Comparison of the Oxygen Delivery Efficiency of Five Different Nasal Cannula Designs

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Background/Introduction: Ideally, 100% of the oxygen delivered by a nasal cannula reaches the lungs when the patient inhales completely or partially through the nostrils. 100% efficient cannulas are ideal because they deliver all of the oxygen to the lungs and none to the surrounding air, minimizing operating room fire hazard and oxygen desaturation events. Several different nasal cannulas are available for delivering supplemental oxygen. We evaluated the oxygen delivery efficiency of these cannulas for various combinations of inhalation flow rate, oxygen flow rate and mouth opening. To do this, we designed a bench test to evaluate the fraction of oxygen that is inhaled and to compare the oxygen delivery efficiency of five different cannulas. We then compared the theoretical (ideal) oxygen delivery against the actual volume inhaled by simulating supplemental oxygen delivery and measuring resultant FiO_2.

Methods: We placed each cannula onto a 3D printed model of the nares, oral and nasal passages and upper airway. Mouth open and closed inhalation were simulated by drawing air through the model airway using a vacuum gas flow controller. The vacuum flow controller drew constant flow rates of 5, 10, 20, and 30 LPM through the mouth and nostrils for mouth open inhalation and through only the nostrils for mouth closed inhalation. The controller flow rate was verified using a gas flow analyzer (VT Plus, Fluke Biomedical, Everett, WA). A mass flow controller (Alicat Scientific, Tucson, AZ) delivered oxygen flow rates of 1, 2, and 4 LPM through the test cannulas. Intra-nasal pressure was measured at every setting. We assumed that a negative pressure in the nares was indicative of inhalation through the nostrils. We evaluated the oxygen delivery efficiency of five different models of adult nasal cannulas (Salter Labs four prong #4002, and split lumen #4707, Westmed dual lumen #0503, Ventlab bottom port #4107, and Teleflex Medical Softech® Bi-Flo #1844). All of these cannulas have CO_2 monitoring capability. FiO_2 was measured in the simulated trachea using an anesthesia gas analyzer (Datex, Helsinki, Finland). Ideal FiO_2 were obtained for each combination of settings by measuring O_2 in a closed system where air and supplemental O_2 were mixed in a hose and 100% of the oxygen delivered was inhaled. The difference between the oxygen fraction observed using a nasal cannula and the ideal oxygen fraction observed using a closed system were recorded.

Results: Negative intra-nasal pressure was observed for each setting. The graph below shows the oxygen delivery efficiency of all cannulas when the mouth was open. For both mouth open and mouth closed inhalation, the lowest efficiency was observed at an oxygen flow of 4 LPM and an inhalation flow of 5 LPM, using cannulas designed to deliver oxygen outside of the nares. The efficiency profiles for mouth open and mouth closed inhalation were similar. For settings resulting in efficiency less than 100%, mouth open inhalation resulted in slightly lower efficiency compared to mouth closed inhalation.

Conclusion: Supplemental oxygen delivery is very near ideal as long as intra-nasal pressure is negative, oxygen flow is less than airflow through the nostrils and O_2 is delivered inside of and not outside of the nostrils. Compared to cannulas delivering O_2 outside the nostrils, cannulas delivering O_2 inside the nostrils are more efficient. Cannulas that deliver O_2 outside of the nostrils may be less prone to oxygen induced distortion of capnography but efficiency of oxygen delivery is compromised.