Original article

Effect of oxygen injection sites on fraction of delivered oxygen (FDO_2) during noninvasive ventilation – An experimental lung model study

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Abstract

Introduction: The two-level noninvasive positive pressure ventilation (NPPV) is the most commonly used mode of ventilation in the treatment of early respiratory failure. During NPPV, the inspired oxygen fraction (FiO_2) could be influenced by various factors such as the inspiratory positive airway pressure (IPAP), the expiratory positive airway pressure (EPAP), the O_2 flow rate and the site where O_2 is added to the circuit. **Aim:** To investigate the effect of IPAP, EPAP, O_2 flow rate, leak and the O_2 injection sites on the fraction of delivered oxygen (FDO_2). **Methodology:** A lung model was constructed to simulate noninvasive ventilation with bilevel positive airway pressure (BiPAP) without leak and with 10% leak, the oxygen analyser was placed proximal to the ventilator to measure FDO_2 when oxygen was injected at three different sites. The portable BIPAP device was set to spontaneous/timed mode. Inspiratory and expiratory pressures of the BIPAP device were set at 10/5, 15/5, 15/10 and 20/10 cm H_2O. **Results:** This study revealed that there is a variation in the FDO_2 with a change in the position of connection of oxygen tubing, leak in the system and the oxygen flow rate. **Conclusion:** During NPPV, the FDO_2 varies significantly with O_2 flow rate and presence of leak. Higher O_2 flow rates and lower amounts of leak provide a higher FDO_2. Higher FDO_2 is achieved if the oxygen tubing is connected proximal to the patient whereas the effect of ventilator settings on FDO_2 is not significant.

Keywords: Delivered oxygen concentration, noninvasive ventilation, oxygen injection site.

Introduction

Noninvasive ventilation (NIV) has become the preferred mode of ventilation to treat acute respiratory failure due to exacerbation of chronic obstructive disease, acute cardiogenic pulmonary oedema and to wean patients from endotracheal intubation.[1-3] NIV support reduces work of breathing providing rest to the fatigued respiratory muscles, improves ventilation, reduces respiratory rate and dyspnoea, and improves arterial oxygenation.

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The two-level noninvasive positive pressure ventilation (NPPV) is the most commonly used mode of noninvasive respiratory support.[4-5] During NPPV, oxygen is often added to improve the inspired oxygen fraction (FiO_2) and patient's oxygenation. Oxygen supplementation during noninvasive ventilation is typically accomplished by adding a constant flow of oxygen into the ventilator circuit. A single-tube circuit is regularly used for NIV. In the leak port circuit, an intentional leak is integrated, into the circuit or the mask, to wash out CO_2.[16] The site of oxygen injection, leak at the interface, and the type of exhalation valve may impact the delivered oxygen concentration. Other factors influencing the FIO_2 include inspiratory positive airway pressure (IPAP), expiratory positive airway pressure (EPAP) and O_2 flow rate.[6-15]

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The aim of this study was to investigate the effect of parameters such as inspiratory positive airway pressure (IPAP), expiratory positive airway pressure (EPAP), oxygen flow rate and the effects of oxygen injection sites on the fraction of delivered oxygen (FDO_2). The effects were checked with and without creating leak on the lung simulator.

Methodology

A lung model (*Figure 1*) was constructed to allow simulated noninvasive ventilation with bilevel positive airway pressure (BiPAP). A lung simulator (Adult Demonstration lung model, INGMAR Medical, Pittsburg, USA), Bilevel positive airway pressure device (BIPAP) (ResMed,VPAP TM VPAP ST, S Australia) and a Galvanic fuel cell oxygen analyser (Oxiquant MC, Envite, Vadodara, India) 1.5 metre-long single limb circuit (Flexicare BIPAP breathing system), a standard O_2 flow meter and a humidifier (Fisher and Paykel, New Zealand) were used for the simulation purpose. A 2-point calibration of the O_2 analyser was done between each trial. Oxygen was injected at three different sites - proximal to the ventilator, at the humidifier outlet, proximal to the patient and FDO_2 was measured with oxygen analyser. The lung simulator with and without creating 10% of leaks in the system was simulated.

Figure 1: Experimental setup

Experimental setup

An oxygen flow meter was connected to a 50 psi wall oxygen source and oxygen was injected into the circuit at three different sites through an extension tube. The portable BIPAP device was set in the spontaneous/timed breathing mode. The inspiratory and expiratory pressures from the BIPAP device were set at 10/5, 15/5, 15/10 and 20/10 cm H_2O. The settings of the ventilator were as follows - Respiratory rate: 12 b/min, Inspiratory time: 1.6 sec. Trigger sensitivity was kept low. The FDO_2 under different simulated conditions with varying O_2 flow rates of 5, 10 and 15 L/min were measured. Each test was repeated thrice for each oxygen flow rate and the best of three was recorded for the analysis.

Results

There were 36 sets of final values. At an IPAP/EPAP of 10/5 cm H_2O with 5 L/min flow rate of oxygen, the FDO_2 was 34.9% when oxygen tubing connected to the ventilator end. When oxygen was connected to humidifier, FDO_2 reduced to 32% and when connected at the patient end, it was 31%. Generally the FDO_2 was highest when oxygen was connected at the ventilator end, if the system was without leaks but the difference ranged only between 2 - 4%. With leaks, the FDO_2 was highest when the oxygen was connected at the patient end than at the ventilator end with a difference of 3-4%. However, when oxygen flow rate was 15 L/min, and a 10% leak was introduced into the system, FDO_2 which was 48% at the ventilator end, decreased to 40% at the humidifier and increased to 57.5 % at the patient end. The effects of changing flow rates of oxygen, changing the site of connection of oxygen tubing and changing IPAP and EPAP, with and without leaks in the system are illustrated in *Figures 2-5*.

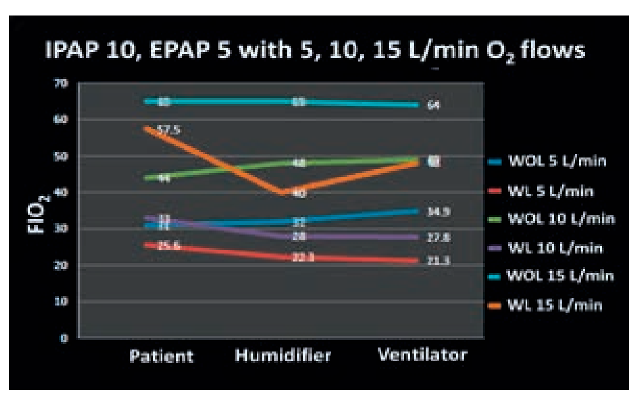

Figure 2: Effect of changing oxygen flow rates, when connected at different sites of the breathing system, with and without leak, when the IPAP/EPAP of 10/5 cm H_2O. WOL (without leak), WL (with leak).

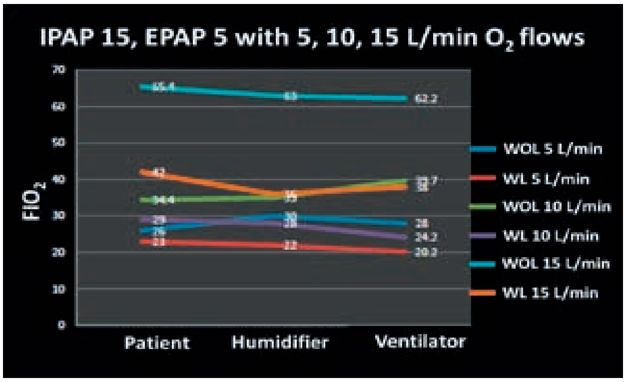

Figure 3: Effect of changing oxygen flow rates, when connected at different sites of the breathing system, with and without leak, when the IPAP/EPAP of 15/5 cm H_2O. WOL (without leak), WL (with leak).

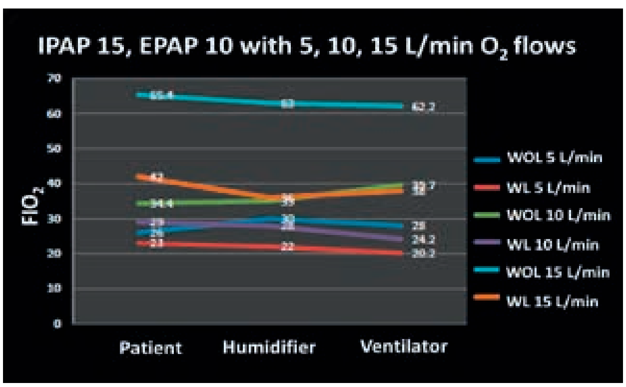

Figure 4: Effect of changing oxygen flow rates, when connected at different sites of the breathing system, with and without leak, when the IPAP/EPAP of 15/10 cm H_2O. WOL (without leak), WL (with leak).

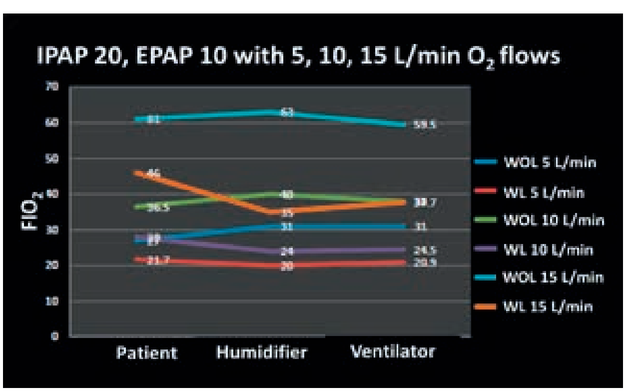

Figure 5: Effect of changing oxygen flow rates, when connected at different sites of the breathing system, with and without leak, when the IPAP/EPAP of 20/10 cm H_2O. WOL (without leak), WL (with leak).

Discussion

Noninvasive ventilation has gained popularity as it has been found to be effective in the treatment of early respiratory failure. It has been found to be useful in averting endotracheal intubation as well as preventing reintubation. Oxygen needs to be often supplemented in these patients. This study evaluated the effects of introducing oxygen at three different sites in the breathing system, with varying flow rates of oxygen and varying IPAP/EPAP settings. Each of these were again checked by introducing 10% leak into the system.

This study showed that there is a variation in the FDO_2 with a change in the position of connection of oxygen tubing. Predictably, the FDO_2 tends to be higher when there no leak in the system and when the oxygen flow rate is increased. However, when a leak is introduced, there is a fall in FDO_2 irrespective of the flow rate or ventilator settings. The extent of fall is higher with a higher flow rate. Similarly the FDO_2 is higher when the leak is at the patient end and least when the leak is at the humidifier.

A study by Thys *et al* compared various IPAP settings and conducted their experiments with the leak port in the circuit.[17] They studied three sites for connecting the oxygen tubing: at the outlet of the ventilator, at the inlet to the mask, and at a midpoint in the circuit. The oxygen concentrations delivered was lower with higher IPAP settings and higher when oxygen was added at the ventilator outlet than at the mask inlet. Schwartz *et al* found that the type of exhalation valve affected FiO_2. FiO_2 was greater when oxygen was added proximal to the ventilator with the leak port located in the mask, or when oxygen was added to the mask and the leak port was in the respiratory circuit.[18] A randomised crossover design by Miyoshi E demonstrated that the FiO_2 is dependent on the location of oxygen insertion and the presence of leak.[19]

In this study, it is also useful to note that the FDO_2 is nearly 0.21 (the patients are practically breathing room air) when the oxygen flow rate is 5 L/min when there is a 10% leak in the system, especially when the oxygen tubing is connected at the ventilator end, irrespective of the ventilator settings. There is a 5-10% decrease in FDO_2 when there a leak and the oxygen flow rate is set at 10 L/min. Similarly, there is a 15-20% decrease in FDO_2 when there a leak and the oxygen flow rate is set at 15 L/min. Thus the effect of leak is more when the FDO_2 is higher. The ventilator settings do not seem to have much influence on the FDO_2. The change in FDO_2 with the position of oxygen tubing is also not very significant (approximately 5%). The biggest effect on FDO_2 is produced by the presence of a leak, especially when the flow rates are higher.

Conclusion

During noninvasive ventilation, the inspired fraction of oxygen varies significantly with oxygen flow rate and presence of leak. Higher oxygen flow rates and lower amounts of leak provide a higher percentage of oxygen. The FDO_2 is higher if the oxygen tubing is connected closer to the patient whereas the effect of ventilator settings is not significant.

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