FRESH GAS REQUIREMENTS OF AN ENCLOSED AFFERENT RESERVOIR BREATHING SYSTEM IN ANAESTHETIZED, SPONTANEOUSLY BREATHING ADULTS


SUMMARY

Using two methods of determining the onset of rebreathing, we have determined the minimum fresh gas flow rate (Vf) of the Ohmeda enclosed afferent reservoir breathing system (EAR) in anaesthetized, spontaneously breathing adults. Rebreathing as defined by the Kain and Nunn criteria did not occur when the Vf/Ve ratio was greater than 0.70. A mathematical model was used to calculate the degree of rebreathing at each Vf. From this model, rebreathing did not occur when Vf was 0.86 Ve or more and this value of Vf/Ve is considered appropriate to eliminate rebreathing in clinical practice. (Br. J. Anaesth. 1993; 70: 468–470)

KEY WORDS

Anaesthesia: general. Equipment: breathing system, EAR system.

The enclosed afferent breathing system (EAR), developed by Ohmeda, has been demonstrated to be an efficient breathing system for paediatric use during both controlled [1] and spontaneous ventilation [2], and during controlled ventilation in adults [3]. This study was undertaken to determine the minimum fresh gas flow required to prevent rebreathing when the EAR is used during anaesthesia with spontaneously breathing adults. Preliminary work suggests that the efficiency of the EAR is maintained during anaesthesia in relatively young, healthy adults in the supine position [4]. This study aimed to determine the minimum fresh gas requirements for this system when used in elderly patients in the lithotomy position, thus assessing the efficiency of the system under less favourable circumstances found in clinical practice.

APPARATUS

A brief description of the EAR is given below (fig. 1). A rising bellows, with a capacity of 1500 ml, is incorporated in the inspiratory limb of the system. It is filled from the fresh gas flow and drawn upon during inspiration. A one-way valve is situated in the machine end of the expiratory limb and prevents rebreathing of gas from the expiratory limb during inspiration. Gas passes back on expiration along the inspiratory limb and fills the bellows; thereafter, it spills through the one-way expiratory valve, which has an opening pressure of 1.9 cm H2O. The system thus functions as a Mapleson A system during spontaneous ventilation.

METHODS

District Ethics Committee approval was obtained and we studied 15 patients aged 64–80 yr, ASA I–III and undergoing elective urological surgery. The patients were not premedicated. Anaesthesia was induced with propofol up to 2.5 mg kg−1 and maintained with 66% nitrous oxide and 2–3% halothane in oxygen via a laryngeal mask airway. The concentration of halothane was adjusted to obtain adequate anaesthesia and remained constant thereafter. Heart rate, arterial pressure and arterial oxygen saturation (Sao2) were monitored non-invasively.

The following measurements were made:

Respiratory flow was measured at the junction between the patient and the breathing system using a heated pneumotachograph (Fleish No. 2). The flow signal from the pneumotachograph was integrated electronically to obtain tidal volume (Vt) and expired minute volume (Ve).

Respiratory gases were sampled continuously from the connector of the laryngeal mask and were analysed for carbon dioxide using an infra-red carbon dioxide analyser (Datex Normocap) to determine end-tidal carbon dioxide partial pressure (PeCO2). This sampling resulted in the loss of 150 ml min−1 from the system, which was allowed for in subsequent calculations.

All data were recorded on tape (Tandberg Instrumentation Recorder series 100) and analysed via a chart recorder (Grass).

Fresh gas flow (Vf) was initially set at 100 ml kg−1 min−1 and the above measurements were made after a 5-min period of stabilization. Vf was then reduced by increments of 0.1 x minute volume. Readings were repeated after a 5-min period of stabilization.

stabilization or when one of the following rebreathing criteria, originally outlined by Kain and Nunn [5], was met:

(i) An increase in $V_E$ or tidal volume of 10% or more, not accompanied by a corresponding decrease in $P_{E\text{CO}_2}$.

(ii) An increase in $P_{E\text{CO}_2}$ of 0.66 kPa or more, which could not be accounted for by a decrease in $V_E$.

(iii) An increase in $V_E$ of 5% or more, accompanied by an increase in $P_{E\text{CO}_2}$ of 0.6 kPa or more.

When the criteria for rebreathing had been met, $V_F$ was increased to 100 ml kg$^{-1}$ min$^{-1}$.

The mathematical model described by Meakin and colleagues [2] was then used to determine the rebreathed volume. Briefly, this assumes that, in the absence of longitudinal mixing of expired gas, rebreathing occurs when $FF$ is less than alveolar ventilation ($VA$). Thus:

$$VR = VA - VF$$

but

$$VA = VT - VD$$

so

$$VR = VT - (VD + VF)$$

where $VR$ = volume of rebreathed alveolar gas per breath; $VA$ = volume of expired alveolar gas per breath; $VT$ = volume of fresh gas per breath; $VD$ = apparatus plus anatomical deadspace.

Deadspace—apparatus plus anatomical—was determined by Fowler's method using a custom-written computer program and microcomputer. Flow and capnography signals were aligned at the point of end-expiration by associating the sudden decrease in carbon dioxide concentration with the onset of inspiratory flow [6]. $P_{E\text{CO}_2}$ was then plotted against expired volume, giving a sigmoid curve. $VD$ was the volume expired when the areas above and below this sigmoid portion of the curve were equal. The rebreathed volume calculated above was expressed as a percentage of the tidal volume ($VR/VT\%$); this was plotted against $VT/V_E$.

### RESULTS

Table I shows the values of $VT/V_E$ and $VR/VT\%$, together with changes in $P_{E\text{CO}_2}$ and $V_E$, for the values of $VT$ at which rebreathing, according to the Kain and Nunn criteria, were detected. The mean volume of $VR/V_E$ at which these criteria were fulfilled was 0.60, corresponding to a mean $V_F$ of 62.3 ml kg$^{-1}$. Rebreathing according to the Kain and Nunn criteria was not seen in any patient when $VT/V_E$ was > 0.7. Rebreathing was not detected in four patients.

The degree of rebreathing ($VR/VT\%$) was related inversely to $VT/V_E$ (fig. 2). Fitting an arbitrary cubic regression (by Figure Perfect; Biosoft) to the data

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<th>Patient no.</th>
<th>$VT/V_E$ (ml kg$^{-1}$ min$^{-1}$)</th>
<th>$VR/V_E$</th>
<th>$\Delta P_{E\text{CO}_2}$ (kPa)</th>
<th>$\Delta V_E$ (%)</th>
<th>$VR/VT%$</th>
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Fig. 2. Plot of the degree of rebreathing (Vf'/Ve %) against the ratio of fresh gas flow to minute volume (F'/F).

DISCUSSION

Our results indicate that the onset of rebreathing as determined by the Kain and Nunn criteria [5] occurred at mean Vf'/Ve of 0.6 and was not seen at values of Vf greater than 0.7 Ve. Norman, Adams and Sykes reported that, with the Mapleson A system, the onset of rebreathing occurred when Vf'/Ve was 0.6–0.7 [7], whilst in Alexander's study the onset of rebreathing occurred when Vf'/Ve was 0.76 [8]. Our results are consistent with these studies.

The onset of rebreathing as determined by calculation occurs when Vf'/Ve decreases to less than 0.86. The validity of the derived onset of rebreathing depends on the validity of the assumption that there is little longitudinal mixing of expiratory gas in the delivery tube—an assumption which is fundamental to the explanation of the efficiency of the EAR and the Mapleson A system on which it is based. The Vf'/Ve value of 0.86 is to be compared with the equivalent value (0.78) for the use of the EAR in anaesthetized children breathing spontaneously which was reported by Meakin and colleagues [2] and with data obtained during bench testing of the EAR in which the onset of rebreathing occurred at 0.87 Ve [9].

This method, whilst not suitable for routine monitoring of patients, is useful in that it does not (unlike the Kain and Nunn criteria) rely on a physiological response to rebreathing. It demonstrates rebreathing at an early stage and is of potential value during the assessment of anaesthetic breathing systems in determining values of Vf which avoid rebreathing in the clinical situation.

In the present study, the mean Vf at which rebreathing occurred as determined by the Kain and Nunn criteria [5], was 62.3 (SEM 2.98) ml kg⁻¹. Unlike controlled ventilation, during which Vf is under the control of the anaesthetist, there is a wide variability in Vf seen in anaesthetized adult patients undergoing surgery whilst breathing spontaneously. This limits the value of recommendations for Vf to eliminate rebreathing in terms of ml kg⁻¹ min⁻¹ and management, as always, has to be guided by the clinical condition of the patient.

In conclusion, the results of this study indicate that the EAR may be used safely in anaesthetized, spontaneously breathing adults with a Vf of 0.86 Ve and thus support the view that the EAR may be regarded as a universal anaesthetic breathing system.

ACKNOWLEDGEMENTS

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REFERENCES