

Efficacy of Nasal Cannula Oxygen as a Preoxygenation Adjunct in Emergency Airway Management

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Study objective: Although preoxygenation for emergency airway management is usually performed with nonrebreather face masks or bag-valve-mask devices, some clinicians also deliver supplemental high-flow oxygen by nasal cannula. We aim to measure the efficacy of supplemental nasal cannula oxygen delivery to conventional bag-valve-mask and nonrebreather face mask preoxygenation both with and without a simulated face mask leak.

Methods: We conducted a randomized crossover trial using healthy volunteers. We randomized subjects to preoxygenation with bag-valve-mask or nonrebreather face mask. In random sequence, subjects underwent 3-minute trials of preoxygenation with oxygen through mask alone at 15 L/min, oxygen through mask at 15 L/min with standardized leak, oxygen through mask at 15 L/min+oxygen through nasal cannula at 10 L/min, and oxygen through mask at 15 L/min+oxygen through nasal cannula at 10 L/min with standardized leak. The primary outcome was single-breath exhalation end-tidal oxygen (ET_{O_2}). We compared ET_{O_2} between preoxygenation modalities, using nonparametric techniques.

Results: We enrolled 60 subjects (30 nonrebreather face mask and 30 bag-valve-mask). In scenarios without a mask leak, ET_{O_2} was similar between bag-valve-mask and bag-valve-mask+nasal cannula (mean 79% versus 75%; difference -3%; 95% confidence interval [CI] -8% to 1%). In bag-valve-mask scenarios with a mask leak, ET_{O_2} was higher for bag-valve-mask+nasal cannula than bag-valve-mask alone (mean 66% versus 41%; difference 25%; 95% CI 21% to 29%). ET_{O_2} was higher for nonrebreather face mask+nasal cannula than nonrebreather face mask (mean 67% versus 52%; difference 15%; 95% CI 12% to 18%). In nonrebreather face mask scenarios with a mask leak, ET_{O_2} was higher for nonrebreather face mask+nasal cannula than nonrebreather face mask (mean 65% versus 48%; difference 17%; 95% CI 13% to 20%).

Conclusion: Although not aiding bag-valve-mask preoxygenation with a good mask seal, supplemental nasal cannula oxygen improved preoxygenation efficacy in the presence of a bag-valve-mask mask leak. Supplemental nasal cannula oxygen improved nonrebreather face mask preoxygenation both with and without a mask leak. Supplemental nasal cannula oxygen may be helpful for preoxygenation before emergency airway management. [Ann Emerg Med. 2015;■:1-7.]

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INTRODUCTION

Background

In emergency airway management and rapid sequence intubation, clinicians commonly perform preoxygenation before performing laryngoscopy and intubation. Preoxygenation denitrogenates the functional residual capacity of the lungs, creating an oxygen reservoir to allow periods of apnea during intubation.¹ Preoxygenation is essential to help prevent hypoxemia during emergency airway management.^{2,3}

Common devices used for emergency airway preoxygenation include bag-valve-mask and the nonrebreather face mask, both of which vary by manufacturer in their delivered FiO_2 .⁴⁻⁸ In addition to bag-valve-mask or nonrebreather face mask, some clinicians

provide supplemental high-flow oxygen through nasal cannula to increase the total oxygen flow. Bag-valve-mask or nonrebreather face mask seal may be difficult to maintain in emergency airway cases (for example, because of facial injuries or agitation), compromising preoxygenation, so some clinicians advocate the use of supplemental high-flow nasal cannula oxygen in the presence of a mask leak.⁹⁻¹¹

Importance

Although supplemental nasal cannula oxygen for preoxygenation before emergency airway management theoretically increases oxygen delivery, to our knowledge there are no studies evaluating its efficacy. In addition, to our knowledge there are no studies evaluating the efficacy

Editor's Capsule Summary*What is already known on this topic*

Before emergency airway management, clinicians commonly perform preoxygenation with bag-valve-mask or nonrebreather mask.

What question this study addressed

Does supplemental high-flow nasal cannula oxygen improve preoxygenation?

What this study adds to our knowledge

In this randomized trial on 60 healthy volunteers, nasal cannula oxygen at 10 L/min improved end-tidal oxygen levels with nonrebreather mask, nonrebreather with a mask leak, and bag-valve-mask with a mask leak. Addition of nasal cannula did not improve end-tidal oxygen with well-sealed bag-valve-mask.

How this is relevant to clinical practice

Although requiring validation in clinical emergency department patients, supplemental nasal cannula oxygen may aid emergency airway management preoxygenation efforts.

of supplemental nasal cannula oxygen for rapid sequence intubation preoxygenation in the presence of a bag-valve-mask or nonrebreather face mask leak.

Goals of This Investigation

In this study using healthy volunteers, we sought to assess the efficacy of supplemental nasal cannula oxygen in preoxygenation for simulated emergency airway management, with and without face mask leak.

MATERIALS AND METHODS**Study Design and Setting**

We performed a randomized crossover study using healthy volunteers. All trials were conducted in the operating room or ICU of St George Hospital. The study was approved by the South Eastern Sydney Local Health District Ethics Review Committee (HREC/15/POWH/54) and registered at the Australia and New Zealand Clinical Trials Registry.

Selection of Participants

Volunteers were requested from operating theater, emergency department (ED), or ICU staff at St George

Hospital. Exclusion criteria were known respiratory or cardiac disease; current cardiac or respiratory medications, including inhalers; pregnancy; exposure to bleomycin or amiodarone; and facial hair or previous facial injury likely to affect mask seal. Male volunteers were asked to be clean-shaven on the day of testing. One participant was excluded before commencing because of previous exposure to amiodarone.

Interventions

After informed consent, each participant was randomized to either nonrebreather face mask or bag-valve-mask according to a random sequence generated with the statistical software R (version 3.1.2; R Foundation for Statistical Computing). Participants then underwent 4 trials of preoxygenation consisting of mask alone (bag-valve-mask or nonrebreather face mask), mask (bag-valve-mask or nonrebreather face mask) with simulated leak, mask+nasal cannula (bag-valve-mask+nasal cannula or nonrebreather face mask+nasal cannula), and mask+nasal cannula with simulated leak. The sequence of the 4 trials was randomized with a balanced Latin square design so that the order of trials of one participant was completed in the opposite order of another participant.

Bag-valve-mask preoxygenation was performed with a disposable self-inflating resuscitator (bag-valve-mask) with a 2-L reservoir bag (Mayo Healthcare, Mascot, NSW, Australia) and expiratory cap¹² connected to a heat moisture exchange filter and catheter mount. For the nonrebreather face mask, we used a standard adult nonrebreather mask with reservoir and safety vent (Mayo Healthcare).¹³ Adult straight-prong nasal cannulae (Mayo Healthcare)¹⁴ were used for all participants. For both bag-valve-mask and nonrebreather face mask, oxygen was delivered at 15 L/min. The adult nasal cannula oxygen flow rate was set at 10 L/min.

To create simulated mask leaks, we used 2 pieces of 4-cm-long nontapering portions of 16-French nasogastric tube (Medtronic, Minneapolis, MN). We inserted the pieces of nasogastric tube under both sides of the mask on the upper lip to create a standard disruption to the mask seal (Figure 2).

The subjects were placed supine with a pillow under their head for comfort. For each preoxygenation trial, the participant breathed normal tidal volume breaths for 3 minutes. The bag-valve-mask was manually held in place and participants were allowed to adjust their masks if they sensed a leak. At the end of the 3-minute period, they were asked to exhale a single breath into the end-tidal concentration of oxygen (ETO₂) measuring device.

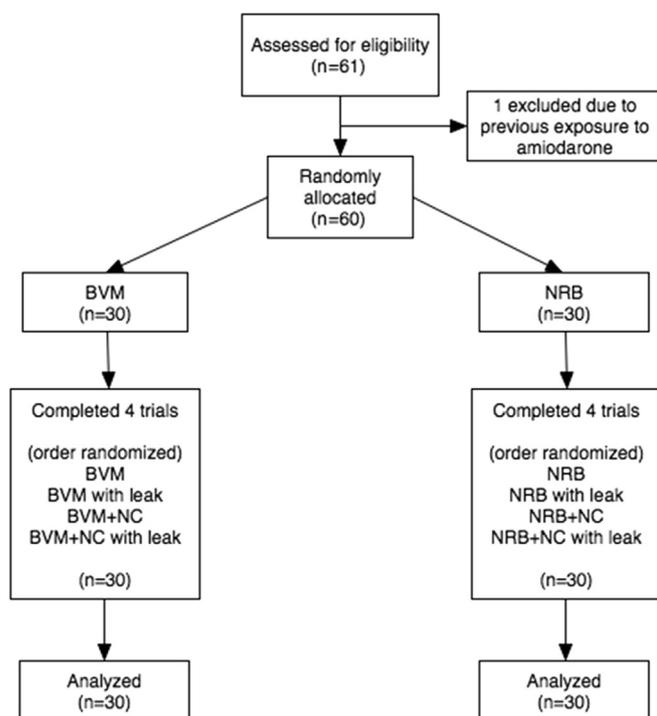


Figure 1. Consort diagram. BVM, Bag-valve-mask; NRB, nonrebreather bag; NC, nasal cannula.

Each trial was followed by a 2- to 3-minute washout period, with the subject breathing room air without the bag-valve-mask or nonrebreather face mask in place. To verify adequate oxygen washout, we measured ET_{O_2} ; if the ET_{O_2} remained 2% above baseline or greater, the rest period was extended in 1-minute increments until baseline ET_{O_2} was achieved.

Methods of Measurement and Outcome Measures

The primary outcome was ET_{O_2} concentration, measured at the end of each of the preoxygenation conditions (mask alone, mask+nasal cannula, mask alone+leak, mask+nasal cannula+leak).

In the operating theater, the adequacy of preoxygenation is measured routinely by continuous gas monitoring, giving the ET_{O_2} as a percentage approximating the alveolar concentration. Healthy adults can achieve ET_{O_2} 90% after 3 minutes of normal breathing through an anesthetic circuit with tight-fitting face mask.^{1,9,15,16}

The measurement of ET_{O_2} consisted of a simple exhalation device connected by standard gas sample line to a portable anesthetic monitor (Datex Omeda S5; GE Healthcare, Helsinki, Finland). This monitor had a standard paramagnetic oxygen analyzer that sampled gases through a gas sample line at a rate of 250 mL/min, measuring oxygen every 400 ms. The oxygen concentration was presented on the monitor as a continually updated waveform and digital display of the maximum current oxygen concentration.¹⁷

The oxygen analyzer had an accuracy of SD 2% and was calibrated by biomedical technicians before enrollment of the first participant and used exclusively by the researchers for the duration of the study.

The exhalation device was a single disposable flexible anesthesia circuit connector, to which we attached the gas sampling line. Participants were asked to remove the bag-valve-mask or nonrebreather face mask and, without breathing room air, seal their mouth around the device and exhale a single normal-effort 3- to 4-second breath. ET_{O_2} was recorded as the maximum value of the alveolar plateau observed on the monitor. During ET_{O_2} measurements, the preoxygenation devices were disconnected from the oxygen source to avoid contamination of the exhaled samples. Measurements were recorded by authors (C.H.-B. and M.M.).

Primary Data Analysis

Statistical analysis was performed with R statistical software (R Foundation for Statistical Computing).¹⁸ Significance tests were performed with a univariate type III repeated-measures ANOVA with ET_{O_2} as the dependant variable, preoxygenation trials as the within-subjects variable, and preoxygenation method as the between-subjects variable. Sphericity was examined with Mauchly's test, and if these were violated, Greenhouse-Geisser correction to P values was used. Planned post hoc comparisons were performed on the preoxygenation trials within the bag-valve-mask and nonrebreather face mask groups, and between bag-valve-mask and nonrebreather face mask for the same preoxygenation trial only (for example bag-valve-mask+nasal cannula and nonrebreather face mask+nasal cannula), using the R packages PHIA¹⁹ and multcomp.²⁰ Confidence intervals (CIs) for the differences in means within the bag-valve-mask and nonrebreather face mask groups were calculated with the method described by Loftus and Masson.²¹ A 2-sided $P=.05$ was considered significant, and Bonferroni correction to P values was used for the post hoc tests.

Two methods were used to calculate the sample size. A clinically significant difference of 5% in ET_{O_2} was chosen to equate to approximately an extra 30 seconds of safe apnea time ($[5\% \times 2,400 \text{ mL}] / \text{oxygen consumption at } 250 \text{ mL/min}$) in an 80-kg man.²² The sample size was calculated for each subgroup (bag-valve-mask and nonrebreather face mask). The pooled SD from previous studies was 0.068. The effect size (mean difference/SD) was calculated as 0.74. The above values were applied to a sample size calculation with Cohen's method,²³ with a power of 0.8 and significance of .05, and returned a sample size of 26. As a check, a second calculation was made for an independent 2-sample t test because this can

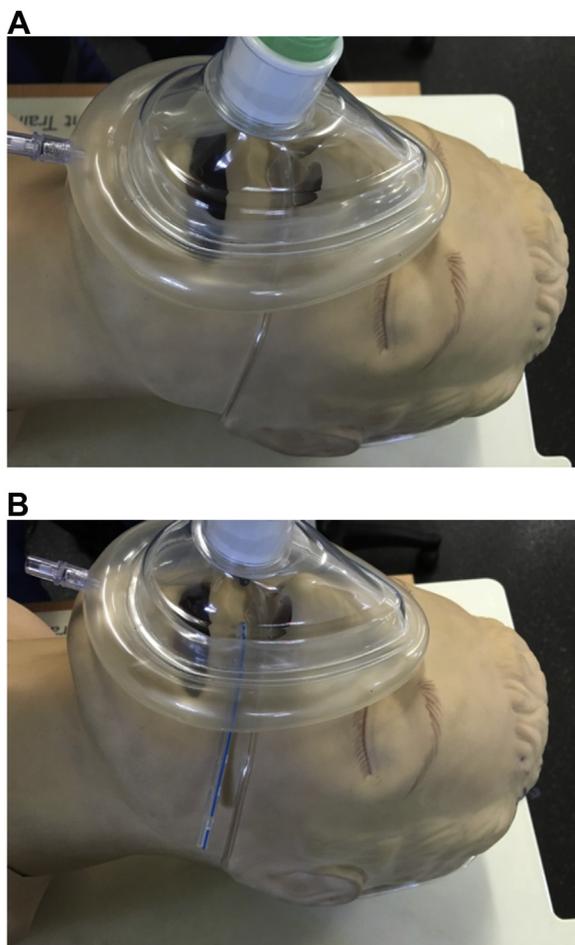


Figure 2. Experimental leak method. The face mask was manually held while applied to the face by a researcher to achieve best possible seal (A). The leak: A short piece of 16-French nasogastric tubing was placed between the face mask and upper lip, as on the manikin (B).

be used to calculate sample size for crossover study designs.²⁴ This returned a sample size of 30 in each subgroup, making a total required sample size of 60 participants.

RESULTS

Characteristics of Study Subjects

Sixty healthy volunteers were tested during a 2-month period, 30 in the bag-valve-mask group and 30 in the nonbreather face mask group (Figure 1). The bag-valve-mask and nonbreather face mask groups were similar in body mass index and sex ratio, but the bag-valve-mask group was younger (Table 1). All participants completed the study protocol (Figure 1).

Main Results

In the absence of a leak, the ET_{O_2} was similar for bag-valve-mask alone and bag-valve-mask+nasal cannula

Table 1. Subject demographics.

Demographics	Median (IQR)	
	BVM	NRB
n	30	30
Age, y	30 (5.5)	37.5 (12.75)
Sex, male	8	10
BMI	22.3 (4.5)	25.5 (6.1)

BMI, Body mass index.

(Table 2 and Figures 3 and 4). The presence of a mask leak reduced bag-valve-mask ET_{O_2} .

With the mask leak, supplemental nasal cannula improved bag-valve-mask ET_{O_2} , but not to levels of bag-valve-mask without a mask leak (Table 2 and Figures 3 and 4).

There was no difference in ET_{O_2} between nonbreather face mask with and without a leak. Supplemental nasal cannula increased ET_{O_2} both with and without a mask leak.

In comparisons of bag-valve-mask and nonbreather face mask, the bag-valve-mask alone resulted in higher ET_{O_2} values compared with nonbreather face mask alone (difference in mean ET_{O_2} 27%; 95% CI 23% to 31%); however, in the presence of a mask leak, ET_{O_2} was higher for nonbreather face mask than bag-valve-mask (difference in mean ET_{O_2} 7%; 95% CI 4% to 10%). In the presence of a mask leak, ET_{O_2} was similar for nonbreather face mask+nasal cannula and bag-valve-mask+nasal cannula (difference in mean ET_{O_2} 2%; 95% CI -1% to 5%).

LIMITATIONS

Although ET_{O_2} may be measured continuously by in-line sampling, we chose the single-breath method to avoid contamination by the continuous free flow of oxygen.

Table 2. Changes in exhaled ET_{O_2} (%) values in the absence and presence of a simulated leak and with the addition of supplemental high-flow nasal cannula oxygen.

Facemask	ET_{O_2} %, Mean (SD)		Difference in Means, NC vs No NC (95% CI)
	Mask	Mask + NC	
BVM	79 (14)	75 (8)	-3 (1 to -8)
BVM with leak	41 (7)	66 (8)	25 (21 to 29)
Difference in means (no leak vs leak) (95% CI)	-37 (-33 to -41)	-9 (-5 to -13)	
NRB	52 (8)	67 (12)	15 (12 to 18)
NRB with leak	48 (7)	65 (10)	17 (13 to 20)
Difference in means (no leak vs leak) (95% CI)	-3 (0 to -7)	-2 (2 to -5)	

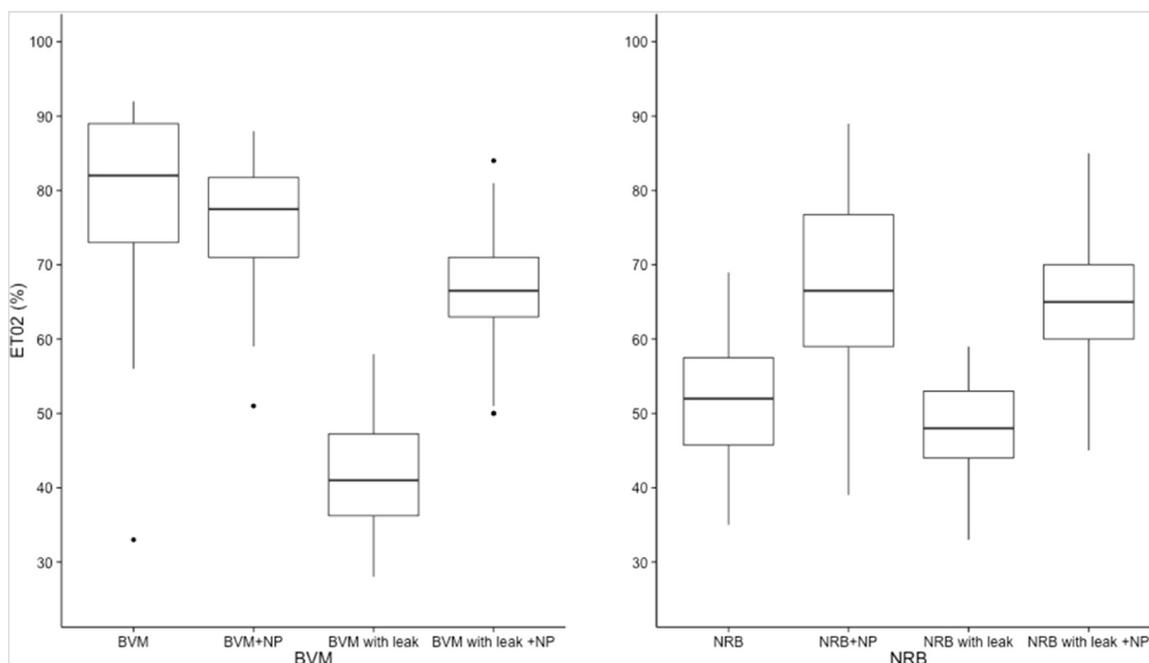


Figure 3. Box plots of ET_{O_2} (%) showing median and interquartile range achieved for each preoxygenation group with and without a mask leak. Whiskers represent the first and fourth quartiles, with dots representing outliers greater than $1.5 \times$ the IQR outside the first and fourth quartiles. Left figure shows 4 conditions tested with BVM; right figure shows 4 conditions with NRB. BVM, Bag-valve-mask with heat moisture exchange and connector with oxygen flow at 15 L/min, with good face mask seal; NP, nasal prong oxygen flow 10 L/min; NRB, nonrebreather bag with oxygen flow 15 L/min; with leak, leak created under face mask.

Although we created a standard mask leak to allow comparisons with other studies,²⁵ this approach may not reflect the range of mask leaks occurring in clinical patients. We used cooperative and healthy volunteers in our study; the results must be validated with clinical patients undergoing emergency airway management. Measuring ET_{O_2} concentration is common in anesthetic practice but is not widely available in the ED or the out-of-hospital setting.

The equipment chosen was that used by our out-of-hospital service (Greater Sydney Area Helicopter Emergency Medical Service, New South Wales Ambulance, Australia). Not all disposable equipment is equal in performance, however, particularly in terms of air entrainment and hence FiO_2 delivered during spontaneous inspiration through bag-valve-mask devices, and our results may not extrapolate to other institutions.

DISCUSSION

We sought to investigate whether the addition of high-flow nasal cannula oxygen would improve preoxygenation in emergency airway management. Our results suggest that although not aiding bag-valve-mask preoxygenation with a good mask seal, supplemental nasal cannula oxygen may be helpful in the presence of a bag-valve-mask mask leak.

Furthermore, we observed that supplemental nasal cannula oxygen is useful for nonrebreather face mask preoxygenation both with and without a mask leak.

Contrary to our expectations, adding nasal cannula oxygen to bag-valve-mask without a leak did not enhance ET_{O_2} . Two explanations are possible for this observation. Maximum preoxygenation may have been achieved by bag-valve-mask, precluding additional enhancement by nasal cannula. Alternatively, the nasal cannula may have created a small leak, mitigating the efficacy of the additional oxygen flow. We did not study the ET_{O_2} achieved by bag-valve-mask when nasal cannulae were present but not connected to oxygen, but would caution against such practice because we suspect the ET_{O_2} would decrease from the possible nasal cannula leak. We chose to use flow at 10 L/min through nasal cannula because this was shown to be superior to 5 L/min for apneic diffusion oxygenation during laryngoscopy.²⁶

The addition of nasal cannula oxygen to nonrebreather face mask improved preoxygenation in the presence and absence of a mask leak. This is likely due to the increase in oxygen flow delivered by the combination of the 2 devices. Weingart and Levitan²⁷ proposed that nonrebreather face mask used at high flow rates could provide adequate preoxygenation. Our study offers some of the first data to

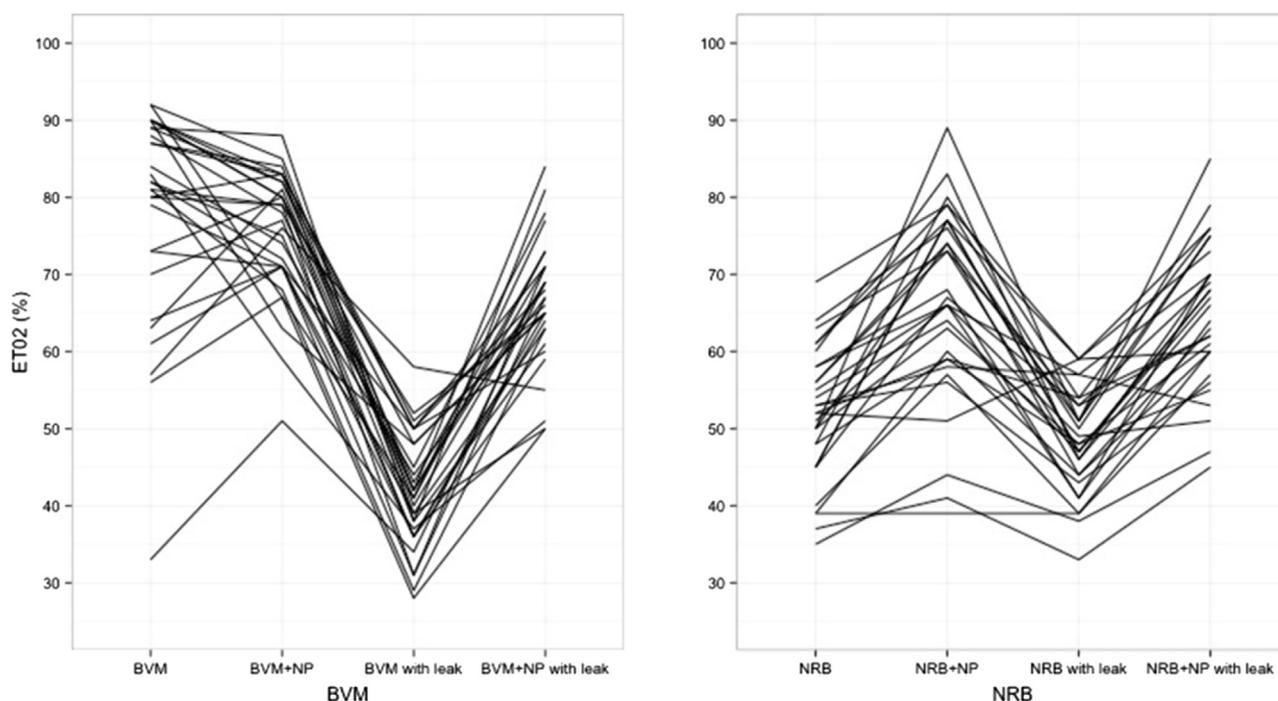


Figure 4. Line plots of ET_{O_2} (%) achieved for each participant in the different conditions. Left figure shows 4 conditions tested with BVM; right figure shows 4 conditions with NRB. BVM with heat moisture exchange and connector with oxygen flow (BVM) at 15 L/min with good face mask seal; nonrebreather bag with oxygen flow at 15 L/min (NRB); leak created under face mask (with leak); nasal prong oxygen flow at 10 L/min (NP).

validate this practice. Despite this improvement, ET_{O_2} with a nonrebreather face mask leak was lower than with a well-sealed bag-valve-mask. Thus, in clinical practice, in addition to augmenting nonrebreather face mask with nasal cannula, practitioners must consider the merits of switching to bag-valve-mask for preoxygenation.

Our findings are consistent with those of Russell et al,²⁵ who demonstrated that a face mask leak with anesthetic circuit preoxygenation could be overcome by nasal cannulae oxygen. Our results are particularly relevant to emergency airway management because, in the absence of ET_{O_2} monitoring, face mask leak and air entrainment reducing efficacy of preoxygenation may be difficult to detect. Although it is reported that mask leak might be detectable by physical assessment of mask fit, watching reservoir bag movement, or capnography tracing; these methods have never been formally assessed²⁸ and we observed that bag-valve-mask reservoir bag collapse still occurred with our created leak. Collapsible reservoir bags may not be used for all practitioners and settings.

In summary, although not aiding bag-valve-mask preoxygenation with a good mask seal, supplemental nasal cannula oxygen improved preoxygenation efficacy in the presence of a bag-valve-mask mask leak. It improved nonrebreather face mask preoxygenation both with and

without a mask leak, and it may be helpful for preoxygenation before emergency airway management.

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