT USING A LUNG MODEL

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The Magill attachment was introduced, approximately 60 years ago, to provide an efficient system for spontaneous ventilation, with facility for providing intermittent positive pressure ventilation in an emergency [1]. The inefficiency of the system has been documented clearly in respect of carbon dioxide elimination during controlled ventilation [2]. Marshall and Henderson [3] reported that, in spite of the presence of rebreathing, it was possible to reduce arterial carbon dioxide concentrations when using the Magill attachment for controlled ventilation with fresh gas flows far smaller than those suggested by Sykes [2], if the level of ventilation was increased. This report and our own clinical observations stimulated us to re-evaluate the Magill system during controlled ventilation.

We have used a lung model to reassess the efficiency of the Magill attachment when used for intermittent positive pressure ventilation. We have examined the effect of varying the inspiratory:expiratory ratio when the pattern of ventilation, tidal volume and fresh gas flows were varied.

METHODS

The arrangement of apparatus used in this experiment is shown diagrammatically in figure 1. A standard Magill attachment was used, with a 2-litre reservoir bag enclosed in an aspirator bottle. A Servo 900C ventilator was connected to this bottle so that the desired pattern of controlled ventilation could be simulated. The Heidbrink valve was connected via a Fleisch pneumotachograph head to a non-compliant deadspace tubing of 130 ml, and thence to an electronic Wright's Respirometer (Ohmeda) and the lung simulator (Ohmeda). The compliance of the lung was set at 50 ml/cm H$_2$O and the resistance at 5 cm H$_2$O litre$^{-1}$ s$^{-1}$. The accuracy of these settings was confirmed using a water manometer. A continuous flow of carbon dioxide 210 ml min$^{-1}$ was supplied to the centre of the lung. The fresh gas supply to the Magill attachment was carbon dioxide-free compressed air. The gas flow to the Magill attachment and the carbon dioxide supply to the lung model was supplied by universal rotameters (Gapmeter Lab Kits – A6) which had been calibrated previously against a spirometer of known accuracy (Ohio 840). The Heidbrink valve in the system was checked to comply with the specification of Nunn [4], measured by a method previously described [5]. It was adjusted so that all the desired patterns of ventilation could be achieved and remained in this position throughout the experiment. Five sampling lines were incorporated into the system (fig. 1).

Gas analysis from the sample sites was performed by mass spectrometry (Centronic 200...
The readings were displayed graphically on a chart recorder (Brush 200 Gould), simultaneously with flow patterns measured by the Fleisch pneumotachograph.

The system was checked to ensure that it was leak-proof before and after each series of readings, by using a soap film technique. Gas was collected from the Heidbrink valve into a spirometer and compared with the volume of fresh gas and carbon dioxide supplied to the system. During the experiment the ventilatory rate was 15 b.p.m. and peak pressure within the system did not exceed 20 cm H$_2$O.

Three experiments were performed.

**Experiment A**

The lung model was ventilated with a fresh gas flow of 10 litre min$^{-1}$ and an inspiratory:expiratory ratio of 1:4. The effect of changing from a ramp to a square inspiratory waveform was studied at tidal volumes of 300–700 ml.

**Experiment B**

The lung model was ventilated with a fresh gas flow of 10 litre min$^{-1}$ and with a square inspiratory waveform. Tidal volume was varied between 300–700 ml with an inspiratory:expiratory ratio from 1:1 to 1:4.

**Experiment C**

The lung model was ventilated with a square inspiratory waveform and a tidal volume of 500 ml. The fresh gas flow was varied between 9 litre min$^{-1}$ and 13 litre min$^{-1}$ and the effect of varying the inspiratory:expiratory ratio from 1:1 to 1:3 was studied.
tidal carbon dioxide concentration when the tidal volume was varied between 300 and 700 ml (fig. 2).

**Experiment B**

At low tidal volumes, there was not difference in end-tidal carbon dioxide concentrations when the inspiratory:expiratory ratio was varied. As tidal volume was increased, the end-tidal carbon dioxide concentration decreased. The concentration of carbon dioxide for any given tidal volume was lower with an inspiratory:expiratory ratio of 1:4 (fig. 3).

**Experiment C**

With a fresh gas flow of 9 litre min⁻¹, the end-tidal carbon dioxide concentration was lower when the inspiratory:expiratory ratio was 1:3. As the fresh gas flow was increased, the end-tidal carbon dioxide concentration decreased. At all fresh gas flows, the end-tidal carbon dioxide concentration was lower with an inspiratory:expiratory ratio of 1:3 (fig. 4).

**DISCUSSION**

A change from ramp to square inspiratory waveform did not affect the elimination of carbon dioxide from the Magill attachment during controlled ventilation. If the tidal volume or fresh gas flow was increased, the system became more efficient in respect of carbon dioxide removal. These findings confirm those reported previously [2]. However, at any given tidal volume or fresh gas flow, the system became more efficient as the expiratory phase was prolonged. When controlled ventilation with an inspiratory:expiratory ratio of 1:3 was used, the system was efficient when a fresh gas flow of 9 litre min⁻¹ was supplied at a tidal volume of 500 ml. As fresh gas flow was increased at this inspiratory:expiratory ratio, relatively little was gained in the efficiency of carbon dioxide removal from the system. When an inspiratory:expiratory ratio of 1:1 was used, however, high fresh gas flows were needed to achieve an acceptable inspired concentration of carbon dioxide.

When the Magill attachment is used for controlled ventilation, the Heidbrink valve is closed sufficiently to allow positive pressure to be applied to the reservoir bag to ventilate the patient’s lungs. During the inspiratory phase, gas is forced through the Heidbrink valve. The escape of gas ceases when the pressure decreases sufficiently during expiration for the valve to close. Once the valve has closed, expiratory gases pass retrogradely up the circuit. Failure of the elimination of this expired gas from the circuit is the cause of rebreathing [2]. A comparison of the carbon dioxide concentrations measured from all the
sampling sites during a single ventilatory cycle at inspiratory-expiratory ratios of 1:1 and 1:4 illustrates what happens to this expired gas.

In figure 5, carbon dioxide concentrations at sample points 2–5 (see figure 1) are shown, timed with the pneumotachograph signal. In this instance the inspiratory-expiratory ratio was 1:1. At the beginning of inspiration, carbon dioxide is present at sampling sites 4 and 3 (fig. 1). This is carbon dioxide which has passed retrogradely during expiration and has failed to be cleared from the breathing system. The bulk of carbon dioxide elimination via the Heidbrink valve occurs during inspiration, as indicated by the high concentration at sample site 5 (fig. 1). The same sequence of events can be seen in figure 6, when the inspiratory-expiratory ratio was 1:4. Here the bulk elimination of carbon dioxide from the circuit occurs during the expiratory phase. Carbon dioxide is cleared more efficiently from the system, as can be seen by reference to the carbon dioxide concentrations at sample point 4, which is zero and sample point 3, which is just over 1%. The net result of using the inspiratory-expiratory ratio of 1:4 at any given tidal volume and fresh gas flow is to allow a longer period of exhaled carbon dioxide to be flushed from the system by fresh gas flow.

Because the composition of vented and inspired gas can be affected by so many variables, the Magill attachment must be considered a system with a largely unpredictable performance when used during controlled ventilation. This unpredictability can be overcome by monitoring inspired gas concentrations. We do not recommend that the Magill attachment is used for controlled ventilation, but when it is used for short periods in clinical practice, improved efficiency can be obtained by adjusting the inspiratory-expiratory ratio to ensure a prolonged expiratory phase.

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REFERENCES