Preoxygenation with the Mapleson D system requires higher oxygen flows than Mapleson A or circle systems

[La préoxygénation avec le système Mapleson D requiert un débit d'oxygène plus élevé que les systèmes Mapleson A ou en cercle]

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Purpose: This study investigates the efficacy of preoxygenation with Mapleson A and Mapleson D breathing systems vs the circle system with CO₂ absorber.

Methods: Thirteen healthy volunteers underwent tidal volume breathing for three minutes via facemask using Mapleson A, Mapleson D breathing systems or the circle system with CO₂ absorber while breathing 100% O₂ at flow rates of 5 L·min⁻¹ and 10 L·min⁻¹. Each volunteer acted as his/her own control by going through each of six preoxygenation protocols in random order. Fractional end-tidal O₂ concentration (F_{ETO2}) was measured at 30-sec intervals. The results were compared among the three anesthesia systems at the two fresh gas flow rates.

Results: At a fresh gas flow rate of 5 L·min⁻¹, the Mapleson A and circle systems achieved F_{ETO2} values of 90.8 ± 1.4% and 90.0 ± 1.1%, respectively, compared with the lower F_{ETO2} (81.5 ± 6.3%, *P* < 0.05), achieved with the Mapleson D system. When breathing O₂ at 10 L·min⁻¹, the F_{ETO2} values after three minutes were similar with the Mapleson A, circle, and Mapleson D breathing systems (91.8 ± 2.3%, 91.2 ± 1.7%, 90.6 ± 2.7%, respectively).

Conclusion: When using the Mapleson A and the circle systems for preoxygenation, an oxygen flow rate of 5 L·min⁻¹ can adequately preoxygenate the patient within three minutes, while an oxygen flow of 10 L·min⁻¹ is required to achieve a similar fractional end-tidal O₂ concentration with the Mapleson D system.

Objectif: Cette étude examine l'efficacité de la préoxygénation avec les systèmes de respiration Mapleson A et D vs le circuit en cercle avec chaux sodée.

Méthode: Treize volontaires sains ont respiré à volume courant durant trois minutes via un masque facial, en utilisant les systèmes de respiration Mapleson A, Mapleson D ou en circuit en cercle avec chaux sodée, en respirant 100 % O₂ à des débits de 5 L·min⁻¹ et 10 L·min⁻¹. Chaque volontaire a été son propre témoin en parcourant six protocoles de préoxygénation dans un ordre aléatoire. La concentration fractionnelle d'O₂ télé-expiratoire (F_{ETO2}) a été mesurée à intervalles de 30 sec. Les résultats ont été comparés dans les trois systèmes d'anesthésie aux deux débits de gaz frais.

Résultat: À un débit de gaz frais de 5 L·min⁻¹, on a atteint des valeurs de F_{ETO2} de 90,8 ± 1,4 % et 90,0 ± 1,1 % avec le système Mapleson A et le circuit en cercle, respectivement, et une F_{ETO2} plus faible (81,5 ± 6,3 %, *P* < 0,05) avec le système Mapleson D. Après trois minutes de respiration d'O₂ à 10 L·min⁻¹, les valeurs de F_{ETO2} étaient semblables pour les systèmes de respiration Mapleson A, le circuit en cercle et Mapleson D (91,8 ± 2,3 %, 91,2 ± 1,7 %, 90,6 ± 2,7 %, respectivement).

Conclusion: Lorsqu'on utilise le système de respiration Mapleson A ou le circuit en cercle pour la préoxygénation, un débit d'oxygène de 5 L·min⁻¹ peut préoxygéner le patient de façon adéquate en trois minutes, alors qu'un débit d'oxygène de 10 L·min⁻¹ est requis pour atteindre une concentration fractionnelle d'O₂ télé-expiratoire semblable avec le système Mapleson D.

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PREOXYGENATION essentially depends on denitrogenation of the functional residual capacity (FRC) of the patient's lungs and replacing the nitrogen with oxygen. Hamilton and Eastwood have shown that denitrogenation is 95% complete within two to three minutes when breathing 100% oxygen using the circle CO₂ absorber system at a fresh gas flow (FGF) rate of 5 L·min⁻¹ and tidal volume breathing.¹ Monitoring preoxygenation by measuring fractional end-tidal oxygen concentration (F_{ETO2}) is probably the best surrogate marker of lung denitrogenation.²⁻⁴

Mapleson suggested that the degree of rebreathing during spontaneous breathing is less with Mapleson A system than with Mapleson D system.⁵ Such differences in the degree of rebreathing may affect the efficacy of preoxygenation. This study was designed to investigate the hypothesis that oxygen flow and anesthetic system type may influence the efficacy of preoxygenation.

Methods

The study was approved by the institutional Research Ethics Board and informed consent was obtained from all volunteers prior to their participation in the study. Thirteen non-smoking healthy subjects (five females and eight males) with no history of heart or lung disease were enrolled. Subjects were not recruited if they were edentulous or if they had a beard. Also excluded were individuals < 20 or > 40 yr of age, and those who weighed < 55 kg or > 90 kg.

The subjects were asked to lie supine, and were familiarized with the procedures by breathing normally while maintaining a tight-fitting facemask. A pulse oximeter (Novamatrix, Wallingford, CT, USA) was applied to a finger tip for continuous monitoring of oxygen saturation.

A standard anesthesia machine (Datex ADU AS/3 Anesthesia Monitor, Helsinki, Finland) was used throughout the study. Three anesthetic systems were investigated: the circle system, an adult Mapleson A system (Magill system) and an adult Mapleson D system. The Mapleson A and Mapleson D systems consisted of 107 cm corrugated tubes and a 2-L capacity breathing bag. The circle system consisted of an absorber (Datex-Ohmeda Compact Absorber containing 550 g of soda lime), two 150-cm corrugated breathing tubes, and a 2-L capacity breathing bag. Prior to each preoxygenation trial, the anesthesia systems were flushed for five minutes with 100% O₂ at a flow rate of 10 L·min⁻¹ to eliminate any residual air or nitrous oxide.

The reservoir bag was fully inflated using the oxy-

FIGURE 1 The fractional end-tidal oxygen concentrations (F_{ETO2}) for the Mapleson A, the circle, and the Mapleson D anesthesia systems during preoxygenation with 100% O₂ for three minutes at a fresh gas flow rate of 5 L·min⁻¹. **P* < 0.05 *vs* Mapleson A system; †*P* < 0.05 *vs* circle system.

gen flush, and the mask was partially occluded with the palm of the hand. Preoxygenation was performed with 100% O₂ and a tight fitting facemask. Tidal volume breathing for three minutes was performed using the three anesthetic systems, while subjects breathed 100% O₂ at FGF rates of 5 L·min⁻¹ and 10 L·min⁻¹ in random order. Each volunteer acted as his/her own control by going through each of six protocols of preoxygenation in a random order, separated by rest periods of five minutes breathing room air. The randomization sequence was computer-generated.

Side stream respiratory gases were sampled from a sampling port placed next to the mask and filter. Measurements of inspired fraction of oxygen (F_IO₂) and F_{ETO2} were recorded using a calibrated gas monitor (Datex ADU AS/3 Anesthesia Monitor, Helsinki, Finland). Calibration with known gas mixtures was carried out according to the manufacturer's specifications.

Sample size calculation was based upon an expected clinically significant change in F_{ETO2} of 10%. Assuming a type I error of 5% and a type II error of 10%, with a standard deviation estimate of 10% derived from a pilot study, at least ten subjects were needed for the study. For all subjects, the F_IO₂ and the F_{ETO2} values were collected during tidal volume breathing at 30-sec intervals during preoxygenation for a period of three minutes. The means and standard deviations of the F_IO₂ and the F_{ETO2} values obtained with the Mapleson A, the Mapleson D, and the circle systems at each 30-sec interval (i.e., at 30 sec, 60 sec, 90 sec, 120 sec, 150

FIGURE 2 The fractional end-tidal oxygen concentrations (F_{ETO2}) for the Mapleson A, the circle, and the Mapleson D anesthesia systems during preoxygenation with 100% O_2 for three minutes at a fresh gas flow rate of 10 $L \cdot min^{-1}$.

sec, and 180 sec) were compared at O_2 flow rates of 5 $L \cdot min^{-1}$ and 10 $L \cdot min^{-1}$ using a paired Student's *t* test and repeated measures ANOVA with the Dunnett's correction for post hoc analysis. Also, non-linear regression analysis was used for assessing the changes in F_{ETO2} over time and the respective correlation coefficients were determined. Statistical significance was assumed when $P < 0.05$.

Results

All subjects completed all six phases of the study protocol. Using an O_2 flow of 5 $L \cdot min^{-1}$, the $F_{I}O_2$ increased to maximal levels of $96.0 \pm 2.7\%$ and $94.8 \pm 3.7\%$ within 30 sec of preoxygenation with the Mapleson A system and the circle system, respectively. However, with the Mapleson D system, the $F_{I}O_2$ at 30 sec was significantly lower ($86.7 \pm 8.3\%$) as compared to the Mapleson A and the circle systems. At an O_2 flow of 10 $L \cdot min^{-1}$, the $F_{I}O_2$ increased in the Mapleson A, the circle, and the Mapleson D systems within 30 sec of preoxygenation, up to $98.3 \pm 1.2\%$, $98.1 \pm 0.8\%$, and $97.6 \pm 1.9\%$ respectively, with no significant differences among the three systems.

Using an O_2 flow of 5 $L \cdot min^{-1}$, the F_{ETO2} values increased significantly from a baseline value of $17.2 \pm 1.2\%$ to $90.8 \pm 1.4\%$ after three minutes of preoxygenation with the Mapleson A system, and from a baseline of $17.1 \pm 1.3\%$ to $90.0 \pm 1.1\%$ with the circle CO_2 absorber system. Also, after three minutes of preoxygenation, the F_{ETO2} value with the Mapleson D system was $81.5 \pm 6.3\%$, which was lower ($P = 0.001$) than that achieved with the Mapleson A system (90.8

FIGURE 3 The fractional end-tidal oxygen concentration (F_{ETO2}) with the Mapleson D system during preoxygenation with 100% O_2 for three minutes at fresh gas flow rates of 5 $L \cdot min^{-1}$ vs 10 $L \cdot min^{-1}$. * $P < 0.05$ vs 10 $L \cdot min^{-1}$.

FIGURE 4 The fractional end-tidal oxygen concentration (F_{ETO2}) with the Mapleson A anesthesia system during preoxygenation with 100% O_2 for three minutes at fresh gas flow rates of 5 $L \cdot min^{-1}$ vs 10 $L \cdot min^{-1}$. * $P < 0.05$ vs 10 $L \cdot min^{-1}$.

$\pm 1.4\%$) and the circle absorber system ($90.0 \pm 1.1\%$) (Figure 1). The F_{ETO2} values at each time interval and after three minutes of preoxygenation were not different between the Mapleson A and the circle system. In contrast, when the Mapleson D system was used, the F_{ETO2} at each time interval throughout the preoxygenation period was significantly lower than that achieved with both the Mapleson A and the circle absorber systems.

FIGURE 5 The fractional end-tidal oxygen concentration (F_{ETO2}) with the circle system during preoxygenation with 100% O_2 for three minutes at fresh gas flow rates of 5 $L \cdot min^{-1}$ vs 10 $L \cdot min^{-1}$. * $P < 0.05$ vs 10 $L \cdot min^{-1}$.

Using an O_2 flow of 10 $L \cdot min^{-1}$ for preoxygenation, the F_{ETO2} values increased at all time intervals throughout the preoxygenation period with the three systems. After three minutes, the F_{ETO2} values were not significantly different when comparing the Mapleson A, the circle system, and the Mapleson D systems ($91.8 \pm 2.3\%$, $91.2 \pm 1.7\%$, $90.6 \pm 2.7\%$ respectively) (Figure 2). At an O_2 flow of 10 $L \cdot min^{-1}$, the F_{ETO2} with the Mapleson D system at 180 sec ($90.6 \pm 2.7\%$) was not significantly different from the F_{ETO2} values of the Mapleson A and the circle absorber systems at 180 sec when using an O_2 flow of 5 $L \cdot min^{-1}$ ($90.8 \pm 1.42\%$ and $90.0 \pm 1.1\%$ respectively).

Comparing the rate of preoxygenation for each system at 5 $L \cdot min^{-1}$ vs 10 $L \cdot min^{-1}$ showed that when using the Mapleson D system increasing the O_2 flow from 5 $L \cdot min^{-1}$ to 10 $L \cdot min^{-1}$ resulted in significant increases in F_{ETO2} values at 30, 60, 90, 120, 150, and 180 sec throughout the preoxygenation period (Figure 3). However, with the Mapleson A system, increasing the O_2 flow from 5 $L \cdot min^{-1}$ to 10 $L \cdot min^{-1}$ increased the F_{ETO2} values at 30, 60, 90, 120, and 150 sec during the preoxygenation period, resulting in similar F_{ETO2} values at 180 sec (Figure 4). Also, with the circle absorber system, increasing the O_2 flow from 5 $L \cdot min^{-1}$ to 10 $L \cdot min^{-1}$ increased the F_{ETO2} values at 30, 60, 90, 120, and 150 sec during the preoxygenation period, resulting in similar F_{ETO2} values at 180 sec (Figure 5).

The F_{ETO2} increased exponentially over time with the Mapleson D ($r^2 = 0.998$) (Figure 3), the Mapleson A ($r^2 = 0.999$) (Figure 4), and the circle ($r^2 = 0.998$)

(Figure 5) systems. The most significant increases in F_{ETO2} with all three systems occurred during the first 60 to 90 sec of preoxygenation (Figure 2).

Discussion

The present report shows that with an O_2 flow of 5 $L \cdot min^{-1}$, the F_{ETO2} achieved with the Mapleson D system after three minutes of preoxygenation is significantly lower than that achieved by the Mapleson A and the circle CO_2 absorber systems. Increasing the O_2 flow to 10 $L \cdot min^{-1}$ improved both the F_{I,O_2} and the F_{ETO2} values obtained with the Mapleson D system to the same levels achieved by using an O_2 flow of 5 $L \cdot min^{-1}$ with the Mapleson A and the circle CO_2 absorber systems. The decreased F_{ETO2} with the Mapleson D anesthesia system at 5 $L \cdot min^{-1}$ can be attributed to a higher degree of rebreathing, as reflected by the lower F_{I,O_2} levels throughout the preoxygenation period.

Preoxygenation depends on spontaneous breathing of 100% O_2 in order to denitrogenate the FRC of the lungs and to increase the O_2 stores in the FRC. Hamilton and Eastwood have shown that denitrogenation is 95% complete in two to three minutes at an O_2 flow of 5 $L \cdot min^{-1}$ and tidal volume breathing using the circle CO_2 absorber system.¹ Other anesthesia systems such as the Mapleson A (Magill system), and Mapleson D system including the Bain modification,⁶ may also be used for preoxygenation.

On a theoretical basis, Mapleson suggested that rebreathing during spontaneous ventilation may be less with the Mapleson A system compared to Mapleson D system.⁵ With the Mapleson A system, the FGF is delivered distally near the reservoir bag, while the overflow valve is located proximally near the patient end of the system, which decreases the degree of rebreathing. In contrast, with the Mapleson D system, the FGF is delivered proximal to the patient, while the outlet valve is distally located near the reservoir bag, which increases the possibility of rebreathing. Baraka *et al.* have shown in spontaneously breathing children that a FGF equal to one-minute volume can adequately prevent CO_2 rebreathing when using the Mapleson A system.⁷ In contrast, a FGF equivalent to two-minute volumes is required to eliminate rebreathing when the Mapleson D system is used.⁷ In adult patients using the Magill system, Kain *et al.* have even shown that a FGF equivalent to alveolar ventilation volume can adequately prevent rebreathing.⁸ The circle system includes unidirectional inspiratory and expiratory valves that can minimize rebreathing of exhaled gases and subsequently improve the rate of preoxygenation.

The degree of rebreathing as monitored by the $F_{I}O_2$ using the different anesthesia systems can affect the washout of exhaled nitrogen from the FRC and hence may explain our results concerning preoxygenation by the different anesthesia systems as evidenced by the F_{ETO2} . Thus, using an O_2 flow equivalent to one alveolar minute ventilation volume in adults (i.e., 5 L·min⁻¹) provides adequate preoxygenation within three minutes when the Mapleson A and the circle absorber systems are used. In contrast, when the Mapleson D system is used, an O_2 flow equivalent to two alveolar minute ventilation volumes (i.e., 10 L·min⁻¹) is required to achieve the same degree of preoxygenation.

The F_{ETO2} increased exponentially over time during preoxygenation with the three anesthesia systems. This exponential increase in F_{ETO2} is equivalent to, and mirrors the exponential wash-out of nitrogen during the preoxygenation period.⁹ In the present report using tidal volume breathing and an O_2 flow of 10 L·min⁻¹ with all three systems, the most significant rate of increase in F_{ETO2} up to and greater than 70%, occurred within the first 60 to 90 sec of the preoxygenation period.

In conclusion, the present report shows that when using the Mapleson A and the circle CO_2 absorber systems for preoxygenation, an O_2 flow of 5 L·min⁻¹ can adequately preoxygenate the patient by tidal volume breathing within three minutes, while an O_2 flow of 10 L·min⁻¹ is required to achieve a similar fractional end-tidal O_2 concentration with the Mapleson D system.

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