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Original Article

Supplementation of standard pre-oxygenation with nasal prong oxygen or machine oxygen flush during a simulated leak scenario

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Summary

The presence of a facemask leak significantly reduces the effectiveness of pre-oxygenation and increases the risk of post-induction hypoxia. We randomly assigned 24 healthy volunteers to a six-period crossover trial with and without a simulated facemask leak. Pre-oxygenation was performed using a standard anaesthesia machine circuit supplemented either by nasal prong oxygen or by anaesthesia machine flush oxygen. Each intervention was completed with both 3-min tidal breathing and 8 deep breath techniques: end-tidal oxygen fraction was used as the measure of pre-oxygenation effectiveness. The presence of a stimulated mask leak significantly reduced the effectiveness of pre-oxygenation regardless of the breathing method used. With a simulated facemask leak introduced, the mean (SD) end-tidal oxygen fraction with the 3-min tidal breath technique was 74.7 (9.3)% compared with 57.5 (6.2%) for the 8 deep breath technique with 3-min tidal breathing and a leak. End-tidal oxygen fractions increased by 11.0% (95% CI 7.8–14.3%) ($p < 0.0001$) with the addition of nasal prong oxygenation and 16.8% (13.6–20.0%) ($p < 0.0001$) with machine oxygen flush compared with standard pre-oxygenation. When a leak is present, 3-min tidal breathing with either nasal prong or anaesthesia machine flush oxygenation is an effective pre-oxygenation method, and preferable to the 8 deep breath method.

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Introduction

Pre-oxygenation is a commonly used technique to prolong the apnoeic duration before desaturation [1]. Ideally, it requires a co-operative patient with a tight-fitting facemask and high-flow, high-concentration oxygen [2]. A tight-fitting facemask without a leak may not be possible in claustrophobic, unco-operative, bearded or edentulous patients and patients with facial abnormalities [3]. Even in patients with teeth and normal facial anatomy, ~12% may have a leak [4]. Previous studies have examined the effects of patient position, different equipment, flow rates and breathing techniques on pre-oxygenation but there are few studies assessing pre-oxygenation when a leak is present [5–9].

The most common methods of pre-oxygenation involve 8 deep breaths over 60 s (8DB) or 3 min of tidal volume breathing (3TV) using high-flow 100% oxygen via an anaesthesia machine [8]. Leaks can be minimised by ensuring the inspired oxygen flow rate exceeds the patient's maximum inspiratory flow rate, with minimal rebreathing [10, 11]. The majority of anaesthesia machines with circuits and reservoir bags are limited to oxygen flow rates of 15 $l.min^{-1}$. The use of nasal prongs and anaesthesia machine oxygen flush are two readily available, additional and simple methods to increase the overall oxygen delivery. The objective of this study was to compare the effect of these two methods of supplementation on pre-oxygenation effectiveness, with a simulated facemask leak using 8DB and 3TV methods.

Methods

The study was registered at ANZCTR (ACTRN12613000126718) and was approved by the King Edward Memorial Hospital Ethics Board. Written consent was obtained from 24 healthy, unmedicated and fasted volunteers aged > 18 years. Volunteers were not studied if they were pregnant or if they had a beard, dentures or lung pathology. Subjects were given a brief introduction to the anaesthesia facemask, machine and nasal prongs.

This was a randomised six-period crossover study to compare the effects of six treatments on pre-oxygenation effectiveness. The participants were randomly allocated to one of six sequences of the treatments based on a 'latin square' design. The variables were: two types of breathing during pre-oxygenation (3TV or 8DB); three types of oxygen supplementation (standard, oxygen flush or nasal prongs); and the presence of leak or not. Each sequence included the six treatments (labelled i–vi below) in a balanced design. All treatments were performed on each of the 24 participants, with the randomised sequence revealed immediately before performing the first treatment. Treatment allocations included: (i) standard pre-oxygenation; (ii) standard plus nasal prongs; (iii) standard plus oxygen flush; (iv) standard with simulated mask leak; (v) standard with simulated mask leak plus nasal prongs; (vi) standard with simulated mask leak plus oxygen flush.

Pre-oxygenation was delivered via a Datex Ohmeda Aestiva 3000 anaesthesia machine (GE Health Care, Belmont, WA, Australia) and a Mayo Healthcare 99073 breathing circuit (Mayo Healthcare Pty Ltd, Rosebery, NSW, Australia) consisting of a 2-l reservoir bag and two 72-inch lengths of corrugated tubing. The flow was set at 15 $l.min^{-1}$ oxygen with the adjustable pressure limiting valve (APL) fully open. For each participant an appropriately sized Boss system respiratory anaesthesia facemask (Koo Medical Equipment Co Ltd, Shanghai, China) was chosen. A gas sampling line was placed under the facemask to minimise any circuit dead space and attached to S/5 Compact Module M – CAiO gas analyser (GE Health Care). A simulated mask leak was achieved using 5 cm of a size-16 Ryles nasogastric tube taped onto the volunteer's skin where the mask edge sits as described previously [9]. When required, nasal prongs oxygen was delivered at 5 $l.min^{-1}$ and an anaesthesia machine oxygen flush, delivering oxygen at approximately 35 $l.min^{-1}$, was used.

The circuit and reservoir bag were flushed with 100% oxygen before each run. Volunteers were positioned supine and commenced each run after tidal breathing exhalation. Each treatment was conducted using either 3TV and 16 deep breaths (of which data for the first 8 deep breaths were analysed) in a randomised fashion. For 3TV, participants were asked to breathe normally, whereas for deep breaths participants were advised to take large slow breaths every 7–8 s. Following each pre-oxygenation run, volunteers breathed room air until their end-tidal oxygen fraction ($F_{ET}O_2$) returned to its baseline value. The effectiveness of pre-oxygenation was measured by the $F_{ET}O_2$ via the anaesthesia machine at 30-s intervals. Immediately before $F_{ET}O_2$ measurements, the nasal prong oxygen and machine oxygen flush were temporarily ceased before exhalation commenced to avoid potential measurement errors. Following each treatment run, volunteers were asked to rate the tolerances of the treatment on a numerical rating scale from 0 (unpleasant) to 10 (no discomfort).

The primary endpoint was the effectiveness of pre-oxygenation as measured by the $F_{ET}O_2$ after 8 deep breaths. A sample size of 24 was chosen to ensure a balanced design allowing for four participants per sequence (six sequences) and the comparison of treatments and assessment of possible period effects with an alpha level at 0.05.

Data were analysed at our primary time points of 3TV and 8DB. Oxygen fraction among treatment methods was analysed using general linear models, with subject, treatment and period modelled as fixed effects [12]. The absence of a carry-over effect was assumed as there was a washout period and return to baseline oxygenation between each treatment. The design and analysis allowed for a possible period effect. Seven pre-planned comparisons were made between pairs of treatments, and a Bonferroni correction of $\alpha = 0.05/7 = 0.007$ level of significance was applied. Oxygenation targets were compared between treatments using generalised linear models with an independence estimating equation approach. The Friedman test was used to compare combined tolerance scores between the three treatments methods: standard pre-oxygenation; standard plus nasal prongs; and standard plus oxygen flush. Statistical analysis was performed using SAS software, Version 9.3 of the SAS System for Windows (Cary, NC, USA).

Table 1 End-tidal oxygen percentage with 3TV and 8DB for the six treatment allocations. Values are mean (SD).

Treatment	3TV	8DB	p value
With good mask seal			
Standard pre-oxygenation	83.0 (7.1)	78.1 (9.6)	0.005
Standard plus nasal prongs	86.5 (6.9)	74.2 (7.3)	< 0.001
Standard plus oxygen flush	91.2 (3.8)	80.4 (7.5)	< 0.001
With simulated mask leak			
Standard	74.7 (9.3)	57.5 (6.2)	< 0.001
Standard plus nasal prongs	85.8 (9.7)	66.5 (12.5)	< 0.001
Standard plus oxygen flush	91.5 (4.8)	73.9 (10.1)	< 0.001

p values < 0.008 considered significant (post hoc Bonferroni correction after Friedman test $\alpha = 0.05/6 = 0.008$).

Results

There were no missing data and all participants were included in the analysis. The median (IQR [range]) age was 48 (38–54 [21–60]) years, BMI was 24 (22–27 [18–42]) $kg.m^{-2}$ and 18/24 (75%) participants were women.

Both 3TV and 8DB methods increased $F_{ET}O_2$, with and without a leak (Table 1). As expected, the leak reduced the efficacy of pre-oxygenation regardless of the breathing technique used (Table 1). However, 3TV was more effective for all treatments compared with 8DB, with the greatest difference seen during the simulated leak tests (Table 1). When a simulated facemask leak was introduced, the 3TV resulted in a smaller reduction, 8.3% (95% CI 5.1–11.5%) ($p < 0.0001$) in end-tidal oxygen fraction compared with 8DB, 20.6% (95% CI 16.1–25.0%, $p < 0.0001$). The mean end-tidal oxygen fraction for the simulated mask leak treatments are shown in Fig. 1.

Pairwise comparisons between the treatments were performed for 3TV and 8DB breathing techniques. In the absence of a leak, the addition of nasal prongs to standard pre-oxygenation did not significantly change the end-tidal oxygen fraction for either breathing technique. The addition of machine oxygen flush during the 3TV significantly increased end-tidal oxygen (estimated mean treatment difference 8.2%, 95% CI 5.0–11.4%, $p < 0.0001$) but there was no significant change during 8DB.

In the simulated leak condition, the addition of nasal prongs during standard pre-oxygenation significantly increased end-tidal oxygen with an estimated mean treatment difference of 11.0% (95% CI 7.8–14.3%, $p < 0.0001$) during 3TV and 8.8% (95% CI 4.3–13.2%, $p = 0.0002$) during 8DB. The supplementation of standard pre-oxygenation with oxygen flush was more effective than the addition of nasal prongs with an estimated mean treatment difference of 16.8% (95% CI 13.6–20.0%, $p < 0.0001$) during 3TV and 16.4% (95% CI 11.9–20.8%, $p < 0.0001$) during 8DB.

Participants found the nasal prongs were the least comfortable method of treatment. Median (IQR [range]) tidal breathing tolerance scores were 6 (5–7 [2–10]) for nasal prongs compared with 9 (7–10 [5–10]) and 8 (7–9 [5–10]; $p < 0.001$) for the standard and oxygen flush, respectively. Deep breathing tolerance scores were 6 (5–7 [5–10]) for nasal prongs compared with 7 (7–9 [3–10]) and 8 (7–9 [5–10]) for the standard and oxygen flush, respectively. No complications were detected during the study.

Discussion

A significant number of patients may have inadequate pre-oxygenation due to a facemask leak and are at risk of hypoxia during anaesthesia induction and intubation attempts. If a leak is suspected from the circuit bag deflating or a failure to reach an adequate $F_{ET}O_2$

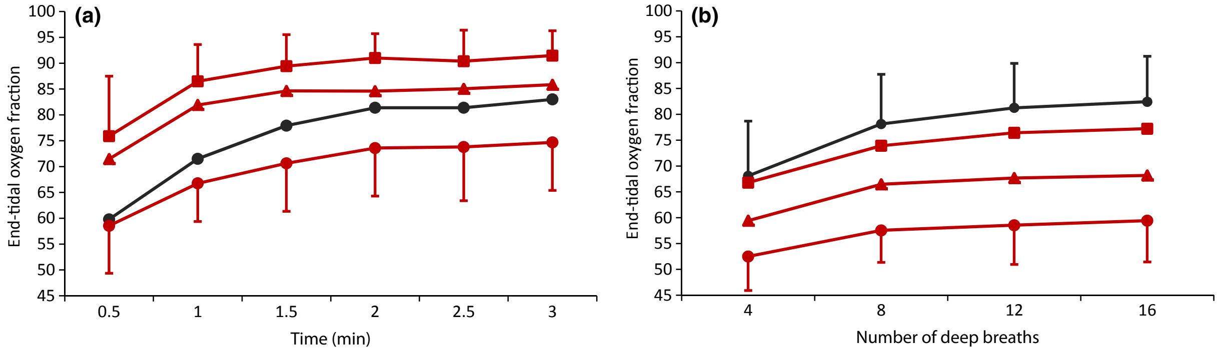

Figure 1 Mean end-tidal oxygen fraction recorded every 30 s for (a) 3TV and (b) 8DB techniques by treatment groups: standard ●; standard with mask leak ●; standard with mask leak plus nasal prongs ▲; standard with mask leak plus oxygen flush ■. For clarity, unidirectional error bars (SD) have been used (omitted from some plots).

within a reasonable time, it may be rectified by mask repositioning, increased oxygen flow rate or oxygen fraction or even by the patient's breathing directly from the circuit tubing rather than via a mask. Nevertheless, sometimes a leak is unavoidable.

We found that (a) 3TV method is more effective than 8DB and (b) both nasal prongs and oxygen flush increase the degree of pre-oxygenation (especially the last). Thus the most effective combination is probably 3TV, no leak, with oxygen flush. Importantly, nasal prongs did not significantly reduce the effectiveness of pre-oxygenation with either 3TV or 8DB.

Our findings that a leak significantly impairs pre-oxygenation are similar to those reported by Gagnon et al., although they only assessed a 4 deep breath technique [2] Compared with 8DB, 3TV is a more effective breathing method when no leak is present and this difference is amplified in the presence of a leak. This is perhaps counterintuitive as deep breathing might be presumed to overcome the adverse effects of leak. When pre-oxygenation is slower than expected (e.g. with a leak) it is not uncommon for anaesthetists to encourage deep breaths. However, this may be counterproductive as this might only serve to draw in more air via the leak.

There are several possible reasons for the improved speed and effectiveness of pre-oxygenation with nasal oxygen and machine oxygen flush. The high flow rates minimise the amount of inhaled air from the leak and if the oxygen delivery flow rate exceeds the maximum inspiratory flow rate, the effect of a leak becomes negligible [10, 11]. However, most anaesthesia machines are limited to 15 $l.min^{-1}$, which is lower than maximum inspiratory flow rates in patients breathing at rest. Reservoir bags partially overcome the problem of limited maximum flow rates. Previous studies have also found no benefit in increasing flow rates from 5 to 10 $l.min^{-1}$ in an anaesthesia machine circuit with reservoir bag [5, 7]. The addition of nasal prong and oxygen flush increased the total flow rate by 33% and 233%, respectively. As nasal prongs only modestly increased total flow rates, there are likely to be other reasons for better pre-oxygenation in addition to just higher flows. The application of nasal prong oxygenation has been shown to improve flushing of exhaled carbon dioxide from the mask and thus reduces rebreathing [10, 13]. As the carbon dioxide is flushed away, a higher oxygen fraction is inspired. Anaesthesia machine oxygen flush, and to a lesser extent nasal prong oxygen, may also result in the application of continuous positive airway pressure (CPAP). There is conflicting evidence on the effectiveness of CPAP during pre-oxygenation and its effect would be minimised when a leak is present [14–17].

Concerns about the application of high-flow oxygen via nasal prongs or the anaesthesia machine oxygen flush revolve around the potential high pressures that could be generated. In our study, the risk of potential damage was minimised by having the APL valve fully opened, releasing the nasal prong or flush oxygen every 30 s, knowing that a leak was present and having the subject fully conscious so he/she could remove the mask and alert us if he/she felt any discomfort. The anaesthesia machine flush is also pressure limited to 40 cmH_2O. Given there is still potential for barotrauma and gastric insufflation, its use should be restricted to when pre-oxygenation using standard methods is ineffective, a large leak is known to be present or when only a brief pre-oxygenation is possible. Compared with machine oxygen flush, nasal oxygenation may be a safer option and is only marginally less effective. It also has the advantage of being left in place to provide apnoeic oxygenation during intubation attempts. The use of either technique should be restricted to when the benefits of pre-oxygenation outweigh the potential risks.

Tolerance of any technique is important as an unpleasant experience may result in ineffective pre-oxygenation due to breath-holding, reduced minute ventilation and head movement causing a facemask leak. While nasal prongs had the lowest tolerance score, the majority of volunteers had acceptable tolerance scores.

There are several limitations to our study. First, our study only included co-operative subjects with no known lung pathology. Second, we have only examined the effects with a standardised leak size, so the results may not be applicable for smaller or larger leaks. Third, we did not measure airway pressure, so the effects of any CPAP created by our techniques of oxygen supplementation are unknown. Fourthly, the sampling line placed under the mask may have created a small additional leak.

In summary, 3-min tidal breathing is the preferred breathing technique and the addition of nasal prong or anaesthesia machine flush oxygenation may be useful when a leak is present or rapid pre-oxygenation required.

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Competing interests

No other funding or competing interests declared.

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