COMPARISON OF FOUR METHODS OF PREOXYGENATION

J. W. McCORY AND J. N. S. MATTHEWS

SUMMARY
We studied four different techniques of preoxygenation in 20 healthy volunteers, by continuous analysis of respired gases. Three minutes of tidal breathing from a Magill breathing system or four vital capacity breaths from a non-rebreathing system were found to be equally effective, whereas four vital capacity breaths from a Magill breathing system were less effective. Maximal expiration before application of the face mask resulted in improved oxygenation when four vital capacity breaths were taken from a Magill system.

KEY WORDS
Oxygenation: techniques.

Preoxygenation before rapid sequence induction of general anaesthesia has become standard practice. Pulmonary nitrogen washout and its replacement by oxygen increases oxygen reserve within the lungs and reduces the risk of hypoxia during a period of apnoea.

A rapid and effective preoxygenation technique would have several advantages over a 3-min tidal breathing technique [1].

It has been suggested that three or four vital capacity breaths from a Magill or circle breathing system results in adequate preoxygenation [2–4]. One of these studies [4], which involved comparisons of mean $P_{A}O_{2}$ values achieved by two separate groups of term parturients has been criticized [5] on the grounds that a wide inter-patient variation in alveolar–arterial oxygen content difference is known to occur at term pregnancy [6]. Other groups have found these rapid methods to be inferior to a full 3 min of tidal breathing [7, 8].

With normal lung function, the rate of pulmonary oxygen washin (and nitrogen washout) is mono-exponential [9] and depends upon the minute volume of respiration and the inspired oxygen concentration ($FiO_{2}$) [10]. In theory, an increase in minute volume (by vital capacity breathing) should increase the rate of oxygen washin. However, vital capacity breathing with a Mapleson A or D system (with an oxygen supply of 8–10 litre min$^{-1}$) results in some rebreathing of expired gases [8, 10]. Inevitably, this reduces $FiO_{2}$ and so decreases the rate of oxygen washin. This might explain the observation that rapid, vital capacity preoxygenation techniques are inferior to a full 3 min of tidal breathing [7, 8].

The aim of this study was to compare the effectiveness of "standard" tidal volume, vital capacity and "modified vital capacity" techniques of preoxygenation. In addition, the influence of initial lung volume and phase of ventilation upon the subsequent course of preoxygenation were investigated. As the study involved healthy volunteers, end-expiratory oxygen concentration ($Fe'O_{2}$) was used as the index of oxygen washin.

SUBJECTS AND METHODS
The study was approved by the Joint District Ethics committee. Twenty healthy, non-pregnant volunteers (12 female) were studied and their age, sex, height, weight and forced vital capacity were recorded. Each subject underwent successive preoxygenation cycles using four different techniques (described below). The order of technique was determined by randomization to a four-treatment, four-period crossover design using a Williams square [11].

Each technique was performed with the subject supine.

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**Delivery system**

Oxygen was delivered to an anaesthetic breathing system from a standard Gardner anaesthetic machine at 10 litre min\(^{-1}\). Additional oxygen was supplied from the emergency oxygen flush device if the reservoir bag was nearly empty. A Magill breathing system modified to comprise two 2-litre reservoir bags, a standard 1-m length of corrugated antistatic rubber hose, Heidbrink expiratory valve, angle piece and face mask was used in all techniques. In technique IV, a non-rebreathing (Ambu E) valve was added (fig. 1). In all subjects the breathing system was pre-filled with oxygen [1] by occluding the aperture of the face mask with the palm of the hand.

**Breathing patterns for preoxygenation techniques**

Each technique was performed for 3 min.
- Technique I: mask applied without regard to phase of ventilation; tidal breathing.
- Technique II: mask applied without regard to phase of ventilation; vital capacity breathing.
- Technique III: mask applied at residual volume; vital capacity breathing.
- Technique IV: mask applied at residual volume; vital capacity breathing with the non-rebreathing Ambu-Magill combination.

The anaesthetic face mask was held by the investigator, who attempted to maintain a gastight seal.

Following each test, the subject breathed room air for at least 5 min. \(F_E'_{O_2}\) was measured to ensure a return to the baseline value.

Respired gases were sampled continuously (at 30 ml min\(^{-1}\)) using a tube mounted in the anaesthetic face mask close to the subject’s lips. Oxygen and carbon dioxide concentrations were measured by a mass spectrometer (Airspec) and recorded by a two-channel potentiometric recorder (Devices).

Both mass spectrometer and chart recorder were calibrated against reference samples of gas for oxygen (15 and 100%) and carbon dioxide (0 and 8%) before each technique was performed. The accuracy of calibrating gas samples were quoted as \(\pm 1\%\) of stated value by the manufacturer. No correction for spectral overlap was necessary. The mass spectrometer was stated by the manufacturer to possess a 95% rise time of 320 ms, and a limit of resolution of 10 p.p.m.

During each preoxygenation sequence, \(F_E'_{O_2}\), end expiratory carbon dioxide concentration (\(F_E'_{CO_2}\)) and inspired carbon dioxide concentration (\(F_I_{CO_2}\)) were noted after both four breaths and 3 min. The time taken to complete the first four breaths was also noted. All data were analysed using crossover analysis of variance. All the variables were assumed to follow a normal distribution; this was verified with probability plots.

**RESULTS**

Mean (sd) age of the subjects was 29.4 (4.66) yr, height 168 (13.37) cm, weight 67 (13.1) kg and forced vital capacity 4830 (1482) ml.

Values for \(F_E'_{O_2}\), \(F_E'_{CO_2}\) and \(F_{I_{CO_2}}\) after four breaths and 3 min, and the times taken to complete four breaths with each preoxygenation technique are shown in table I. The standard errors quoted are pooled estimates obtained from the residual mean square in the crossover analysis of variance. Learning or carryover effects were found to be insignificant. Nonetheless, to avoid
any possible bias, all values quoted were adjusted for possible learning and carryover effects [12]. These adjustments were no greater than 0.5% for $FE'_{O_2}$ and 0.1% for $F_{I_{CO}}$ and $FE'_{CO_2}$. $F$ ratios from analysis of variance, and associated significance levels for various comparisons are shown in table II.

There was no difference between mean $FE'_{O_2}$ achieved after 3 min tidal breathing with the Magill system (I) (fig. 2) and four vital capacity breaths with the Magill-Ambu combination (IV) (fig. 3) (95% confidence interval for difference $= -4.6, 2.3$).

Three minutes tidal breathing with the Magill system (I) (fig. 2) resulted in a greater $FE'_{O_2}$ than four vital capacity breaths from the Magill system (II and III) (figs 4, 5, respectively) ($P < 0.01$). Four vital capacity breaths from the Magill system resulted in a greater $FE'_{O_2}$ if expiration to residual volume preceded application of the face mask (III vs II) (figs 5, 4, respectively) ($P < 0.01$).

After 3 min of each technique there was no significant difference in $FE'_{O_2}$ between any of the groups.

There were no significant differences between mean $FE'_{CO_2}$ values after four breaths of each technique. After 3 min vital capacity breathing with the non-rebreathing Magill–Ambu combination (IV) (fig. 3), $FE'_{CO_2}$ was less than with the other three techniques ($P < 0.01$).

Tidal breathing with the Magill system (I) (fig. 2) and vital capacity breathing with the non-rebreathing Magill–Ambu combination (IV) (fig. 3) resulted in a lesser $F_{I_{CO}}$, than vital capacity breathing with the Magill system (II and III) (figs 4, 5, respectively) at both four breaths and 3 min ($P < 0.01$).

The time taken to perform four tidal breaths (I) (fig. 2) was significantly shorter than that to take four vital capacity breaths (techniques II, III and IV) (figs 3–5) ($F_{S,A1} = 23.6; P < 0.001$).

**DISCUSSION**

Mean values for $FE'_{O_2}$ achieved after 3 min normal tidal breathing (I) (89.9%) or four vital capacity breaths (II) (76.4%), from a Magill system in this study compare closely to values obtained by Russell and colleagues [8]. These results confirm that a simple four vital capacity breath technique is not as effective as 3 min of tidal breathing.

In contrast, there was no difference in $FE'_{O_2}$ achieved after 3 min tidal breathing from a Magill
TABLE II. F ratios and statements of probability for comparisons of mean $F'_{O_2}$, $F'_{CO_2}$ and $F_{CO_2}$ achieved with preoxygenation techniques I, II, III and IV at four breaths and 3 min. See text for details.

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<th>Technique</th>
<th>Four breaths</th>
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<tr>
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<td>$F'_{O_2}$</td>
<td>$F'_{CO_2}$</td>
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<tr>
<td>I</td>
<td>$F_{3.51} = 125$</td>
<td>$F_{3.51} = 1.94$</td>
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<td>II</td>
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<td>$F'_{CO_2}$</td>
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<td>I</td>
<td>$F_{3.51} = 1.10$</td>
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<td>I</td>
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Fig. 2. Inspired and expired concentrations for oxygen (upper trace) and carbon dioxide (lower trace) during technique I.  
Fig. 3. Inspired and expired concentrations for oxygen (upper trace) and carbon dioxide (lower trace) during technique IV.
system (I) or four vital capacity breaths from a non-rebreathing Magill–Ambu combination (IV). $F_{I O_2}$ was maintained at or near 100% during both of these techniques (figs 2, 3). Therefore, four vital capacity breaths from the non-rebreathing Magill–Ambu combination is equally effective with 3 min tidal breathing.

Vital capacity breathing with the Magill system (II and III), led to rebreathing of carbon dioxide and, presumably, nitrogen. Over four breaths this caused an obvious decrease in $F_{I O_2}$ (figs 4, 5) and accounts for the significantly lesser mean $F'_{E O_2}$ achieved with these two techniques. Such rebreathing may have been avoided by making the internal volume of "corrugated" tubing equal to the subject's vital capacity and fresh gas flow equal to the minute volume of ventilation. Alternatively, the fresh gas flow could be made equal to the subject's peak inspiratory flow rate. These two options represent a less than practical alternative to the Magill–Ambu combination.

Mean $F'_{E O_2}$ after four vital capacity breaths from the Magill system was improved significantly by expiring to residual volume before application of the face mask (III vs II). This manoeuvre minimizes lung nitrogen content and the subsequent dilution of incoming oxygen by nitrogen washout. The observed improvement in $F_{I O_2}$ (fig. 5 vs fig. 4) and hence $F'_{E O_2}$ is thus explained.

Despite the use of two 2-litre reservoir bags, additional oxygen was necessary occasionally to prevent collapse of the bag during vital capacity breathing. As expected, this was more common with the non-rebreathing Magill–Ambu combination; unfortunately, this volume was not measured. Nevertheless, the total flow to the breathing system would not need to exceed the subject’s minute volume of ventilation. This total flow would not prevent rebreathing during vital capacity breathing from a Magill system, without an increase in the internal volume of the corrugated tubing, as discussed previously.

The combination of adjustable pressure relief and Ambu valves in technique IV prevented development of pressure and subsequent sticking of the Ambu valve during inspiration. The combination proved easy to manage and tended to isolate the subject from the unpleasant effects of high gas flow during the addition of extra oxygen.

In this study, the face mask was applied at residual volume before using the Magill–Ambu combination. In clinical practice, the mask could be applied at any time during expiration to...
residual volume, as the non-return valve prevents rebreathing.

The success of any preoxygenation technique depends partly upon the provision of a gas tight seal between the patient and face mask. The longer the period of oxygenation, the greater the potential for an imperfect seal, because of operator fatigue or distraction, or patient intolerance. Previously described rapid techniques have failed usually to provide optimal oxygen washin, because of rebreathing of expired gas or leaks during inspiration following collapse of the reservoir bag.

The results of this study show that oxygen washin following four vital capacity breaths was equally effective with 3 min tidal breathing provided that: rebreathing is prevented by the addition of a non-rebreathing valve to the anaesthetic breathing system; an adequate fresh gas reservoir is used; and reservoir bag collapse during inspiration is avoided by the addition of oxygen from the emergency oxygen flush device when necessary.

It is recognized that some patients may be unable to perform four full vital capacity breaths, because of either acute or pre-existing medical conditions. For those who are able to comply, it is suggested that this technique provides a practical, acceptable and effective method of preoxygenation.

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REFERENCES