Behind the Mask

Patients with acute respiratory distress could benefit from a new mask that provides an \( \text{FiO}_2 \) of more than 80\% at an oxygen-flow rate of 8 L/min.

The treatment objective for severe hypoxemia resulting from acute respiratory failure is optimization of alveolar (and, thereby, arterial) \( \text{P}_\text{aO}_2 \). Conditions causing acute respiratory distress are often associated with hyperventilation. The patient's high minute ventilation and associated high inspiratory flows severely limit the \( \text{FiO}_2 \) that most masks can deliver. When sufficiently high \( \text{Paco}_2 \) cannot be provided by mask use alone, the therapeutic option defaults to endotracheal intubation, which is associated with considerable discomfort, morbidity, and cost.

There have recently been several new indications for the inhalation of high \( \text{FiO}_2 \). Greif et al. reported that postoperative patients treated with high concentrations of oxygen had half the episodes of nausea and vomiting of those treated with 30\% oxygen. A similar report on the benefits of more than 80\% oxygen has shown reduced nausea in patients more than 60 years old who were transported for minor trauma; maternity transport cases may also benefit (Y. Yucel, MD, unpublished data 2001). A randomized controlled trial sponsored by the US National Institutes of Health showed that patients undergoing bowel resection who were treated with more than 80\% oxygen in the perioperative period had 50\% fewer postoperative infections, although both treatment groups received the recommended preoperative dose of antibiotics.

Effective delivery of high concentrations of oxygen depends on the mask's ability to match the oxygen flow to the patient's minute ventilation and peak inspiratory flow without diluting that oxygen with room air. Peak flows in breathless patients can reach several hundred liters per minute. One common approach is to try to match the peak inspiratory flows with oxygen flow to the mask; however, most oxygen flowmeters are calibrated to deliver only 15 L/min. At the flush setting, they still limit flow to approximately 25 L/min, far less than peak flow requirements. Delivery of higher flows into the mask requires a tandem setup of multiple flowmeters, increasing the complexity and cost of the system.

Another approach is a mask with an oxygen reservoir on the inspiratory side, with or without a one-way valve between the reservoir and the mask. In theory, the reservoir fills with oxygen during exhalation, and that oxygen is then available to meet peak inspiratory flow demands during inspiration. In practice, there is an obligatory entrainment of room air throughout inspiration, limiting the \( \text{FiO}_2 \). The volume of entrained air depends on the relative resistance to flow in the side ports of the mask and the oxygen inlet. Differences in performance between the nonrebreathing and partial-rebreathing masks may be small. On one hand, the valve at the oxygen inlet of the nonrebreathing mask prevents expired gas from entering the reservoir; on the other, it increases resistance to flow from the bag to the mask and results in entrainment of more air (and a further decrease in \( \text{FiO}_2 \)), assuming both mask types fit the face equally well, as air entralled around the mask will also dilute inspired oxygen.

A new mask was recently developed to provide a compact, effective means of delivering \( \text{FiO}_2 \) levels of more than 80\% with oxygen flows no greater than minute ventilation. Its performance was compared with that of standard configurations of a nonrebreathing mask, a partial-rebreathing mask, and a simple oxygen mask.

The new mask is composed of inspiratory and expiratory limbs, each containing a one-way valve of very low resistance, and a sequential dilution conduit (leading from the atmosphere to the inspiratory limb) with a one-way valve that has a slightly positive cracking pressure. There is a gas reservoir on the inspiratory limb. During inspiration, gas from the oxygen source and the reservoir are drawn in preferentially. If the oxygen flow is equal to or greater than the minute ventilation, no atmospheric air is entrained and the patient gets pure oxygen. If the minute ventilation exceeds the oxygen flow, the reservoir collapses, the sequential dilution valve opens, and the remainder of the inspired gas is drawn from the atmosphere.
The subject increased his ventilation by any combination of tidal volume and frequency to decrease PETCO₂ by 5 mm Hg (as prompted by visual feedback from the capnograph). After a steady state had been obtained, data were recorded for 1 minute. The analog signals for Pco₂ and P0₂ were digitized and recorded using an analog-to-digital converter. The peak-detection function was used to identify PETCO₂ and end-tidal fraction of oxygen (FETO₂) for each breath. These values were exported to a commercial spreadsheet program. Net FIO₂ was calculated from the FETO₂ by solving the alveolar gas equation for FIO₂.12

$$\text{FIO}_2 = \frac{\text{PETCO}_2(\text{RQ}+\text{FACO}_2)-\text{FACO}_2}{\text{RQ}+\text{FACO}_2(1-\text{RQ})}$$

where RQ is the respiratory quotient and is assumed to be 0.8 and FACO₂ =PETCO₂/Barometric pressure.

Results were compared using appropriate t-tests with corrections for multiple comparisons; P<.05 was considered significant. All results are reported as mean±SD.

The new mask provided a FIO₂ of 97%±1%, 42% more than the next-best oxygen mask tested. When subjects increased ventilation, PETCO₂ values fell from 42.6±0.5 mm Hg to 37.4±0.2 mm Hg. At this higher level of ventilation, FIO₂ was 90%±5% with the new mask, which was not significantly different from the resting FIO₂, but was 34% more than the next-best oxygen mask tested (see Figure, page 24).

The new mask is configured as a compact manifolds and mask with a profile similar to that of nonbreathing or partial-rebreathing masks. All of the masks tested, except for the new mask, provide lower FIO₂ because of obligatory entrainment of room air through their side holes throughout inspiration. These side ports allow expiration, but are also necessary to provide negative-pressure relief when minute ventilation exceeds oxygen flow. In contrast, the new mask is completely sealed and the relief ports for inspiration and expiration are located on the other side of one-way valves. This prevents dilution of the inspired oxygen by air as long as the oxygen flow is equal to or greater than the minute ventilation. If it is less than minute ventilation, sequential gas delivery means that the oxygen flow can, theoretically, be about 30% less than the minute ventilation at rest without compromising the effective (alveolar) FIO₂. This is also likely to be why the FIO₂ is higher with the new mask than with the nonbreathing and partial-rebreathing masks at the higher ventilation level of testing. It may also ensure a high FIO₂ during rapid shallow breathing (as seen in patients with rib fractures or such restrictive lesions as pulmonary edema or fibrosing alveolitis).

The new mask was the only mask to provide an FIO₂ of more than 80% at an oxygen-flow rate of 8 L/min. This high FIO₂ may provide clinically significant benefits, or be useful when conservation of oxygen is needed in field situations.

References


3. Goldstein RS, Young J, Rebusch BS. Effect of breathing pattern on oxygen concentration received from standard face masks, Lancet. 1985;i:1885-1890.

