Comparing Lung Oxygen Delivery with Three Different High FiO2 Masks

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Introduction

Effective delivery of high concentrations of oxygen depends on the ability of oxygen delivery masks to provide adequate oxygen flow to meet the inspiratory demands of the patient and without allowing entrainment of room air into the inspired flow that would dilute the oxygen.[1] For most oxygen masks on the market, their basic "open" design, which might include the side ports holes provided for exhalation, allows room air to enter the inspired gas stream throughout inspiration, particularly at high inspired flows.

Several publications have compared the Hi-Ox high FiO2 oxygen mask to the standard non-rebreathing mask and have demonstrated its ability to delivery higher inspired oxygen concentrations at any matching flow.[2-9] More recently, two oxygen masks with different designs than the standard non-rebreathing mask have entered the market with suggestions that they can deliver high inspired oxygen concentrations at modest oxygen flow rates.

We therefore performed a study to compare the oxygen delivery capability of the recently reintroduced Ceretec Hi-Ox High FiO2 Oxygen Mask against the BLS FLO2MAX Oxygen Mask and the Southmedic 1425-8 Oxygen Mask to determine if there were performance differences.

Background on the Measurement of Actual FiO2

When monitoring inspired oxygen concentration, many investigators simply monitor the concentration of oxygen at the mouth and determine that this represents the inspired oxygen concentration. However, without measuring actual inspired flow, there is no way to determine the "volume" of oxygen that is inspired. If a subject holds their breath, the concentration at their lips might reach 100% if monitoring only the oxygen concentration at their lips, while no oxygen actually entered their lungs. Therefore, the only way to understand the effectiveness of any oxygen delivery system is to measure the concentration that leaves the lungs at the end of an exhalation (the alveolar concentration). That is a truer measure of inspired oxygen.

The inspiratory flow of patients is not a square wave, constant flow. There are higher flows early in the breath and slower flows towards the end of the breath. Therefore more volume enters the lungs early in the breath and dilution effects are greater than late in the breath.

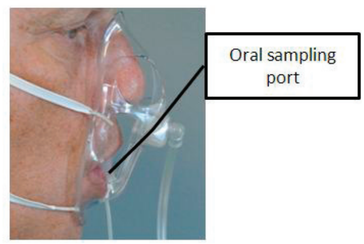

Figure 1. Oral sampling port, side view.

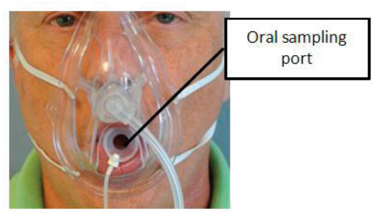

Figure 2. Oral sampling port, front view.

We do note that the exhaled oxygen concentration will be a few percentage points below the actual inspired oxygen as the exhaled concentration doesn't account for the uptake of oxygen by the blood in the lungs. However, at the very least, it represents the lowest alveolar oxygen concentration. In summary, measuring inspired oxygen entering the lungs (concentration only) is a misrepresentation of the actual oxygen delivery capabilities of a mask.

Methods

A Teledyne ultra-fast oxygen sensor (model UFO-130-2) was connected to a vacuum sample pump drawing gas for analysis at 275 ml/min. The analyzer was calibrated with a 2-point calibration at 21% with room air and at 100% with a pure oxygen cylinder source.

The 1/16th inch diameter sample line was connected to an adapter placed between the teeth of the subject, just in front of their lips for side-stream sampling of inspired and expired oxygen (Figures 1 and 2). The adapter barely extended beyond the lips and created a patent pathway to the lungs for gas analysis. The output of the analyzer was connected to a LabView Data Acquisition BNC-2120 sampling at 100 Hz.

With several publications for the performance of the Hi-Ox throughout a wide range of oxygen flows already in the peer reviewed literature, it was only tested at an oxygen flow of 8 LPM to confirm the performance under this test configuration.

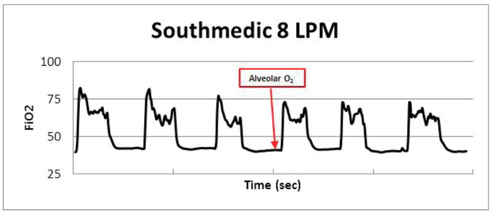

Figure 3. Southmedic: Alveolar oxygen 40-41%

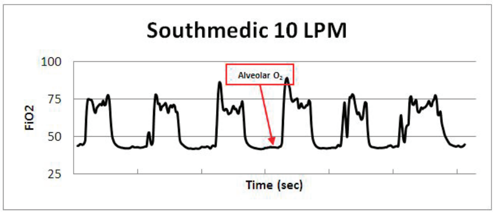

Figure 4. Southmedic: Alveolar oxygen 43%

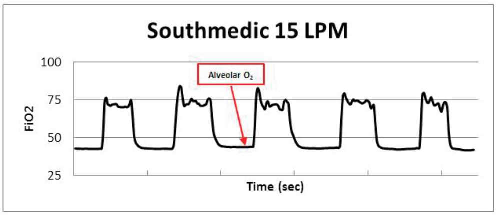

Figure 5. Southmedic: Alveolar oxygen 43%

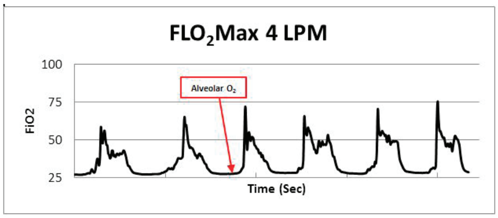

Figure 6. FLO2MAX: Alveolar oxygen 28%

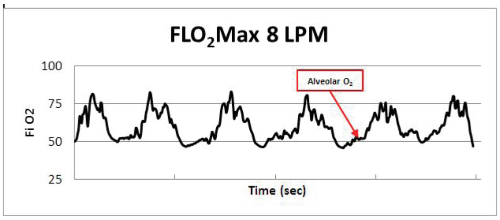

Figure 7. FLO2MAX: Alveolar oxygen 52%

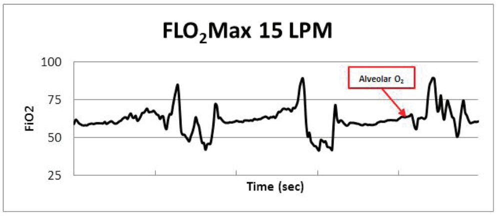

Figure 8. FLO2MAX: Alveolar oxygen 62%

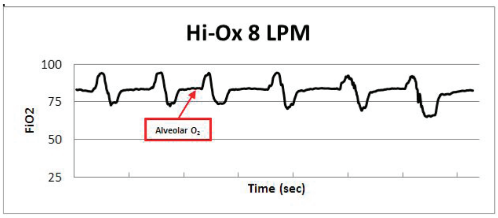

Figure 9. Hi-Ox: Alveolar oxygen 84%

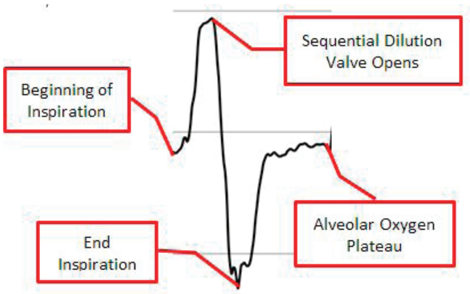

Figure 10. Single Hi-Ox breath

The Southmedic mask was tested at 8, 10 and 15 LPM and the BLS mask was tested at 4, 8 and 15 LPM.

After breathing on each mask at a resting ventilation level for seven minutes to allow for washout of nitrogen from the lungs and establish a steady state end-tidal oxygen concentration, the oxygen waveforms from several breaths were collected and analyzed on each mask and at each flow rate.

The end-tidal oxygen concentration for each breath was determined as the oxygen plateau just prior to inspiration where the oxygen concentration started on its next rise.

Results

Figures 3, 4 and 5 are data from the Southmedic mask at 8, 10 and 15 LPM respectively.

Measurements from these graphs demonstrate that although the "inspired oxygen" reached up to the 80% range at some point in the breath, the actual concentration in the alveoli never exceeded 45%.

Figures 6, 7 and 8 are data from the BLS mask at 4, 8 and 15 LPM respectively. Measurements from these graphs demonstrate that although the "inspired oxygen" reached up to the 80% range at some point in the breath, the actual concentration in the alveoli ranged from 28 to 62%.

Figure 9 is the data from the Hi-Ox at 8 LPM. Measurements from this graph demonstrate that the Hi-Ox delivers at least 80% oxygen at 8 LPM and the data is consistent with the previous publications describing its performance.

Discussion

To explain the differences between performance of the Ceretec Hi-Ox and BLS or Southmedic mask, we found the important difference being in that the Hi-Ox is a sequential dilution mask. That means that the patient inhales only oxygen from the flow meter and the reservoir until the reservoir is empty. Towards the end of the breath and following the collapse of the inspiratory reservoir, the sequential dilution valve opens and then allows room air to enter the mask. This dilution at the end of the breath dilutes the oxygen in the airways and mouth, but limits dilution in the alveoli. Therefore as the tracing in Figure 10 shows, there is a high inspired oxygen early in the breath, which drops lower as the dilution valve opens. On exhalation, the first gas exhaled is the diluted oxygen at a lower concentration from the airways followed by the alveolar gas representative of the effectiveness of the mask. In the case of the Hi-Ox, it is above 80%.

This data supports the previous publications that no other oxygen mask can deliver the same FiO2 as the Hi-Ox at the same or even higher flows. Figure 10 describes the timing of actions of the Hi-Ox throughout a single breath. It can be observed that the time between the sequential dilution valve opening and the end of inspiration is fairly short. Additionally, this is towards the end of inspiration when the inspiratory flow is also low. Therefore the volume of diluted oxygen is also small and has little effect on the alveolar concentration.

These characteristics of the Hi-Ox explain why it is able to deliver these high oxygen concentrations. The almost 40% difference in alveolar concentration with the Hi-Ox when compared to the Southmedic mask represents a 280 mmHg higher PiO2 and creates a situation whereby patients in respiratory distress may be able to avoid intubation solely to treat hypoxemia. In the case of the BLS mask, at matching flow rates, it's a 228 mmHg difference and even with the BLS running on 15 LPM, it's a 156 mmHg difference.

Conclusion

We have demonstrated that the published data on the Hi-Ox can be repeated on Ceretec Hi-Ox High FiO2 mask. It is also clear from this data that the Ceretec Hi-Ox is significantly better than the Southmedic or BLS oxygen masks at delivering inspired oxygen to the alveoli for the treatment of hypoxic patients.

References

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Guest editorial…continued from page 4

Many respiratory care departments have a Patient Driven Protocol in place, where the therapist can get the patient on the appropriate respiratory treatment and/or modality. Unfortunately this hasn't prevented the endless calls for prn bronchodilators. I am, along with a colleague, in the process of conducting a prn study in which we are tracking how many prn treatments are called for in a day. We are averaging about 20 calls in a 24 hour period, and approximately three-fourths of these prn calls are not indicated. In our institution, respiratory care provides nurses and residents with bronchodilator education on a routine basis, yet the calls for unnecessary treatments keep coming in. And I have a strong feeling this isn't happening in just one hospital, but in hospitals nationwide. So as respiratory therapists, how can we begin to deal with this problem? Ordering and giving drugs that are not indicated, no matter how minor the side effects can be, is not appropriate care for our patients, and our patients' best interest is of the utmost importance. At the completion of this prn study, I hope to have a protocol in conjunction with our Patient Driven Protocol, one that doctors and nurses have access to as well. It will state the indication for a bronchodilator to be ordered, the symptoms associated with this indication and an algorithm to follow. The goal is to decrease unnecessary bronchodilator use, to educate patients as well as doctors and nurses and to help reduce the cost of healthcare.

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