A HIGH FLOW SEMI-OPEN SYSTEM FOR PREOXYGENATION:
AN EVALUATION

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SUMMARY
We have compared an alternative breathing system for preoxygenation comprising a Hudson face mask with high oxygen inflow (48 litre min⁻¹) and a Mapleson A breathing system (100 ml kg⁻¹ min⁻¹). The study consisted of two parts: the first involved adult volunteers (10 male, seven female) and the second part used a lung model for spontaneous ventilation with a sinusoidal ventilatory wave pattern. In the volunteers, preoxygenation was achieved at mean times of 138 (SD 31.3) s and 164 (SD 36.7) s with the high flow semi-open and Mapleson A systems, respectively. In the lung model, at peak inspiratory flow rates of 30 and 40 litre min⁻¹, the preoxygenation times were 139 and 120 s, respectively, with the semi-open system and 167 and 156 s with the Mapleson A system. The high flow semi-open system may be an alternative for current techniques, provided peak inspiratory flows are not excessive.

KEY WORDS
Anaesthetic techniques: preoxygenation Equipment breathing systems.

The benefits of preoxygenation have been acknowledged since the 1950s [1, 2]. Preoxygenation before induction of general anaesthesia increases the safe apnoea time in most adults to between 3 and 6 min before arterial oxygen desaturation occurs [3, 4]. In the United Kingdom, the Mapleson A semi-closed breathing system is used frequently for preoxygenation. The success of this technique depends on achieving an air-tight seal with the anaesthetic face mask, which may be difficult in certain clinical situations such as mask phobia, facial injuries or burns.

The purpose of this study was to investigate an alternative solution to the airtight seal using a semi-open system with high inflow rate. The efficacy of this system for preoxygenation was assessed in both human volunteers and a lung model.

SUBJECTS AND METHODS
The semi-open system used in this study comprised a disposable Hudson face mask attached via a corrugated plastic anaesthetic tube (1.5 m long, 22 mm diameter) to the common gas outlet of a Boyle anaesthetic machine. The oxygen flow was set at 8 litre min⁻¹ and the oxygen flush was held continuously, achieving a flow rate of 48 litre min⁻¹. This was confirmed using a flow meter (Gap-meter A10) previously calibrated with a spirometer of known accuracy (Ohio 840).

The study comprised two phases: a human volunteer phase followed by a lung model study.

Volunteer study
Seventeen healthy volunteers (seven females; age range 22–33 yr) were recruited with approval of the local Research Ethics Committee. Each volunteer underwent preoxygenation using both the high flow semi-open system and the Mapleson A (Magill) system.

The end-point in preoxygenation was taken as the time for peak expired nitrogen concentration $E_N$ to decrease to less than 5%. Nitrogen concentrations in the respired gases were measured using a mass spectrometer (Centronics 200 MGA), sampling at 20 ml min⁻¹ from a fine-bore catheter positioned in the nasopharynx of the subject. The mass spectrometer was calibrated with a British Oxygen Company (BOC) certified gas mixture. The study was conducted with the volunteer sitting upright and breathing through the nose with the mouth closed. Before the start of the study, a period of at least 30 min was allowed for each volunteer to become accustomed to breathing through the two systems and settle to a steady breathing pattern. During this time inspiratory flows were measured also using a pneumotachograph head (Fleisch No. 3) attached to the BOC face mask. The pneumotachograph had been calibrated previously using a spirometer (Ohio 840). The average peak inspiratory flow rate was measured after 10 min, when the readings were stable.

The oxygen flow rate used for the Mapleson A breathing system was 100 ml kg⁻¹ min⁻¹; the system was pre-filled with oxygen as far as possible by occluding the opening of the face mask with the palm of the hand before applying the mask at the start of preoxygenation.

Laboratory study

Each of these two systems was evaluated under identical in vitro conditions using a lung model for spontaneous ventilation which has been described and validated in a previous study [5]. A plastic face mould taken from an intubation mannikin was used for the patient-mask interface. The tip of the mass spectrometer sampling probe was positioned in the "trachea" of the lung model, enabling measurement of nitrogen, oxygen and carbon dioxide concentrations. A Wright electronic spirometer and pneumotachograph head were mounted also in the trachea, enabling measurement of minute ventilation ($V_{E}$) and peak inspiratory flow rate (PIFR), respectively.

Comparisons of preoxygenation times were made at four different peak inspiratory flow rates: 30, 40, 50 and 60 litre min$^{-1}$. The different flow rates were achieved by altering the frequency of breaths delivered by the ventilator. Tidal volume was kept constant at 900 ml. The geometric volumes of the plastic tubing and apparatus mounting, corresponding to the deadspace also was kept constant, at 290 ml. Thus, the deadspace to tidal volume ratio ($V_{D}/V_{T}$) was 0.32.

In addition to the time taken to achieve the defined end-point in preoxygenation, $P_{E}CO_{2}$ and mean expired carbon dioxide tension ($P_{E}CO_{2}$) were measured also with the two techniques at equilibrium, defined to have occurred when there was no further change in $P_{E}CO_{2}$ over a 10-min period. The $P_{E}CO_{2}$ and $P_{E}CO_{2}$ values were used to calculate the physiological deadspace (modified Bohr's equation) at equilibrium with both breathing systems.

RESULTS

Volunteer study

The results are summarized in table I. One of the volunteers did not satisfy the criteria for preoxygenation when using the high flow semi-open system; his peak $E_{S}$ did not decrease to less than 10%. In the remaining 16 volunteers, the time taken to reach the predetermined end-point in preoxygenation was significantly shorter for the semi-open system ($P < 0.01$, paired t test) (95% confidence interval 14.7–37s).

Lung model study

Preoxygenation times were shorter for the semi-open system at peak inspiratory flows of 30 and 40 litre min$^{-1}$ (table II). However, the criterion for preoxygenation was not fulfilled using this system when the inspiratory flow rates were 50 and 60 litre min$^{-1}$ and the minimum peak $E_{S}$ were 9.4% and 11.7%, respectively.

No differences in either $P_{E}CO_{2}$, $P_{E}CO_{2}$ or $V_{E}$ were recorded between the two systems at each inspiratory flow rate. At equilibrium, there were no differences in the calculated deadspace (Bohr) of 0.37 ($V_{D}/V_{T}$). This value was constant throughout the experiment.

DISCUSSION

The results suggest that preoxygenation could be achieved with a semi-open system with high gas flows, and took less time to achieve a predetermined end-point ($E_{S} < 5\%$).

Most of the current techniques of preoxygenation involved breathing 100% oxygen through a tight
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FIG. 1. Nitrogen washout with the Mapleson A system in the lung model study. The peak values in the waveform correspond to the peak expired nitrogen concentration (FEn) and the inspired nitrogen concentration is given by the trough values.

FIG. 2. Nitrogen washout with the high flow semi-open system in the lung model.

fitting mask of a semi-closed breathing system, which many patients find unacceptable and unpleasant. To overcome this problem of the air-tight seal, the present study evaluated the use of high gas inflow semi-open system (Hudson mask) as an alternative. To ensure that the inspired oxygen concentration received from the Hudson mask is consistently 100%, the total oxygen flow delivered to the mask must equal or exceed the PIFR of the subject [6]. In this study, the average PIFR in the group of volunteers was 34 (SD 10.5) litre min⁻¹, which agrees with previously quoted values in resting adults [7, 8]. When the oxygen inflow rate is 48 litre min⁻¹, there is an excess of 14 litre min⁻¹. When the excess is expressed over the SD of PIFR, the value obtained is 1.24. As the value of 1.24 SD greater than the mean includes about 90% of PIFR in the population, an oxygen inflow of 48 litre min⁻¹ will exceed the PIFR of most resting adults.

Using the high inflow semi-open system, it was possible to preoxygenate all but one volunteer. This volunteer’s PIFR measured before the start of the study was about 70 litre min⁻¹. This effect was demonstrated in the lung model when PIFR was 50 and 60 litre min⁻¹. The reasons for this individual’s excessive peak inspiratory flow are not clear, but it is interesting to note that he is an accomplished wind instrument player.

It was also of interest that preoxygenation took a shorter time with the high flow system in the rest of the volunteers. There are several possible explanations. These include the human adaptation to breathing through different mask systems, resulting in a change in the pattern of ventilation. It could be a consequence of a pressure effect such as continuous positive airway pressure caused by high gas flows. In addition to physiological explanations, the difference may also be caused by the inherent physical characteristics of the breathing systems, and was studied with the lung model.

The functional characteristics of the Mapleson A system are such that the early expirate, comprising deadspace gas, is conserved, whereas the late expirate, which is the alveolar component, is vented from the system [9]. Whilst this is efficient from the point of carbon dioxide elimination, there is re-inhalation of nitrogen-containing deadspace gas, during the initial phase of preoxygenation. This is evident from the washout curve for nitrogen in the lung model (fig. 1). Rebreathing of nitrogen-containing gas is shown by the failure of the trough values, corresponding to the inspired nitrogen concentrations, to reach the zero baseline. This persists over a number of breaths because of longitudinal mixing of deadspace and fresh gas. This phenomenon occurs despite oxygen flow rates in excess of those recommended to prevent rebreathing (100 ml kg⁻¹ min⁻¹) [9] and ensuring that the reservoir bag was prefilled with oxygen at the start of preoxygenation. In contrast, there is complete elimination of nitrogen in the semi-open system, as is evident from its washout curve (fig. 2). The washout curves obtained from the volunteers showed similar differences. As a nitrogen tension of zero in the inhaled atmosphere is optimum for denitrogenation [10], the time taken for preoxygenation with the semi-open system is shorter.

In conclusion, we have shown that the high inflow semi-open system may provide a suitable alternative to the Mapleson A if flow is not excessive. These results must be extrapolated with caution to the clinical population. Further clinical studies are needed, particularly in patients who are apprehensive and in pain, who may have excessive peak inspiratory flow rates.

REFERENCES