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SCIENTIFIC ARTICLE

Efficacy of preoxygenation using tidal volume breathing: a comparison of Mapleson A, Bain's and Circle system



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KEYWORDS

Anesthesia;
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Abstract

Background: Efficacy of preoxygenation depends upon inspired oxygen concentration, its flow rate, breathing system configuration and patient characteristics. We hypothesized that in actual clinical scenario, where breathing circuit is not primed with 100% oxygen, patients may need more time to achieve $\text{EtO}_2 \geq 90\%$, and this duration may be different among various breathing systems. We thus studied the efficacy of preoxygenation using unprimed Mapleson A, Bain's and Circle system with tidal volume breathing at oxygen flow rates of $5 \text{ L} \cdot \text{min}^{-1}$ and $10 \text{ L} \cdot \text{min}^{-1}$.

Methods: Patients were randomly allocated into one of the six groups, wherein they were preoxygenated using either Mapleson A, Bain's or Circle system at O_2 flow rate of either $5 \text{ L} \cdot \text{min}^{-1}$ or $10 \text{ L} \cdot \text{min}^{-1}$. The primary outcome measure of our study was the time taken to achieve $\text{EtO}_2 \geq 90\%$ at 5 and $10 \text{ L} \cdot \text{min}^{-1}$ flow rates.

Results: At oxygen flow rate of $5 \text{ L} \cdot \text{min}^{-1}$, time to reach $\text{EtO}_2 \geq 90\%$ was significantly longer with Bain's system ($3.7 \pm 0.67 \text{ min}$) than Mapleson A and Circle system (2.9 ± 0.6 , $3.3 \pm 0.97 \text{ min}$, respectively). However at oxygen flow rate of $10 \text{ L} \cdot \text{min}^{-1}$ this time was significantly shorter and comparable among all the three breathing systems ($2.33 \pm 0.38 \text{ min}$ with Mapleson, $2.59 \pm 0.50 \text{ min}$ with Bain's and $2.60 \pm 0.47 \text{ min}$ with Circle system).

Conclusions: With spontaneous normal tidal volume breathing at oxygen flow rate of $5 \text{ L} \cdot \text{min}^{-1}$, Mapleson A can optimally preoxygenate patients within 3 min while Bain's and Circle system require more time. However at O_2 flow rate of $10 \text{ L} \cdot \text{min}^{-1}$ all the three breathing systems are capable of optimally preoxygenating the patients in less than 3 min.

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PALAVRAS-CHAVE

Anestesia;
Pré-oxigenação;
Circuitos
respiratórios;
Volume corrente

Eficácia da pré-oxigenação usando respiração em volume corrente: uma comparação dos sistemas Mapleson A, Bain e Circular

Resumo

Justificativa: A eficácia da pré-oxigenação depende da concentração inspirada de oxigênio, do fluxo de gases, da configuração do circuito respiratório e das características do paciente. Nossa hipótese foi que, no cenário clínico real, onde o circuito respiratório não é preparado com 100% de oxigênio, os pacientes podem precisar de mais tempo para atingir $\text{EtO}_2 \geq 90\%$, e essa duração pode ser diferente entre vários circuitos de respiração. Avaliamos, portanto, a eficácia da pré-oxigenação usando os circuitos não preparados Mapleson A, Bain e Circular com volume corrente de respiração com um fluxo de oxigênio de $5 \text{ L}\cdot\text{min}^{-1}$ e $10 \text{ L}\cdot\text{min}^{-1}$.

Métodos: Os pacientes foram alocados aleatoriamente em um dos seis grupos, nos quais foram pré-oxigenados com o uso do circuito Mapleson A, Bain ou Circular com um fluxo de O_2 de $5 \text{ L}\cdot\text{min}^{-1}$ ou $10 \text{ L}\cdot\text{min}^{-1}$. O desfecho primário de nosso estudo foi o tempo necessário para atingir $\text{EtO}_2 \geq 90\%$ com um fluxo de 5 e $10 \text{ L}\cdot\text{min}^{-1}$.

Resultados: Com um fluxo de oxigênio de $5 \text{ L}\cdot\text{min}^{-1}$, o tempo para atingir $\text{EtO}_2 \geq 90\%$ foi significativamente maior com o circuito Bain ($3,7 \pm 0,67 \text{ min}$) do que com os circuitos Mapleson A e Circular ($2,9 \pm 0,6$ e $3,3 \pm 0,97 \text{ min}$, respectivamente). No entanto, com o fluxo de oxigênio de $10 \text{ L}\cdot\text{min}^{-1}$ foi significativamente menor e comparável entre os três circuitos respiratórios ($2,33 \pm 0,38 \text{ min}$ com Mapleson; $2,59 \pm 0,50 \text{ min}$ com Bain e $2,60 \pm 0,47 \text{ min}$ com o Circular).

Conclusões: Durante respiração espontânea com volume corrente normal e com um fluxo de oxigênio de $5 \text{ L}\cdot\text{min}^{-1}$, o sistema Mapleson A pode pré-oxigenar o paciente de forma ideal dentro de três minutos, enquanto os sistemas Bain e Circular requerem mais tempo. Porém, com um fluxo de O_2 de $10 \text{ L}\cdot\text{min}^{-1}$, todos os três circuitos respiratórios podem pré-oxigenar o paciente de forma ideal em menos de três minutos.

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Introduction

Preoxygenation with 100% oxygen before anesthetic induction, a widely accepted manoeuvre, increases the body oxygen stores thus delaying onset of desaturation during apneic period following induction of anesthesia and muscle relaxation. Preoxygenation is known to increase the safe apnea time in most healthy adults by 3–6 min.¹ Most often, for adequate preoxygenation, patients are required to breathe 100% oxygen for 3–5 min or take 4–8 deep vital capacity breaths for 30–60s respectively. Efficacy of preoxygenation depends upon inspired oxygen concentration, its flow rate, breathing system configuration and patient characteristics.^{2,3} Much of the previous work has focused on patient's characteristics affecting preoxygenation and different methods like tidal volume breathing, four deep breaths, eight deep breaths and vital capacity breathing.^{2–5}

Mapleson suggested that the degree of rebreathing during spontaneous breathing is less with Mapleson A system than with Mapleson D system. Such difference in the degree of rebreathing may affect the efficacy of preoxygenation with different breathing systems.⁶ Taha et al.⁷ compared three breathing systems in healthy volunteers and concluded that primed Mapleson A and Circle System with oxygen flow rate of $5 \text{ L}\cdot\text{min}^{-1}$ could adequately preoxygenate the patients in 3 min, while an oxygen flow rate of $10 \text{ L}\cdot\text{min}^{-1}$ was required to achieve the similar fractional end

tidal oxygen concentration with Mapleson D system.⁷ Monitoring of fractional end tidal oxygen concentration (EtO_2) is known to be the best marker to detect optimal lung preoxygenation.^{2,8} We hypothesized that in actual clinical scenario, where patients are premedicated and breathing circuit is not primed with 100% oxygen, patients may need more time to achieve $\text{EtO}_2 \geq 90\%$, and this duration may be different among various breathing systems depending upon their configuration. Hence we planned to conduct this study with the aim of knowing the efficacy of preoxygenation using unprimed Mapleson A, Bain's and Circle system with tidal volume breathing at oxygen flow rates of $5 \text{ L}\cdot\text{min}^{-1}$ and $10 \text{ L}\cdot\text{min}^{-1}$.

Materials and methods

After getting ethical clearance from our institute's review board and written informed consent from the patients, 156 ASA physical status I and II patients of either sex, aged between 18 and 60 years, who were scheduled for elective surgical procedure under general anesthesia were included in the study. Patients with difficult mask seal, ASA status III/IV, abnormal Pulmonary Function Tests (PFT), morbid obesity ($\text{BMI} > 35 \text{ kg}\cdot\text{m}^{-2}$) and pregnancy were excluded from the study.

Patients were kept nil per oral for 8 h before surgery and were premedicated using tablet Diazepam ($0.1 \text{ mg}\cdot\text{kg}^{-1}$) and tablet Ranitidine (150 mg) a night prior and on the

morning of surgery. Using computer generated random number table, patients were randomly allocated into one of the following six groups:

Group I (M5, n = 27): Patients were preoxygenated using Mapleson A circuit at O₂ flow rate of 5 L.min⁻¹.

Group II (B5, n = 26): Patients were preoxygenated using Bain's system at O₂ flow rate of 5 L.min⁻¹.

Group III (C5, n = 26): Patients were preoxygenated using circle system at O₂ flow rate of 5 L.min⁻¹.

Group IV (M10, n = 25): Patients were preoxygenated using Mapleson A circuit at O₂ flow rate of 10 L.min⁻¹.

Group V (B10, n = 24): Patients were preoxygenated using Bain's system at O₂ flow rate of 10 L.min⁻¹.

Group VI (C10, n = 28): Patients were preoxygenated using Circle system at O₂ flow rate of 10 L.min⁻¹.

Inside the operation theatre all patients were monitored for continuous electrocardiogram (ECG), non-invasive blood pressure (NIBP), peripheral oxygen saturation (SpO₂) and temperature using multichannel monitors (Datex-Ohmeda S/5 Avance). Intravenous line was secured and normal saline infusion was started. The O₂ flow was started at a flow rate of either 5 or 10 L.min⁻¹ using one of the three breathing systems. After 30 s, a well-fitted anatomical face mask was applied on the patients face and patient was instructed to breathe normally. Side stream respiratory gases were sampled from the sampling port placed next to the mask. Inspired fraction of O₂ (FiO₂), EtO₂, SpO₂, respiratory rate (RR) and end tidal carbon dioxide concentration (EtCO₂)

were recorded every 20 s using a calibrated gas monitor (DatexOhmeda Anesthesia monitor).

The endpoint for maximal alveolar preoxygenation was defined as end tidal oxygen concentration (EtO₂) of $\geq 90\%$ for four consecutive breaths. The mean and standard deviations of FiO₂ and the EtO₂ values obtained with the Mapleson A, Bain's and Circle system with absorber at 20 s interval were compared at O₂ flow rates of 5 L.min⁻¹ and 10 L.min⁻¹.

The primary outcome measure of our study was the time taken to achieve EtO₂ $\geq 90\%$ at 5 and 10 L.min⁻¹ flow rates. Our secondary outcomes included time taken for FiO₂ to rise $\geq 95\%$ at patient end at 5 and 10 L.min⁻¹ flow rate, number of patients achieving EtO₂ $\geq 90\%$ earlier and mean respiratory rates, EtCO₂ and EtO₂ at all time points during the study period.

Results

A total of 166 patients were screened for inclusion into the study. Of these, 6 patients did not meet the inclusion criteria and 4 patients refused to give consent for participation in the study. Thus 156 patients were included in the study, completed the study protocol and were eventually analyzed (Fig. 1).

All the six groups were comparable with respect to patient's age, sex, weight, height, body mass index (BMI) and haemoglobin level (Table 1). All the groups were also comparable with regards to the mean respiratory rates and mean EtCO₂ at all time points during the study period.

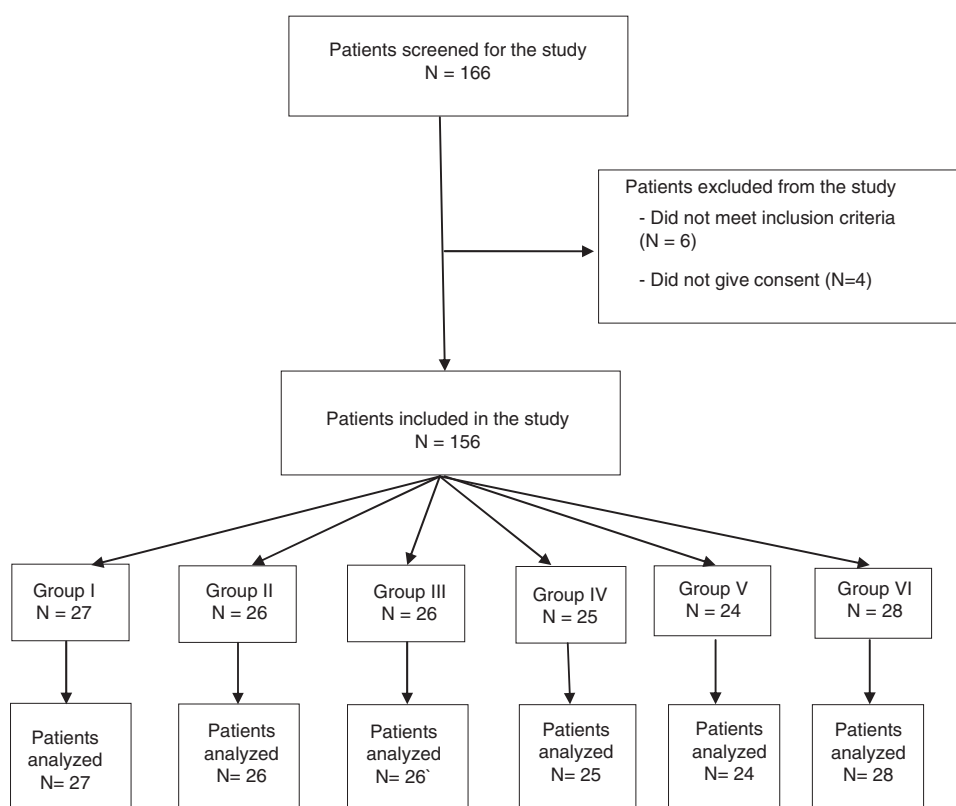


Figure 1 Flow of participants in the study.

Table 1 Demographic variables.

	Group-C ₅	Group-M ₅	Group-B ₅	Group-C ₁₀	Group-M ₁₀	Group-B ₁₀
Age (yrs)	34.8 ± 12.6	37.9 ± 11.3	37.6 ± 12.1	42.9 ± 11.1	35.9 ± 12.9	42.8 ± 10.1
Weight (kg)	55.8 ± 11.1	58.2 ± 10.9	59.5 ± 12.6	59.2 ± 10.2	57.5 ± 9.8	58.8 ± 8.2
Height (cm)	158.8 ± 9.1	159.7 ± 9.7	160.8 ± 11.1	160.7 ± 8.7	160.5 ± 7.7	159.6 ± 7.3
Sex (M:F)	6:20	6:22	6:19	11:17	5:20	11:13
BMI (kg . m ⁻²)	22.0 ± 3.0	22.8 ± 4.0	22.8 ± 3.2	23.0 ± 4.5	22.3 ± 3.4	23.0 ± 2.6
Hb (g . dL ⁻¹)	11.1 ± 1.4	11.5 ± 1.2	11.7 ± 1.2	11.5 ± 1.34	11.4 ± 1.4	11.5 ± 1.0

p-Value > 0.05 (one way ANOVA). All values are expressed as mean ± SD.

Table 2 Time taken for FiO₂ to rise ≥95% at 5 and 10 L.min⁻¹ flow rate (mean ± SD).

	Mapleson A system	Bain's system	Circle system	<i>p</i> -Value
FiO ₂ ≥ 95% rise time with O ₂ flow 5 L.min ⁻¹ (min)	1.40 ± 0.58	2.08 ± 0.78	1.30 ± 0.59	0.001 ^a
FiO ₂ ≥ 95% rise time with O ₂ flow 10 L.min ⁻¹ (min)	1.01 ± 0.37	1.27 ± 0.30	1.09 ± 0.43	0.062
<i>p</i> -Value (comparison between 5 L.min ⁻¹ and 10 L.min ⁻¹)	0.10	0.001	1.00	

^a *p* < 0.05; Bain vs. Mapleson A and Circle system at O₂ flow 5 L . min⁻¹.

Table 3 Time taken to achieve EtO₂ ≥ 90% at 5 and 10 L . min⁻¹ flow rates (mean ± SD).

	Mapleson system	Bain system	Circle system	<i>p</i> -Value
EtO ₂ ≥ 90% rise time with flow of 5 L.min ⁻¹ (min)	2.9 ± 0.60	3.7 ± 0.67	3.33 ± 0.97	0.001 ^a
EtO ₂ ≥ 90% rise time with flow of 10 L.min ⁻¹ (min)	2.33 ± 0.38	2.59 ± 0.50	2.60 ± 0.47	0.058
<i>p</i> -Value (comparison between 5 L.min ⁻¹ and 10 L.min ⁻¹)	0.02 ^a	0.01 ^a	0.015 ^a	

^a *p* < 0.05; Bain vs. Mapleson A.

FiO₂ characteristics of groups

Using an O₂ flow rate of 5 L.min⁻¹, FiO₂ at patient end increased to ≥95% in a significantly longer time in B5 group as compared to M5 and C5 group. However this time duration was comparable between groups M5 and C5. With O₂ flow rate of 10 L.min⁻¹, the time required for FiO₂ to increase to ≥95% was comparable in all the three groups (Table 2). The mean time to reach FiO₂ ≥ 95% was comparable between groups M5 and M10 and between C5 and C10. However, on comparing groups B5 and B10, a significant difference in the time required to reach FiO₂ ≥ 95% was found (Table 2).

EtO₂ characteristics of groups

Using an O₂ flow rate of 5 L.min⁻¹, time taken to preoxygenate to value of EtO₂ ≥ 90% was significantly more in B5 group (*p* = 0.001), as compared to M5 group. However, there was no significant difference between C5 and M5 groups and between C5 and B5 groups on post hoc analysis of means (Table 3).

Using an O₂ flow rate of 10 L.min⁻¹, the time required for EtO₂ values to increase to ≥90% was comparable amongst the three groups on post hoc analysis (Table 3).

On comparing groups with O₂ flow rates of 5 L.min⁻¹ and 10 L.min⁻¹, it was found that the mean time to reach a value of EtO₂ ≥ 90% was significantly shorter in groups using 10 L.min⁻¹ flow rates as compared to those using a flow rate of 5 L.min⁻¹ (Table 3).

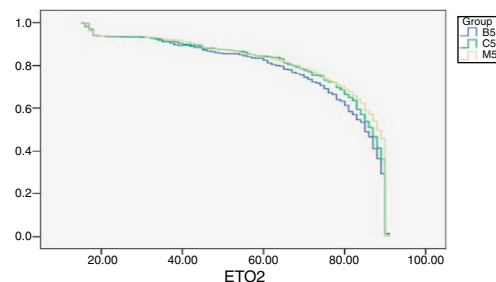


Figure 2 Kaplan-Meier survival curve. Patients achieving EtO₂ ≥ 90% at 5 L.min⁻¹ flow rate (%).

On further analysis of groups using O₂ flow rates of 5 L.min⁻¹ by log-rank statistics, as depicted by Kaplan-Meier graph in Fig. 2, it was obvious that significantly more number of patients achieved EtO₂ ≥ 90% earlier in group M5 as compared to Group C5 (*p* = 0.007). With the use of Mapleson A system, 60% patients achieved EtO₂ ≥ 90% at 3 min, as compared to only 17% with Bain's system and 23% with circle system.

EtO₂ rising profile in the groups

The EtO₂ increased exponentially over time with the Mapleson A (*r*² = 0.542), Circle (*r*² = 0.569) and Bain's (*r*² = 0.604) system. The mean (±SD) EtO₂ at different time intervals during the study period has been shown in Figs. 3 and 4. The

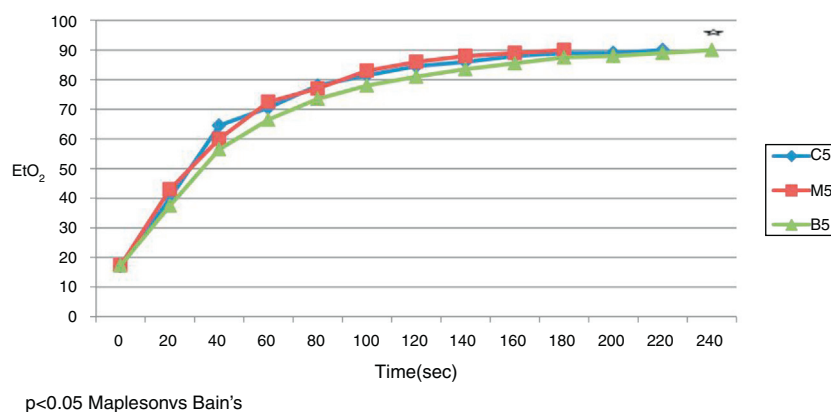


Figure 3 Mean EtO₂ at different time intervals at a flow rate of 5 L.min⁻¹ ($p < 0.05$; Mapleson vs. Bain's).

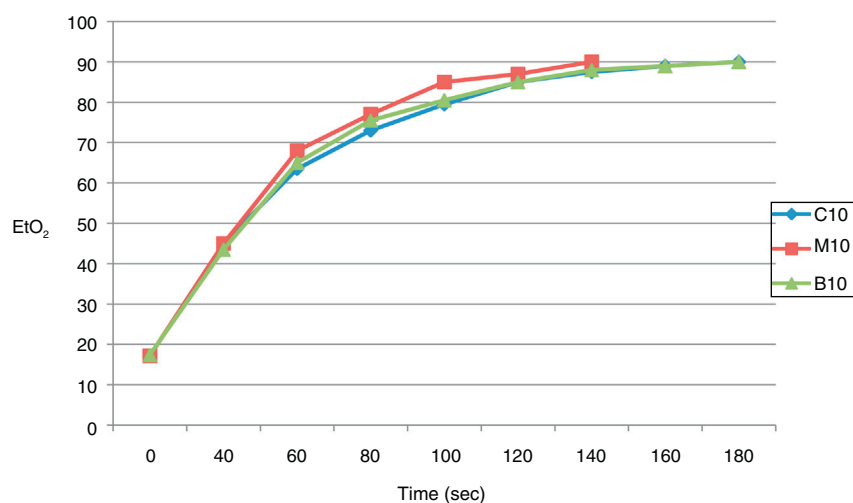


Figure 4 Mean EtO₂ at different time intervals at a flow rate of 10 L.min⁻¹ ($p > 0.05$; Mapleson A vs. Circle; Mapleson A vs. Bain's and Circle vs. Bain's).

most significant increase in EtO₂ occurred during the first 40–80 s of preoxygenation in all the groups, with patients in group M10 achieving EtO₂ $\geq 90\%$ the earliest.

Discussion

In most of the previous studies, the authors have flushed the breathing system with 100% oxygen for a few minutes prior to preoxygenating the patients.^{6,7} However, in actual clinical practice, it has been observed that most of the clinicians seldom prime the breathing systems with 100% oxygen before initiating preoxygenation. Hence in this prospective randomized study, we evaluated the preoxygenation efficacy of three breathing systems with respect to time, without priming the circuits with 100% oxygen. We used the two commonly used fresh gas flow rates, i.e. 5 L.min⁻¹ and 10 L.min⁻¹. The endpoint taken for optimal preoxygenation was an EtO₂ of $\geq 90\%$, which is equivalent to the end tidal Nitrogen (EtN₂) of $\leq 5\%$.

As the respiratory characteristics of the patients are known to affect the time taken for adequate preoxygenation, hence, we evaluated the respiratory profile (respiratory rate and EtCO₂) of our patients. We found that

the respiratory rate and EtCO₂ of our patients were comparable at all time intervals during the study period. Hence any differences in the time to achieve an EtO₂ $\geq 90\%$ observed in our study were most likely due to the differences in breathing system configuration.

During preoxygenation, the configuration of different breathing systems not only affects the EtO₂ achieved, which is representative of the alveolar oxygen concentration, but also affects the rise in FiO₂ at patient end. Hence we studied the rise in FiO₂ at patient end along with the rise in EtO₂.

The results of our study showed that with an O₂ flow rate of 5 L.min⁻¹, the time required for FiO₂ to rise to $\geq 95\%$ was significantly longer with the use of Bain's system as compared to Mapleson A and Circle systems. This can be explained by higher degree of rebreathing with the use of Bain's system at this O₂ flow rate. We did not prime the breathing systems prior to the initiation of preoxygenation, therefore, as compared to previous studies, our results showed a relatively longer time for FiO₂ to rise to $\geq 95\%$ at the patient end. Our findings also suggested that Mapleson A breathing system was more efficacious as compared to the other two systems for preoxygenation in spontaneously breathing patients at O₂ flow rates of 5 L.min⁻¹.

There was no significant difference in the preoxygenation time with the use of either unprimed Mapleson A, Bain's or Circle system at O_2 flow rates of $10\text{ L}\cdot\text{min}^{-1}$. With an O_2 flow rate of $10\text{ L}\cdot\text{min}^{-1}$, time to achieve $\text{EtO}_2 \geq 90\%$, was significantly shorter than the time to achieve the same at O_2 flow rate of $5\text{ L}\cdot\text{min}^{-1}$. This could be due to less rebreathing with higher flow rates.

Taha et al.⁷ also compared preoxygenation in 13 healthy volunteers, with the Mapleson A, Circle system and Bain's system at O_2 flow rates of $5\text{ L}\cdot\text{min}^{-1}$ and $10\text{ L}\cdot\text{min}^{-1}$. They concluded that at oxygen flow rate of $5\text{ L}\cdot\text{min}^{-1}$ preoxygenation was comparable between Mapleson A and Circle system with respect to time; however Bain's system required significantly longer time. O_2 flow rate of $10\text{ L}\cdot\text{min}^{-1}$ is required to achieve similar EtO_2 with Bain's system.⁸ These results were almost similar to those of our study except that in our study, at O_2 flow rate of $5\text{ L}\cdot\text{min}^{-1}$, Bain's and Circle system were comparable to each other and were significantly inferior to Mapleson A. This might be due to the differences in study methodology. Taha et al.⁷ flushed the breathing systems with 100% O_2 prior to applying the mask to the subjects, which was not done in our study.

The longer rise time of $\text{EtO}_2 \geq 90\%$ with Bain's system at $5\text{ L}\cdot\text{min}^{-1}$ can be attributed to higher degree of rebreathing with its use. During conscious spontaneous ventilation, the expiratory pause of the patient might be short, thereby O_2 flow rate of $5\text{ L}\cdot\text{min}^{-1}$ may not be high enough to flush the exhaled gases downstream prior to the next inspiration. Rebreathing is known to have a cushioning effect on both the rise of any new inhaled gas as well as washout of pre-existing gas. Hence rebreathing of expired gases delays washout of nitrogen from lungs. In fact, rebreathing of exhaled alveolar gas occurs unless the FGF is at least two to three times the patient's minute ventilation.^{3,6} Increasing O_2 flow rate to $10\text{ L}\cdot\text{min}^{-1}$ improves both FiO_2 and EtO_2 obtained from the Bain's system. The degree of rebreathing, as monitored by FiO_2 , using the different anesthesia breathing systems, can affect the washout of exhaled nitrogen from FRC and hence explain our results concerning preoxygenation by different breathing systems, as evidenced by EtO_2 at patient end.

The EtO_2 increased exponentially over time during preoxygenation with the three breathing systems and the maximum rise was seen within the first 40–80s of preoxygenation. This exponential increase in EtO_2 is equivalent and mirrors the exponential wash-out of nitrogen during the preoxygenation period.

This study shows that FGF rate is a significant factor in determining the speed of successful preoxygenation; higher the O_2 flow rate, quicker is the preoxygenation. In clinical practice high FGF would also reduce air entrainment from any loose fitted face mask and help in early preoxygenation.

Machlin et al.² suggested that EtO_2 should be used to determine the success of preoxygenation. It is non-invasive and directly measures O_2 content in lungs. Successful preoxygenation is defined as $\text{EtO}_2 \geq 90\%$, which is equivalent to EtN_2 of $\leq 5\%$. It has previously been reported that majority of anesthetists do not use EtO_2 to monitor the effectiveness of preoxygenation, relying instead on other factors such as a 3 min pre-oxygenation period or the patient's arterial oxygen saturation. Rassam et al.⁹ also suggested that a high FGF, with an airtight mask seal aiming for an $\text{EtO}_2 \geq 90\%$ should be used to effectively preoxygenate the patients.

Success of preoxygenation depends on spontaneous breathing of 100% O_2 in order to denitrogenate the FRC of lungs and to increase its O_2 stores. Dillon and Darsie¹⁰ recommended 5 min of 100% oxygen administration before induction of anesthesia to avoid desaturation after induction.

In Mapleson A system, the APL valve is located proximally near the patient end and FGF is delivered at machine end close to reservoir bag. This configuration decreases the rebreathing during spontaneous breathing. While in Bain's system, the APL valve is located distally near the reservoir bag and FGF is delivered proximal to patient which increases the rebreathing due to mixing of FGF with expired gases during expiratory pause of respiration. Degree of rebreathing that occurs with Bain's system depends to some extent upon the pattern of breathing; the longer the expiratory pause, more efficient is the system in segregating fresh gas from expired gas. With slow respiratory rate sufficient time is made available to fill the tubing close to patient end with fresh gas flow, thereby decreasing rebreathing.

Circle system has circuit volume almost equal to FRC of adult patient, hence larger the breathing system's internal volume; greater will be the difference between inspired and delivered concentrations. Canister size is the most important determinant of internal volume of the circle system. So during preoxygenation with circle system, nitrogen has to be flushed from both the breathing system as well as from patient's lungs. In our study we did not flush the breathing systems with 100% oxygen. This may explain the delayed preoxygenation in patients with circle system at low flow rate of oxygen.

Baraka et al.¹¹ have shown that in spontaneously breathing children FGF equal to one-minute ventilation can adequately prevent CO_2 rebreathing when using Mapleson A breathing system. In contrast FGF equal to two-minute ventilation is required to eliminate rebreathing of CO_2 when using Mapleson D breathing system. Kain et al.¹² have shown that in adult patients using Mapleson A system, a FGF equivalent to alveolar ventilation volume can adequately prevent rebreathing. Russel et al.¹³ studied preoxygenation with circle system at O_2 flow rate of $5\text{ L}\cdot\text{min}^{-1}$, $10\text{ L}\cdot\text{min}^{-1}$ and $15\text{ L}\cdot\text{min}^{-1}$ in 20 pregnant patients posted for elective caesarean section and concluded that O_2 flow rate of $\geq 10\text{ L}\cdot\text{min}^{-1}$ is required to optimally preoxygenate the patients.

Previous studies have investigated preoxygenation in specific subset of subjects like healthy volunteers, pregnant women and morbidly obese patients.^{13–15} They have given recommendations for techniques like tidal volume breathing or 4 deep breaths or 8 deep breaths and reported time required for preoxygenation like 2, 3 or 5 min. None of the previous studies have compared different breathing systems and different O_2 flow rates. They have instead concentrated on comparison of deep breath and tidal volume techniques in the context of a fixed oxygen flow rate in particular subset of patients. Various techniques and regimens have been advocated to accomplish preoxygenation. For many years traditional tidal volume breathing for 3–5 min has been commonly practiced. Indeed studies done by Gold et al., Goldenberg et al. and Gambee et al.^{16–18} have shown that there was no significant difference between PaO_2 achieved with 3–5 min of tidal volume breathing compared to four

deep breaths per 30s. Chong et al.¹⁹ compared rapid vital capacity breaths and tidal volume breathing and concluded that vital capacity breaths did not result in effective denitrogenation. They recommended that at least 3 min of tidal volume breathing should be used for pre-oxygenation. Most of these studies have been done using the Circle system, with very few studies using the Mapleson A and Bain's system and most of them have flushed the systems with 100% oxygen prior to preoxygenation.^{4,14,20}

In order to accommodate vital capacity breaths, investigators have used modified or novel breathing systems in previous studies with deep breathing.^{4,5,14} We chose to use tidal volume breathing for preoxygenation in our study. Our aim was to use standard equipment as per routine clinical practice so that our results would be generally applicable.

Conclusion

This study shows that with spontaneous normal tidal volume breathing at oxygen flow rate of 5 L.min⁻¹ Mapleson A can optimally preoxygenate the patient within 3 min while Bain's and Circle system require more time. However at O₂ flow rate of 10 L.min⁻¹ all the three breathing systems are capable of optimally preoxygenating the patients in less than 3 min.

Conflicts of interest

The authors declare no conflicts of interest.

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