Southmedic OxyMask™ compared with the Hudson RCI® Non-Rebreather Mask™: Safety and performance comparison

Keith Lamb RRT-ACCS, David Piper PE

BACKGROUND: The non-rebreather mask (NRBM) is used for many applications and in many patient care scenarios in which hypoxemia and resultant hypoxia are a concern. The NRBM is a low-flow oxygen delivery system that is easily deployed and capable of delivering a relatively high fraction of inspired oxygen (FiO₂). The potential for ineffective carbon dioxide (CO₂) removal at low flow rates is a safety concern.

OBJECTIVE: The authors hypothesized that the use of an OxyMask (Southmedic Inc, Canada) would mitigate these safety concerns while still delivering a relatively high FiO₂.

METHODS: Bench studies were performed in a third-party laboratory by qualified engineers (Piper Medical, USA). A Harvard Respirator Pump (Harvard Apparatus, USA), oxygen source, CO₂ source and a mannequin head were used to simulate varying respiratory conditions. End tidal CO₂ (EtCO₂), FiO₂, fraction of inspired CO₂ and percent drop in CO₂ in the first second of exhalation were measured at different mask flow rates and respiratory rates. There were two categories of flow rates: high-flow (15 L/min) and low-flow (2 L/min). In each flow group, the average parameters were measured using a tidal volume of 400 mL, inspiratory/expiratory ratio of 1:2, EtCO₂ of 5% and a breathing frequency of 15, 20 or 24 breaths/min. Mask performance measurements were obtained and compared.

CONCLUSION: The OxyMask outperformed the traditional NRBM in each tested category. There was a higher inspired oxygen level, lower inspired CO₂ level, and more efficient CO₂ clearance at each mask flow level and simulated patient minute volume. This was especially true during conditions in which there were very low mask flow rates.

Key Words: Delivery; Hypercarbia; Hypoxemia; Hypoxia; Non-rebreather mask; Oxygen; OxyMask; Respiratory failure

The patient safety profile of a non-rebreather mask (NRBM) has been a matter of concern for some time; however, there is very little reference to these performance characteristics in the literature (1-3). Low-flow characteristics and a potential lack of effective washout of exhaled gases can lead to rebreathing of carbon dioxide (CO₂) in certain conditions (1-3). This concern has previously led to aftermarket modifications to the NRBM by way of removing one of the one-way valves that are located on either side of the mask. This modification is intended to reduce or attenuate the rebreathing of exhaled gases and potential for hypercarbic respiratory failure and lower fraction of inspired oxygen (FiO₂) leading to hypoxemia. These conditions may exist when the mask flow is set inadvertently low, is accidently disconnected from its fresh gas source or the very small exhalation port is obstructed (2,4). We hypothesized that the open design of the OxyMask™ (Southmedic Inc, Canada) would mitigate these concerns by allowing for less CO₂ rebreathing while delivering inspired oxygen levels that compare favourably with the Hudson RCI® NRBM™ (Teleflex Inc, USA) (5-7).

METHODS

The CO₂ source was attached to the inhalation limb of the Harvard Pump (Harvard Apparatus, USA) on the piston side of the inhalation check valve. A 0.125 inch OD sensing oxygen line was attached to the
CO₂ measurements were calibrated before testing at laboratory processes met their specifications and requirements before each setting. 3 min to equilibrate a full inhalation and exhalation CO₂.

There were a total of 36 tests (2 samples × 3 tests per sample × 2 oxygen flows at both 2 L/min of oxygen flow or 15 L/min of oxygen flow. 20 breaths/min and 24 breaths/min. Each of these conditions were at three different respiratory rates and minute volumes: 15 breaths/min, 20 breaths/min and 24 breaths/min. Each of these conditions were set to the desired EtCO₂ value, the mask was adjusted to the desired flow rate (2 L/min and 15 L/min, respectively) and placed on the mannequin head as designed. The system was allowed to equilibrate for at least 3 min before obtaining each reading. Each sample was tested three times. The mask was removed from the mannequin head completely and repositioned between each test. Each mask was tested at three different respiratory rates and minute volumes: 15 breaths/min, 20 breaths/min and 24 breaths/min. Each of these conditions were simulated at both 2 L/min of oxygen flow or 15 L/min of oxygen flow. There were a total of 36 tests (2 samples × 3 tests per sample × 2 oxygen flow settings × 3 respiratory settings = 36 tests total). After allowing each setting 3 min to equilibrate a full inhalation and exhalation CO₂ waveform, EtCO₂ and FiO₂ measurements were captured. Performance of each device was evaluated and qualified in terms of each device’s ability to clear CO₂ from the mask during exhalation. All equipment and laboratory processes met their specifications and requirements before and after testing. CO₂ measurements were calibrated before testing at 0% and 5%. Oxygen measurements were calibrated at 21% and 100% before testing. After testing, calibration curves were verified. The equipment list and patient simulation set-up are listed and described in Appendix 1, and Figures 1 and 2, respectively.

TABLE 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory rate, breaths/min</td>
<td>15</td>
</tr>
<tr>
<td>Respiratory rate, breaths/min</td>
<td>20</td>
</tr>
<tr>
<td>Respiratory rate, breaths/min</td>
<td>24</td>
</tr>
<tr>
<td>Tidal volume, mL</td>
<td>400</td>
</tr>
<tr>
<td>Tidal volume, mL</td>
<td>400</td>
</tr>
<tr>
<td>Inspiratory-expiratory ratio</td>
<td>1:2</td>
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<td>1:2</td>
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<tr>
<td>Inspiratory-expiratory ratio</td>
<td>1:2</td>
</tr>
<tr>
<td>End tidal carbon dioxide, %</td>
<td>5</td>
</tr>
<tr>
<td>End tidal carbon dioxide, %</td>
<td>5</td>
</tr>
<tr>
<td>End tidal carbon dioxide, %</td>
<td>5</td>
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</tbody>
</table>

Table 2 summarizes combined mean data collected while testing both masks with oxygen flow rates of 2 L/min and 15 L/min and respiratory rates of 15, 20 and 24 breaths/min. Table 3 summarizes mean data for each individual test. The OxyMask delivered more or an equivalent amount of oxygen compared with the NRBM at the same conditions. The OxyMask resulted in lower or equivalent EtCO₂ levels compared with the NRBM at the same conditions. CO₂ levels dropped faster during exhalation with the OxyMask than with the NRBM. Performance of the two products tended to be farther apart at lower flow rates of oxygen. Significant differences among the covariates were noted (P<0.001; λ=0.332). When controlling for device flow and respiratory rate, there was a statistically significant effect on EtCO₂ (F=29.37; P<0.001), O₂ (F=24.17; P<0.001), inhaled O₂ (F=54.60; P<0.001) and percent drop in CO₂ (F=41.72; P<0.001).

TABLE 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Southmedic OxyMask®</th>
<th>Hudson RCI® NRB Mask®</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>End tidal carbon dioxide, %</td>
<td>5.2±0.35</td>
<td>5.8±0.61</td>
<td>29.37</td>
<td>&lt;0.001</td>
</tr>
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<td>Oxygen</td>
<td>61.8±16.17</td>
<td>57.0±19.03</td>
<td>24.17</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Inhaled carbon dioxide</td>
<td>2.2±.52</td>
<td>3.0±1.13</td>
<td>54.60</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>% drop</td>
<td>83.1±6.85</td>
<td>63.8±13.52</td>
<td>41.72</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Data presented as mean ± SD unless otherwise indicated

RESULTS

Table 2 summarizes combined mean data collected while testing both masks with oxygen flow rates of 2 L/min and 15 L/min and respiratory rates of 15, 20 and 24 breaths/min. Table 3 summarizes mean data for each individual test. The OxyMask delivered more or an equivalent amount of oxygen compared with the NRBM at the same conditions. The OxyMask resulted in lower or equivalent EtCO₂ levels compared with the NRBM at the same conditions. CO₂ levels dropped faster during exhalation with the OxyMask than with the NRBM. Performance of the two products tended to be farther apart at lower flow rates of oxygen. Significant differences among the covariates were noted (P<0.001; λ=0.332). When controlling for device flow and respiratory rate, there was a statistically significant effect on EtCO₂ (F=29.37; P<0.001), O₂ (F=24.17; P<0.001), inhaled O₂ (F=54.60; P<0.001) and percent drop in CO₂ (F=41.72; P<0.001).

DISCUSSION

Patient safety is paramount. It has been historically hypothesized that the use of an NRBM may be unsafe when certain elements exist that create conditions favourable for rebreathing CO₂ (7-10). The literature supporting this notion is virtually nonexistent. Our bench experiments demonstrated, that when the NRBM and OxyMask are used as per the standard (higher flows), they are safe oxygen delivery equipment conditions were introduced by way of changing respiratory rates and oxygen flow rates. Higher oxygen flow rates (15 L/min) were chosen to simulate the standard practice with both masks. Lower oxygen flow rates (2 L/min) were used to simulate an inadvertent decrease from the standard. Increasing respiratory rates were tested to simulate a change in patient condition and minute volume. Our experiments demonstrated, that when the NRBM and OxyMask are used as per the standard (higher flows), they are safe oxygen delivery masks and deliver a relatively high and stable level of inspired oxygen. Additionally, CO₂ appears to be adequately cleared under these conditions. Alternatively, when tested at lower flow rates, the OxyMask appears to outperform the NRBM in terms of CO₂ clearance and at delivering inspired oxygen.
There were limitations to the present study. Although the measurements obtained during these experiments show a statistical significance almost across the board in favour of the OxyMask at lower flow rates, the sample numbers are low and further evaluation may be helpful to suggest a change in safe practice. We believe that our data suggests that the Southmedic OxyMask may be a safer alternative to the Hudson RCI NRBM in which conditions exist that make inadvertent low oxygen delivery flows more likely to occur.

APPENDIX 1: EQUIPMENT LIST
A) SouthMedic Adult OxyMask (SouthMedic, Barrie, Ontario)
B) Hudson RCI Adult Non-rebreathing Mask with Safety Vent (Morrisville, NC, USA)
C) 0-100 psig Pressure Gauge
D) Gilmont glass float type Rotameter (Barrington, IL, USA)
E) Low Flow Rotameter
F) AccuLAB Standard Electronic Balance TS series (Goettingen, Germany)
G) Vacuum source
H) Compressed gas source
I) Oxygen source
J) CO₂ source
K) Velleman Digital Oscilloscope (Fort Worth, Texas, USA)
L) Ohmeda 5200 CO₂ Monitor (Madison, WI, USA)
M) Data Acquisition System
N) Humidity/Temperature Meter
O) Oxygen Sensor
P) Harvard Respiratory Pump (Harvard Apparatus, Holliston, Massachusetts, USA)
Q) Wright Respirometer
R) Adult Mannequin Head (0.875 inch ID oral cavity, head width = 6

DISCLOSURES: Keith Lamb has no financial disclosures or conflicts of interest to declare. David Piper is President of Piper Medical, Inc, Carmichael, California (USA) and performed the bench investigation(s). Mr Piper was compensated for conducting these experiments.

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REFERENCES

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