Oxygen insufflation via the C-MAC® video stylet increased the fraction of inspired oxygen during intubation in general anesthesia: a bench study

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Research Article

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Abstract

Purpose

The C-MAC® video stylet provides optimal visualization and controlled intubation, and oxygen insufflation via the endotracheal tube (ETT) holder oxygen port shortens the apnea period. However, oral saliva and mucus can block the visual field, hindering intubation and prolonging the apnea period. We assessed the fraction of inspired oxygen (FiO₂) under different oxygen flows via the ETT holder port, visibility through the bevel, and factors influencing the FiO₂, including the ETT internal diameter (ID), breathing pattern, and nasal cannula use.

Methods

Artificial oral mucus was spread on the bevel to mimic a visual field barrier during intubation. Different oxygen flows (1-15 L/min) were provided via ETTs with two different IDs (6.5 and 8.0 mm) to break the mucus barrier, and the ratio of visible area was calculated. The FiO₂ was measured at the carina level in 3-min intubating periods, with and without simultaneous nasal cannula use at 3 L/min. Two different breathing patterns were simulated, apnea and shallow breathing.

Results

Oxygen flow (>6 L/min with 6.5-mm or >9 L/min with 8-mm ETT) could break the mucus barrier and provide a visible area of 66-82% within 1 s. Higher oxygen flow, longer oxygen insufflation, larger-ID ETT during apnea, lower-ID ETT during shallow breathing, and simultaneous nasal cannula use provided a significantly higher FiO₂.

Conclusion

Oxygenation via the C-MAC® video stylet improved the visual field and increased the FiO₂ during intubation, and can be used with or without a nasal cannula for safer intubation.

Introduction

The C-MAC® video stylet (Karl-Storz SE & Co. KG, Tuttlingen, Germany) is a hybrid of a flexible and rigid intubation endoscope providing a first-attempt success rate of 80% [1]. The video stylet provides faster intubation than that with a flexible optic bronchoscope [2], and due to its articulating function, higher intubation success rates than those with intubation stylets [3]. However, the oral secretion obstructing the bevel of the endotracheal tube (ETT) remains a main challenge to the visibility of the vocal cords [2, 4]. Massive oral secretion makes the recognition of anatomical structures, such as the epiglottis and glottis, more difficult [5]. In addition, more intubation attempts will stimulate the pharynx and lead to increased oral secretion, further lowering the rate of successful intubation and prolonging the apnea period.

The video stylet has an oxygen port at the ETT holder that enables a function of oxygen insufflation, which may help delay the occurrence of hypoxia and desaturation during intubation, particularly in patients with
difficult airway, high risk of desaturation, or emergency situations. In difficult airway management, awake tracheal intubation with spontaneous breathing is favorable over intubation during apnea [6]. Nasal cannula use can prevent hypoxia before and during intubation, extending the safe apnea period and improving first-attempt success rates [7]. The nasal cannula could be used simultaneously with this device during intubation for oxygenation during apnea [8].

We hypothesized that additional oxygen flow via the oxygen port of the video stylet could increase the fraction of inspired oxygen (FiO₂) and provide better visibility by removing secretions from the ETT bevel, and that combined use of the video stylet with a nasal cannula could provide a higher FiO₂. Therefore, in this bench study, we evaluated the FiO₂ under different oxygen flow rates via the ETT holder port and the visibility through the bevel as primary endpoints. In addition, as a secondary endpoint, we investigated the factors influencing the effectiveness of oxygen supplementation, including the ETT internal diameter (ID), breathing pattern, and nasal cannula use.

Materials And Methods

Simulated adult respiratory system

The test lungs (Vent Aid TTL; Michigan Instruments, Grand Rapids, MI, USA) comprise two independent bellows, driving and passive. The driving bellow was linked to the passive bellow with a rigid metal clip, and connected to a Dräger Primus ventilator, while the passive bellow was connected to the manikin's trachea (AirSim Advance X), which simulated the anatomy of adult airways (Fig. 1). The ventilator was set to manual or volume-controlled mode (tidal volume, 200 mL; respiratory rate, 24 breaths/min) to mimic apnea or shallow breathing patterns, respectively. The driving bellow expanded when the ventilator delivered a tidal volume, and the rigid metal clip pulled the passive bellow, thus simulating the inspiratory phase of breathing. During the expiratory phase, the driving bellow flattened and the passive bellow followed due to the linkage by the metal clip. Compliance of the test lungs was set at 200 mL/cmH₂O, and the inspiration/expiration ratio at 1:2.

Oxygenation assessment

The oxygen port on the ETT holder of the C-MAC® video stylet was connected with an oxygen tube (7FT 84" Taiwan 000329) to an oxygen supply rotameter (NM3, Philips, UK) of an oxygen cylinder Type E for providing oxygen flow. The oxygen flow rates were set at 1−15 L/min. ETTs with two different IDs were used: 6.5 and 8.0 mm. The ETT bevel was kept at uvula level for 180 s (Fig. 2), simulating the situation of difficult intubation and invisible epiglottis and vocal cords.

Oxygen concentration during the 3-min intubating period was measured by the ventilator, which was calibrated before each test. The oxygen concentration at carina level was regarded as the FiO₂, and was measured under two different breathing patterns, apnea and shallow breathing, and with or without nasal cannula use (3 L/min). After completing each experiment, the model was filled with room air gas using the ventilator until the FiO₂ reached 0.21.

Visibility assessment
Artificial oral mucus was prepared by mixing artificial saliva (Pickering Laboratories Inc., Mountain View, CA, USA; 1700−0305) and glue (Elmer’s, E3056, Washable Clear; Newell Rubbermaid, Atlanta, GA, USA) in a 1:1 ratio. Air was injected using a 5-mL syringe (10 injections for each test) to create bubbles. The artificial oral mucus was applied to the ETT bevel to mimic a visual field barrier during intubation. Different oxygen flow rates (1−15 L/min) were used to break the mucus barrier. We recorded the time to barrier break and calculated the ratio of visible area using image processing software (ImageJ) [9].

**Statistical analysis**

Two-way analysis of variance was used to determine whether different ETT IDs (6.5 or 8.0 mm) and oxygen flow rates (1−15 L/min) affected the size of the visible area. A total of 54 data were collected. The null hypothesis of no interaction was rejected when $p<0.05$.

The effectiveness of oxygen supplementation with the video stylet was plotted and analyzed using the polynomial regression model to explore the influence of the oxygen flow rate, ETT ID, and length of oxygenation on the $\text{FiO}_2$ at carina level. A total of 3,552 (1,776×2) data were collected. The paired t-test was used to compare the $\text{FiO}_2$ with or without simultaneous nasal cannula use. Statistical significance was set at $p<0.05$. Statistical analysis was performed using R programming language (Posit Software, PBC, Boston, MA, USA).

**Results**

Oxygen flow at a rate of at least 6 L/min with a 6.5-mm ETT or 9 L/min with an 8-mm ETT could break the mucus barrier and provide a visible area of 66−82% within 1 s (Fig. 3). The two-way analysis of variance also showed that different ETT IDs ($p<0.005$) and oxygen flow rates ($p<0.001$) had a significant effect on the size of the visible area.

Figure 4 shows the relationship of the $\text{FiO}_2$ with the length of oxygenation, ETT ID, and oxygen flow rate. The formula according to the polynomial regression model (Table 1) is as below:

$$
\text{FiO}_{2\text{apnea}} = -52.32 + 0.88\text{Flow} + 1.19\text{ID}_{\text{ETT}} - 1.22\text{Time} + 31.17\sqrt{\text{Time}} - 12.48\log (\text{Time})
$$

$$
\text{FiO}_{2\text{breath}} = 10.68 + 1.7\text{Flow} - 0.93\text{ID}_{\text{ETT}} - 0.46\text{Time} + 10.61\sqrt{\text{Time}} - 0.99\log (\text{Time})
$$
Table 1
Polynomial regression model of the correlation between the fraction of inspired oxygen and the oxygen flow rate, endotracheal tube internal diameter, and length of oxygenation

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Apnea</th>
<th>Shallow breathing</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>-52.32</td>
<td>10.68</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Flow</td>
<td>0.88</td>
<td>1.70</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>ID</td>
<td>1.19</td>
<td>-0.93</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Time (s)</td>
<td>-1.22</td>
<td>-0.46</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>√Time</td>
<td>31.17</td>
<td>10.61</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Log (Time)</td>
<td>12.48</td>
<td>-0.99</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Observation</td>
<td>1,776</td>
<td>1,776</td>
<td></td>
</tr>
<tr>
<td>R²/R² adjusted</td>
<td>0.926/0.926</td>
<td>0.644/0.643</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: FiO₂, fraction of inspired oxygen; ID, internal diameter; CI, confidence interval.

The polynomial regression model revealed that higher oxygen flow rates provided higher FiO₂, both during apnea (estimated coefficient, 0.88; 95% confidence interval [CI], 0.8–0.95; p<0.001) and shallow breathing (estimated coefficient, 1.70; 95% CI, 1.59–1.81; p<0.001). However, the ETT ID exhibited a positive correlation with the FiO₂ during apnea (estimated coefficient, 1.19; 95% CI, 0.73–1.65; p<0.001), and a negative correlation during shallow breathing (estimated coefficient, -0.93; 95% CI, -1.57 to -0.29; p=0.005). The FiO₂ at carina level also had a significant polynomial correlation with the length of oxygenation (p<0.05).

The effect of combined nasal cannula use is shown in Fig. 5. The paired t-test showed that the FiO₂ with nasal cannula use was significantly higher than that without nasal cannula use. Simultaneous nasal cannula use increased the FiO₂ by 1.5% during apnea (95% CI, -1.307 to -1.710; p<0.001) and by 2.62% during shallow breathing (95% CI, -2.018 to -3.224; p<0.001).

**Discussion**

This study showed that oxygen insufflation via the ETT holder port of the video stylet increased the FiO₂ and improved the visibility through the bevel. Furthermore, the FiO₂ was higher with larger-ID ETT during apnea and with lower-ID ETT during shallow breathing. In addition, simultaneous nasal cannula use significantly increased the FiO₂ during difficult intubation.

The intubating process is often hindered by decreased visualization due to oral secretions, such as saliva, mucus, or sputum. In our study, oxygen insufflation through the video stylet could break the oral secretion
membrane and provide a visible area of 66–82% within 1 s. Thus, oxygen flow at a rate of at least 6–8 L/min via the port can optimize the visual field during intubation, enabling the operator of the video stylet to recognize the airway anatomy.

In the experiment for assessing the effect of oxygen insufflation on the visual field during intubation, we used ETTs with two different IDs, and the ratio of visible area was larger with the smaller ETT. Namely, with the 6.5-mm ETT, 6 L/min of oxygen could break the mucus barrier, while 9 L/min were needed with the 8.0-mm ETT. However, with both ETT IDs, the barrier broke in less than 1 s, suggesting the benefit of oxygen insufflation via the ETT holder port for improving visualization in difficult intubation.

According to the continuity equation for gases in pipes \((A_1V_1 = A_2V_2)\) [10] and Newton’s second law \((F = ma)\), the relationship between the force of the oxygen flow in the ETT and the ETT ID can be expressed as follows:

\[
F_{\text{oxygen}} \propto \frac{m_{\text{mucus}}}{ID_{\text{ETT}}^2}
\]

where \(F_{\text{oxygen}}\) represents the force of the oxygen flow and \(m_{\text{mucus}}\) represents the mass of the mucus membrane (kg). Based on the formula for surface tension and Laplace’s law for spherical membranes,

\[
F_{\text{surface}} \propto ID_{\text{ETT}}
\]

where \(F_{\text{surface}}\) represents the force of the surface tension and \(ID_{\text{ETT}}\) represents the ETT ID, under the same oxygen flow, the surface tension force would be lower at the smaller bevel area, allowing the membrane to break more easily. Another possible explanation is that the oxygen flow in the ETT with a smaller ID exerted greater pressure on the membrane, breaking more bubbles, and the remaining bubbles gathered and covered a smaller area. As the 6.5-mm ETT has a smaller bevel area, the mucus membrane broke faster under a lower oxygen flow rate, providing a larger visual field.

In our study, longer oxygen insufflation resulted in higher oxygen concentrations. During apnea, the \(\text{FiO}_2\) at carina level started to increase 10–25 s after intubation, and reached a plateau with an \(\text{FiO}_2\) of up to 99% after 120 s. During shallow breathing, the \(\text{FiO}_2\) increased within 5 s due to gas mixture between the areas above and below the carina, reaching 50–80% depending on the oxygen flow rate. The anatomical structures below the carina include the bronchi and alveoli, where the main gas exchange takes place. This is significant because in patients in whom difficult intubation is predicted, spontaneous breathing is preserved, with limited induction drug administrated, resulting in shallow breathing.

Furthermore, the 8.0-mm ETT provided a higher \(\text{FiO}_2\) at carina level than the 6.5-mm ETT during apnea. This may suggest that a larger-size ETT used with the video stylet is able to supply more oxygen in the intubation process. However, during shallow breathing, the \(\text{FiO}_2\) at carina level was higher with the 6.5-mm than with the 8.0-mm ETT. The possible explanation for this finding is that larger ETTs have a greater inner volume, resulting in slower velocity of the oxygen flow and greater oxygen retention, leading to poor gas mixing and lower \(\text{FiO}_2\) at carina level. In the apnea model, because of the low speed and insufficient kinetic energy, the oxygen molecules could not be pushed below the carina and accumulated at this level, resulting in a higher oxygen concentration measured at the carina. Conversely, in the shallow breathing model, the oxygen
concentration at the carina was the result of partial mixing between the air in the airways and the insufflated oxygen. Several prior studies have investigated the relationship between ETT size and oxygenation during intubation. A similar study with a self-designed oxygen delivery device combined with the Trachway® video stylet showed opposite results; the FiO₂ was higher when oxygen was supplied via a smaller ETT during apnea [11]. However, a larger ETT diameter relative to the bronchoscope diameter has been associated with a higher probability of impingement, leading to difficult or failed intubation [12]. A prospective observational study also showed that a larger ETT size was associated with a longer intubation duration [13]. Thus, further studies are required to evaluate the efficacy of C-MAC® video stylet intubation with larger-sized ETTs.

 Appropriately sized ETTs play an important role during anesthesia. In the past, the largest tube that the larynx could comfortably accommodate was recommended [14]. Recently, using the smallest tube that permits safe conduct of anesthesia was considered. Cao et al. conducted a retrospective cohort study that provided compelling evidence that height alone is a good estimation of tracheal morphology and appropriate ETT size [15]. Smaller ETTs have little impact on the ventilator pressures, reducing larynx injury and postoperative patient discomfort, such as hoarseness or sore throat, and making intubation easier [16, 17]. However, too small ETTs may be more dangerous in patients with high secretion loads and airflow limitation [17].

Preoxygenation before tracheal intubation slows the progression of desaturation during apnea. The benefit is greater if preoxygenation is prolonged and apnea time is shortened, particularly in high-risk patients, such as older adults, children, patients with pulmonary complications, and pregnant women [18]. Apneic diffusion oxygenation is an effective maneuver for prolonging the safe duration of apnea; however, Fraioli et al. [19] demonstrated that patients with a low predicted functional residual capacity/body weight ratio (37 ± 9 mL/kg) could not tolerate apneic oxygenation for more than 5 min. The C-MAC® video stylet provides another continuous oxygenation method even in ongoing intubation, prolonging the oxygenation time and thereby increasing safety.

A review article identified 14 studies that pointed toward the benefits of using a nasal cannula during emergency intubation, and concluded that apneic oxygenation using a nasal cannula prevents desaturation during endotracheal intubation [5]. In our study, combined use of a nasal cannula and our oxygen insufflation device provided a higher FiO₂ than the oxygen insufflation device alone, suggesting a greater benefit in reducing the hypoxia time and increasing the safety of intubation. In addition to the nasal cannula, the efficacy of other supplemental devices that can be simultaneously used during intubation should be further investigated, such as the high-flow nasal cannula (HFNC), bite block, or nasal mask [20]. During flexible bronchoscopy, the HFNC could improve oxygen saturation and decrease the rate of desaturation episodes in patients with mild to moderate acute respiratory failure [21]. Hence, the HFNC may be an oxygenation strategy that provides more safety during intubation.

Previous studies of the C-MAC® video stylet have not evaluated its efficacy of oxygen insufflation, which is the strength of the present study. Nonetheless, there are several limitations to this study. First, because this was a bench study, there was no difference in the composition of the artificial mucus and the number of bubbles between the experiments. However, in the real world, individual differences exist. The physiological structure and degree of dehydration differs across individuals, resulting in differences in saliva adhesion and surface tension. If the saliva the patients produce is thick, there may be more bubbles, resulting in a smaller
visible area, and vice versa. Second, the oxygen concentration at carina level is not equal to the alveolar FiO2. The mucosa and distribution of capillaries make the humidity and temperature in vivo different than that in the artificial test lungs. Finally, when the nostrils are obstructed, the oxygen supply through a nasal cannula will be limited. Use of a nasal airway may help overcome this difficulty. Moreover, because the nasal cannula flow we used was only 3 L/min, the increase in FiO2 was only 1.50–2.62%, which may limit the clinical benefit. However, in a previous bench study, the tidal volume and oxygen flow rate had a substantial impact on the FiO2 [5]. Therefore, it can be expected that a higher nasal cannula flow would result in more effective oxygenation.

In conclusion, this bench study demonstrated that oxygen insufflation through the ETT holder of the C-MAC® video stylet provided better visual field and higher FiO2 during intubation, increasing the safety of the procedure. Oxygenation improved with higher oxygen flow rates, longer insufflation time, and combined use with a nasal cannula. Furthermore, a higher FiO2 could be provided with larger ETTs during apnea and with smaller ETTs during shallow breathing.

Declarations

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Ethics approval: Not applicable.

Consent to participate: Not applicable.

Consent to publish: Not applicable.

References


Figures
Figure 1

Simulation of the breathing circuit during intubation with the C-MAC® video stylet. Oxygen flow was provided via the port on the endotracheal tube holder, with or without nasal cannula use.

(a) (b) (c)

Figure 2

Endoscopic images through the bevel of the endotracheal tube. The bevel was located at the uvula level (a), and images were obtained before (b) and after (c) the artificial oral mucus barrier was broken by the oxygen
Figure 3

Boxplot of the relationship of the ratio of visible area with the oxygen flow rate and endotracheal tube internal diameter.
Figure 4

Fraction of inspired oxygen at carina level during apnea (a) and shallow breathing (b) according to different oxygen flow rates, oxygenation length, and endotracheal tube internal diameter. \( \text{FiO}_2 \), fraction of inspired oxygen.
Figure 5

Comparison of the fraction of inspired oxygen according to the simultaneous use of a nasal cannula during apnea and shallow breathing. FiO₂, fraction of inspired oxygen; CI, confidence interval.