Evaluation of ‘tuskmask’ as an oxygen delivery system

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Abstract

Introduction: Conventionally either partial rebreathing mask or nonrebreathing mask can be used to deliver oxygen concentrations of up to 60%. A simple modification of the partial rebreathing mask using two pieces of respiratory tubing, or ‘tusks’ has been shown to deliver a high FIO₂. Aim: This study aimed to evaluate the efficiency of the ‘tuskmask’. Methods: This was a prospective study. Twenty patients of either gender, 18-70 years, ASA PS I or II and scheduled for elective surgery requiring arterial blood pressure monitoring intraoperatively were studied. On the day of surgery, in the operating room, after establishing standard monitoring, an intravenous access was secured. The radial artery was cannulated using a 20 G cannula and heparinised. A baseline arterial blood gas (ABG) sample was drawn on room air and three more samples taken after breathing oxygen through a 60% Venturi mask, polymask (10 L/min) or tuskmask (10 L/min) for ten minutes each with a ten minute washout period in between. The ABG samples were analysed at the end of study. Results: The mean age (SD) in years was 53.65 (17.10). There were 15 female and five male patients. The PaO₂ obtained with tuskmask was significantly higher with tuskmask compared to polymask and 60% Venturi mask but PaCO₂ was similar with all three masks. The mean (95% confidence interval) derived FIO₂ of tuskmask was 0.924 (0.872 to 0.97). Conclusion: The tuskmask when used with oxygen flow of 10 L/min, consistently delivers a very high concentration (FIO₂ ≥ 0.85) without causing rebreathing.

Keywords: Oxygen delivery system, oxygen mask, tuskmask

Introduction

Oxygen is used as therapy in most critically ill patients under intensive care. It can be life-saving in acute respiratory failure, yet can be lethal if incorrectly used. Oxygen therapy aims at increasing the alveolar oxygen tension (PAO₂) and thereby the arterial oxygen tension (PaO₂) and the oxygen saturation of arterial blood. Patients with hypoxaemic respiratory failure often require 100% oxygen to keep arterial oxygen tension (PaO₂) above 60 mm Hg. In these patients, delivering the highest inspired oxygen concentration (FIO₂) requires mechanical ventilation with positive airway pressure following endotracheal intubation.

In clinical situations where mechanical ventilation is not readily available, or declined by the patient, or one is expecting delay in endotracheal intubation, life-saving concentration of inspired oxygen can be delivered by face mask. Conventionally either partial rebreathing mask or nonrebreathing mask can be used to deliver oxygen concentrations of up to 60%. A simple modification of the partial rebreathing mask using two pieces of respiratory tubing, or ‘tusks’ has shown to deliver a high FIO₂. This modification results in a higher PaO₂ compared to nonrebreathing mask (NRM). The present study was done to evaluate the efficiency of the tuskmask.

Methods

This was a prospective study conducted at Medical College Hospital after obtaining institutional approval. Twenty patients of either gender, between 18-70 years of age, belonging to ASA
PS I or II and patients who were scheduled for elective surgery requiring arterial blood pressure monitoring intraoperatively were included in the study. Patients with cardiopulmonary disease and/or haemodynamic instability were excluded from the study. Informed consent was obtained from all the patients one day prior to surgery. Modified Allen’s test was performed on both hands to confirm the adequacy of ulnar collateral blood supply.

**Tuskmask:** A modification of the commonly used polymask resulted in the development of tuskmask (Figure 1). This consisted of two pieces of corrugated respiratory tubing, each inserted into one of the exhalation ports of the partial rebreathing mask (PRM). The tubings used in this study were both 15 cm long. The tubings did not require any attachment to stay in place. However, it is advisable to fix the tubings to the mask using adhesive plaster to prevent air leak. The efficacy of tuskmask was compared with commonly used oxygen therapy device such as polymask and Venturi mask.

![Figure 1: The ‘tuskmask’](image)

**Method:** On the day of surgery, the patient was shifted to the operating room. After establishing standard monitoring including pulse oximetry, noninvasive blood pressure and electrocardiogram, an intravenous access was secured. The radial artery was cannulated using a 20 G cannula. A 10 cm extension tubing was connected to this cannula and flushed with heparinized saline, locked with a three-way connector and fixed.

Oxygen administration was done using a Penlon AM 600 anaesthesia machine to deliver oxygen to the patient. An oxygen analyser was used to confirm delivery of 100% oxygen from the oxygen cylinder.

While the patient was breathing room air, 1 mL of blood was drawn from the arterial cannula in a 2 mL plastic polypropylene syringe which was earlier flushed with heparin sodium. This sample was labeled as Sample 1 and kept immediately in an ice-box.

The order of oxygen masks was randomised in all patients. The tubing of oxygen mask was connected to a Penlon AM 600 with continuous oxygen supply. The first oxygen mask was applied and an oxygen flow of 10 L/min was given if a polymask or tuskmask was used. An oxygen flow rate of 15 L/min was used if a 60% Venturi mask was in use. The flow rate of 15 L/min from the anaesthesia machine was confirmed using a Wright’s respirometer connected to the fresh gas outlet of the machine. An oxygen analyser was used to confirm the delivery of 60% oxygen from the Venturi device.

Each oxygen mask was applied for 10 min. At the end of 10 min, while the patient was still breathing oxygen through the first mask, an arterial blood gas sample was drawn and labeled as Sample 2. The oxygen mask was removed and a wash out period of 10 min was given. At the end of 10 min, the second mask was applied. After ten minutes of placing this mask, another arterial blood gas sample was drawn and labeled as Sample 3. The oxygen mask was removed and a wash out period of 10 min was given. The study was repeated with the third mask and Sample 4 was collected, after which the study concluded. Care was taken to avoid air bubbles in the syringe while collecting arterial blood samples. Each sample was kept in an ice-box immediately after collection.

At the end of the study, all four heparinised arterial blood samples were sent to clinical biochemistry laboratory for arterial blood gas analysis. The analyser used for blood gas analysis was CIBA Corning – 248 meter.

**Statistical analysis:** The primary response variable was the change in $\text{PaO}_2$ from baseline, measured...
in mm Hg. Comparison of two masks (tuskmask – Venturi mask and tuskmask – polymask) within each group was examined using paired Student’s t test.

**Results**

Twenty patients were studied and each patient had four arterial blood samples drawn, while breathing through each of the following masks: Room air, Polymask, Venturi mask and Tuskmask.

The mean age (SD) in years was 53.65 (17.10). There were 15 female patients and five male patients. All patients were having some type of malignancy. The $\text{PaO}_2$ and $\text{PaCO}_2$ obtained after breathing for 10 min through each of the four masks is given in Table 1.

**Table 1:** The $\text{PaO}_2$ (Mean ± SD) and $\text{PaCO}_2$ (Mean ± SD) obtained after breathing room air and through Polymask, Venturi mask and Tuskmask

<table>
<thead>
<tr>
<th></th>
<th>Room air</th>
<th>Polymask</th>
<th>60% Venturi</th>
<th>Tuskmask</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{PaO}_2$ (mm Hg)</td>
<td>100.78 ± 19.24</td>
<td>186.62 ± 55.89</td>
<td>233.69 ± 51.18</td>
<td>368.54 ± 64.11</td>
</tr>
<tr>
<td>$\text{PaCO}_2$ (mm Hg)</td>
<td>32.9 ± 4.13</td>
<td>33.03 ± 4.01</td>
<td>33.24 ± 4.51</td>
<td>33.62 ± 4.27</td>
</tr>
</tbody>
</table>

The mean difference in $\text{PaO}_2$ and $\text{PaCO}_2$ between tuskmask and 60% Venturi mask, and tuskmask and polymask is given in Table 2.

**Table 2:** Values of mean difference [(d) $\text{PaO}_2$, (d) $\text{PaCO}_2$], standard error of mean difference, p value and the statistical significance of intergroup comparisons of $\text{PaO}_2$ and $\text{PaCO}_2$

<table>
<thead>
<tr>
<th>Index</th>
<th>Tusk-Venturi</th>
<th>Tusk-Poly</th>
</tr>
</thead>
<tbody>
<tr>
<td>d $\text{PaO}_2$ (mm Hg)</td>
<td>Mean ± SE d +134.85 ± 10.23</td>
<td>+172.58 ± 9.55</td>
</tr>
<tr>
<td>P value</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>d $\text{PaCO}_2$ (mm Hg)</td>
<td>Mean ± SE d +0.68 ± 0.78</td>
<td>+0.89 ± 0.74</td>
</tr>
<tr>
<td>P value</td>
<td>&gt; 0.2</td>
<td>&gt; 0.2</td>
</tr>
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</table>

**Derivation of FIO$_2$ of tuskmask**

The FIO$_2$ of tuskmask was derived in each patient through the following steps using alveolar gas equation and assuming that arterial-to-alveolar oxygen tension ratio would be constant with changes in FIO$_2$.

1. Alveolar oxygen tension ($\text{PAO}_2$): This was calculated with measured values of 60% Venturi mask.

   $\text{PAO}_2 = \text{PIO}_2 - (\text{PaCO}_2 / \text{RQ})$ where RQ is the respiratory quotient.

   $\text{PAO}_2 = \text{FIO}_2 \times (\text{Pb} - \text{PiO},\text{O}) - \text{PaCO}_2 / \text{RQ}$

   $\text{PAO}_2 = 0.6 \times (760 - 47) - \text{PaCO}_2 / \text{RQ}$

   $\text{PAO}_2 = 427.8 - \text{PaCO}_2 / \text{RQ}$

   $\text{PaCO}_2$ of the first patient with 60% oxygen by Venturi mask was 26.2 mm Hg. By substituting $\text{PaCO}_2$ value in alveolar gas equation, the $\text{PAO}_2$ of the first patient was obtained.

   $\text{PAO}_2 = 427.8 - (26.2/0.8) = 395.05$ mm Hg

2. Derivation of a/A ratio

   $\text{PaO}_2$ with 60% Venturi mask for the first patient was 321 mm Hg

   Therefore, $a/A = 321/395.05 = 0.81$

3. $\text{PAO}_2$ of tuskmask

   Assuming $a/A$ ratio as a constant for that individual, $\text{PAO}_2$ of tuskmask was calculated.

   $a/A = 0.81$ ; Therefore, $A = a/0.81$

   $\text{PAO}_2$ of tuskmask = $\text{PaO}_2$ tuskmask / ($a/A$ ratio)

   $\text{PAO}_2$ of the same patient on tuskmask = 379.7 mm Hg

   $\text{PAO}_2 = 379.7$ mm Hg / 0.81 = 468.77 mm Hg

4. $\text{PIO}_2$ of tuskmask

   $\text{PAO}_2 = \text{PIO}_2 - (\text{PaCO}_2 / \text{RQ})$

   Therefore $\text{PIO}_2 = \text{PAO}_2 / (\text{PaCO}_2 / \text{RQ})$

   The $\text{PaCO}_2$ values with tuskmask were available from the arterial blood gas analysis. By substituting $\text{PaCO}_2$ of first patient, i.e., 29.7 mm Hg and $\text{PAO}_2$ of tusk for first patient:

   $\text{PIO}_2 = 468.77 + (29.7 / 0.8) = 505.89$ mm Hg

5. $\text{FIO}_2$ of tuskmask

   $\text{FIO}_2 = \text{FIO}_2 \times (\text{Pb} - \text{PiO},\text{O}) = \text{FIO}_2 \times 713$

   Therefore $\text{FIO}_2 = \text{PIO}_2 / 713 = 505.89/713 = 0.71$

   The $\text{FIO}_2$ of tuskmask was derived similarly for all twenty patients and the mean values are shown in Table 3.
Table 3: Derived \( \text{FiO}_2 \) of tuskmask

<p>| | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.924</td>
</tr>
<tr>
<td>SD</td>
<td>0.111</td>
</tr>
<tr>
<td>SEM</td>
<td>0.025</td>
</tr>
<tr>
<td>Mean ± 2.09 SEM (95% Confidence Interval)</td>
<td>0.924±0.071 = 0.872 to 0.976</td>
</tr>
<tr>
<td>Mean ± 2.8609 SEM (99% Confidence Interval)</td>
<td>0.924±0.071 = 0.853 to 0.995</td>
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</table>

It was found that the tuskmask with a flow rate of 10 L/min consistently delivers a very high \( \text{FiO}_2 \geq 0.85 \).

\( \text{FiO}_2 \) of polymask with a flow of 10 L/min was also calculated using the alveolar gas equation, which was found to be having a mean value of 0.51.

After deriving the \( \text{FiO}_2 \) of tuskmask and polymask, the partial pressure of oxygen in inspired air (\( \text{PIO}_2 \)) and partial pressure of oxygen in the alveolus (\( \text{PAO}_2 \)) of both masks were calculated and oxygen cascade consisting of the initial two steps was constructed. This was compared with the values of 100% oxygen, 60% Venturi mask and room air (Figure 2).

Discussion

In patients with hypoxaemic respiratory failure, delivering the highest \( \text{FiO}_2 \) requires mechanical ventilation with positive airway pressure following endotracheal intubation. However, clinical situations are encountered wherein endotracheal intubation, positive airway pressure and mechanical ventilation are either not readily available or have been declined by the patient. Under these circumstances, hypoxaemic patients with ventilation perfusion mismatch or diffusion defects can derive life-saving benefit from high concentrations of inspired oxygen delivered by face mask.

An ideal oxygen delivery system should deliver any desired inspired oxygen concentration (\( \text{FiO}_2 \)) under all clinical conditions. It should be comfortable enough for patients to tolerate for prolonged periods. It should be cheap and simple to use. Oxygen systems are judged according to both the \( \text{FiO}_2 \) they deliver and the stability of this \( \text{FiO}_2 \) under changing patient demands. Using these criteria, oxygen delivery systems are classified into variable performance or fixed performance systems. An ideal oxygen delivery system should deliver any desired inspired oxygen concentration (\( \text{FiO}_2 \)) under all clinical conditions.

Nonrebreathing masks (NRM), with high oxygen flow rates can deliver high \( \text{FiO}_2 \). The NRM has a reservoir bag which is kept filled with high oxygen flow. There is a valve between the reservoir bag and the mask which allows one-way gas flow from this bag. Air is exhaled through one-way valves at the side of the mask.

In a study conducted by Farias and colleagues, they postulated that the one-way valve between the reservoir bag and the NRM caused a high resistance resulting in preferential entrainment of room air from both the expiratory orifices and around the sides of the mask, thereby resulting in lower \( \text{FiO}_2 \) concentration. In their study, the resistance of nonrebreathing valve was found to be greater than the exhalation valve at every rate of oxygen flow tested.

Venturi masks deliver a fixed \( \text{FiO}_2 \) depending on the oxygen flow as well as the amount of air entrained. The \( \text{FiO}_2 \) delivered by a Venturi system is fixed as it delivers a total flow rate equal to the patient’s inspiratory flow rate. These masks must also have large volumes (300 mL or more) to ensure fixed performance.
The partial rebreathing mask (PRM) differs from the NRM in that there are no one-way valves between the reservoir bag and mask or at the two exhalation ports. The PRM system theoretically delivers a lower FIO₂ than the NRM because room air is entrained through the open ports and mixes with inspired oxygen, lowering inspired oxygen content. The FIO₂ also depends on the patient’s respiratory rate and breathing pattern. The patient’s peak inspiratory flow during tidal breathing can be estimated using the following formula:5

\[
\text{Peak inspiratory flow} = \pi V_T / 2 T_i.
\]

Lower FIO₂ can be expected if the patient is tachypnoeic, with a short expiratory pause, as it is in this phase that the reservoir fills with oxygen for the next breath. As expected, reducing the entrainment of room air through the ports shielding them (resembling an NRM system), increases oxygen delivery by the PRM system.

Chechani et al, found that with a few simple modifications, an aerosol mask can be used to deliver higher concentrations of oxygen approximating 100%, and improve oxygenation in patients still hypoxaemic on NRM.2 In this study, three oxygen flowmeters were connected to the mask by using three tubings and they used a total flow of 80 L/min. Two 30 cm pieces were cut from an aerosol tube (with an internal diameter of 2.5 cm) and inserted into the holes of the aerosol mask. The 30 cm tubings served as reservoir of 100% oxygen. Such high flows were deemed necessary for rapid replacement of expired air with oxygen in the 30 cm aerosol tubes before the commencement of next inspiration.

In all individuals, a higher PaO₂ was attained with the modified aerosol mask than with the NRM. Besides improving oxygenation, this mask also permits humidification of the inspired air, administration of aerosolized bronchodilators, oropharyngeal suctioning and performance of bronchoscopy without interrupting delivery of high concentrations of oxygen. The two 2.5 cm diameter, 30 cm long aerosol tubes connected to the mask provide a low resistance escape route for the incoming air. Thus, high flows in the modified aerosol mask did not create a continuous positive airway pressure effect. They concluded that the improvement in oxygenation was due to the reservoir capacity of aerosol tubes. They could not explain the widening of alveolar-arterial oxygen gradient while breathing 100% oxygen and the study used high flow oxygen with a complicated setup.

Another type of modification resulted in the development of tuskmask.6 This consists of two 20 cm pieces of corrugated respiratory tubing, each inserted into one of the exhalation ports of the PRM. This simple modification resulted in a higher inspired oxygen concentration than the NRM. The study conducted by Farias and colleagues demonstrated that a simple tuskmask system could deliver a higher FIO₂ than the NRM at flow rates of 20 and 30 L/min.1

In the tuskmask, because of the absence of one-way valve, the room air entrained is less. Also any air entrained from the tusks is enriched with oxygen. High continuous oxygen flow results in washing out of expired carbon dioxide which results in no rebreathing.

In the present study, the tuskmask was made by connecting two 15 cm, corrugated respiratory tubing into the exhalation ports of PRM. The volume of the tubings was measured and was 150 mL. We used an oxygen flow rate of 10 L/min where as Hnatiuk et al used a flow of 15 L/min in their study.6

We compared the efficacy of tuskmask with commonly used oxygen therapy device such as polymask and a fixed performance device which is known to deliver 60% oxygen (60% Venturi mask). Even with an oxygen flow of 15 L/min, the PIO₂ of Venturi mask was significantly lower than PIO₂ of tuskmask.

With the same flow of oxygen, i.e., 10 L/min, we analysed PaO₂ of three patients by using anaesthesia circuit with a nonrebreathing valve. The PaO₂ values were comparable to PaO₂ of tuskmask in the same patients.
Derivation of FIO$_2$ of tuskmask and its clinical implications: We derived the FIO$_2$ of tuskmask using simple alveolar gas equation and the a/A ratio. The mean FIO$_2$ was 0.924. The simple, easily made modification of partial rebreathing mask, which delivers high FIO$_2$ can be used as an alternative first line therapy in patients with hypoxaemia.

Conclusions
The tuskmask (a simple, easily made, inexpensive modification of the partial rebreathing mask commonly used for oxygen therapy in the emergency room, and recovery and intensive care unit areas) when used with an oxygen flow of 10 L/min, consistently delivers a very high concentration (FIO$_2$ $\geq$ 0.85) without causing rebreathing. The tuskmask provides a simple, lightweight, portable oxygen therapy system in the critically ill patient who is undergoing initial evaluation, or is being readied for tracheal intubation.

Acknowledgement
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References
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