Investigating Intersubject Variability in Pulsed Oxygen Delivery using Adult Nasal Airway Replicas

Charles P. Moore, Warren H. Finlay, and Andrew R. Martin

Department of Mechanical Engineering, University of Alberta, Edmonton AB, Canada

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BACKGROUND & METHODS

BACKGROUND:

Oxygen-conserving devices are frequently used in the administration of long-term supplemental oxygen to extend usage for oxygen sources with limited capacity.

A key aspect of many such systems is the administration of short O_2 pulses timed to coincide with inspiration.

The present work was performed to investigate the influence of inhalation flow rate and intersubject variability in nasal airway geometry on the efficiency of pulsed O_2 delivery through nasal cannulas.

METHODS:

O_2 pulses were delivered through nasal cannula into five adult nasal airway replicas, extending from the nares to the trachea (Figure 1). The replicas were built previously in acrylic plastic using rapid prototyping, based on airway geometries segmented from MR images of healthy subjects[1].

A mass flow controller (Alicat Scientific Inc., AZ) was used to deliver O_2 nominally square-wave pulses with **volume of 50 ml, full-width at half-maximum (FWHM) of 150 ms, and peak flow rate of 16 L/min**.

Tracheal O_2 concentration was measured over time using a laser diode oxygen analyzer (Oxigraf Inc., CA) for inhalation flow rates ranging from **10 to 40 SLPM**. Raw data was corrected for the time response of the analyzer and sampling line[2] (Figure 2).

Tracheal delivery efficiency was defined as the fraction of the O_2 pulse volume arriving at the trachea. Triggering pressure monitored at the nasal cannula supply tubing was also measured

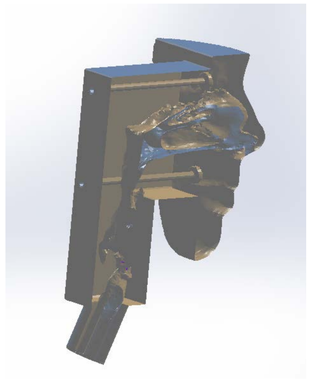
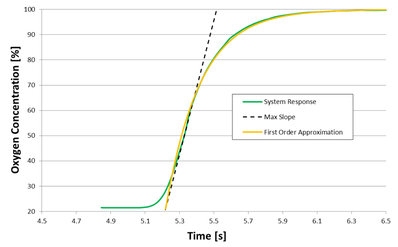


FIGURE 1. Section view of a nasal airway replica (Subject 2)

TABLE1. Geometric parameters for the five adult nasal airway replicas studied[1]

Subject	Sex	Volume [mm^3]	Pathlength [mm]	Surface Area [mm^2]
2	F	44,567	241	28,718
5	F	35,857	210	23,532
6	M	50,125	269	31,345
8	M	47,264	223	28,936
9	M	45,267	239	25,086



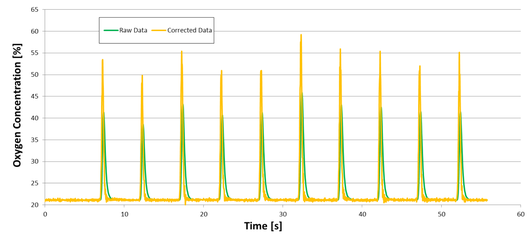


FIGURE 2. Top: System response for the oxygen analyzer and sampling line to a step change from 21% to 100% O_2 is shown along with a first order exponential approximation (time constant = 220 ms). Bottom: Raw data from the oxygen analyzer is shown with data corrected under the approximation of a first-order response.

TRIGGERING PRESSURE

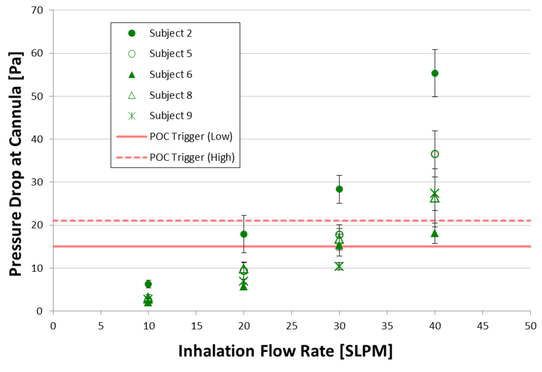


FIGURE 3. The drop in pressure monitored at the cannula supply tubing is plotted versus steady inhalation flow rate for the five nasal airway replicas. High and low range of trigger sensitivity for commercial portable oxygen concentrators[3] (POCs) is displayed for reference. Error bars indicate standard deviation of repeated experiments (n=4).

DELIVERY EFFICIENCY

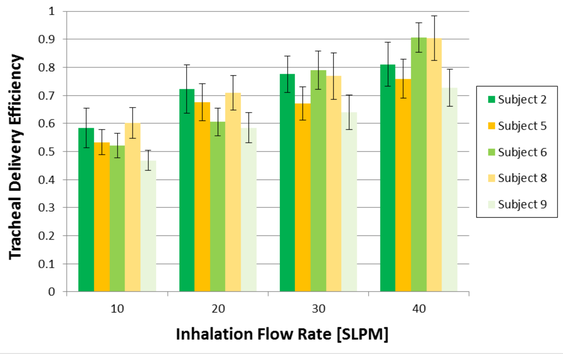


FIGURE 4. Tracheal delivery efficiency (the fraction of the O_2 pulse volume arriving at the trachea) is shown versus steady inhalation flow rate for the five nasal airway replicas. Error bars indicate standard deviation of 4 repeated experiments, with 10 successive pulses analyzed each experiment (n=40).

PULSE DISPERSION

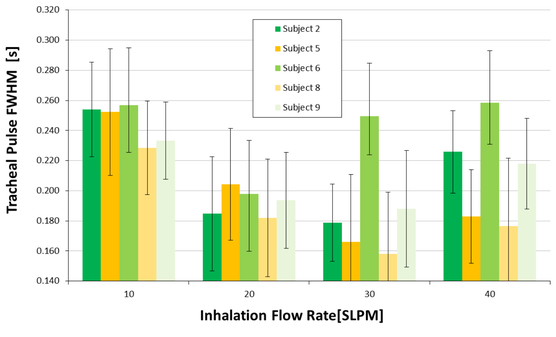


FIGURE 5. Full-width at half-maximum (FWHM) values for oxygen pulses measured at the outlets of the nasal airway replicas are shown versus steady inhalation flow rate. Error bars indicate standard deviation of 4 repeated experiments, with 10 successive pulses analyzed each experiment (n=40). For comparison, the FWHM of oxygen pulses delivered via cannula to the nares was 150 ms.

SUMMARY

KEY RESULTS:

Intersubject variability in tracheal delivery efficiency between airway replicas tended to be smaller than differences due to inhalation flow rate.

Intersubject variability in pressure drop measured at the nasal cannula supply tubing was considerable, ranging from 0.02 to 0.06 cm H_2O at 10 SLPM and from 0.18 to 0.56 cm H_2O at 40 SLPM. The pressure drop fell below typical triggering sensitivities of commercial portable oxygen concentrators for all 5 replicas at 10 SLPM, for 4 of 5 replicas at 20 SLPM, and for 1 of 5 replicas at 30 SLPM.

The influence of inhalation flow rate on O_2 pulse dispersion during transit through the nasal airway replicas was nonlinear, and varied between airway replicas studied. In general, minimal dispersion was measured at intermediate inhalation flow rates. Dispersion of O_2 pulses through upper and central airways may adversely affect efficiency of O_2 delivery to gas-exchange regions of the lungs.

CONCLUSIONS:

Evaluation of O_2 delivery on the bench using realistic upper airway replicas provides means to rapidly assess tracheal O_2 concentration over time.

Notable inefficiencies were measured for pulsed oxygen delivery via nasal cannula, especially at low inhalation flow rates.

REFERENCES

1. Golshahi, L., Noga, M. L., Thompson, R. B., & Finlay, W. H. (2011). *In vitro* deposition measurement of inhaled micrometer-sized particles in extrathoracic airways of children and adolescents during nose breathing. *Journal of Aerosol Science*, 42(7), 474-488.

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