Comparison of pulsed flow from portable oxygen concentrators with continuous oxygen delivery

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Introduction

Long term oxygen therapy has been shown to prolong life in patients with chronic obstructive pulmonary disease.[1, 2] More recently, intermittent delivery methods have been developed as portable or cost saving alternatives to continuous flow oxygen (CFO).[3, 4, 5] Portable oxygen concentrators (POCs) are the latest class of devices in the intermittent delivery paradigm.[3]

The present study had two primary objectives. The first was to compare the performance of several POCs against each other and against CFO, using volume-averaged F_{IO2} at the trachea. The second objective was to characterize the transport of oxygen pulses from the trachea through the conducting airways via computational modelling.

Methodology

In-vitro Experiments

Each of four POCs was connected via nasal cannula to a 3D-printed replica an adult human nasal airways . A test lung simulated three breathing patterns representative of a COPD patient at rest, during exercise and while asleep. The inspiration and expiration flow waveforms were each modeled using a half-sinusoid and actuated using a lung simulator.

The flow of oxygen passing through the trachea over time was calculated by multiplying inspiration flow with measured oxygen concentrations at the same point in time. These oxygen flows were then numerically integrated from the start to the end of inspiration to determine a volume of oxygen inspired for that breath. Finally, volume-averaged FiO2 was obtained by dividing the inspired volume of oxygen by V_T.

An O2 Conserver Testing System was used to obtain oxygen pulse volumes, durations and delays for each setting and each POC.

Computational Modelling

Using oxygen concentration waveforms measured at the trachea over time from the *in vitro* oxygen measurements described above as a boundary condition, a computational model simulated the transport of oxygen to the alveolar region.

The equation modelling dispersion and transport through the airways is a 1-dimensional convection-diffusion equation. Equation (1) was discretized over finite divisions of length using an upwind approximation for the convective term and a central difference approximation for the diffusive term. Concentrations were then advanced in time explicitly using the Euler method. Based on grid size dependence studies, a grid size of 5 divisions per airway generation was chosen. For such a grid size, it was previously found that 5000 time steps per breath were necessary to ensure convergence.

$$A\frac{\partial c}{\partial t} = \frac{\partial}{\partial x}\left(AD_{eff}\frac{\partial c}{\partial x}\right) - \frac{\partial}{\partial x}(Acu) \qquad (1)$$

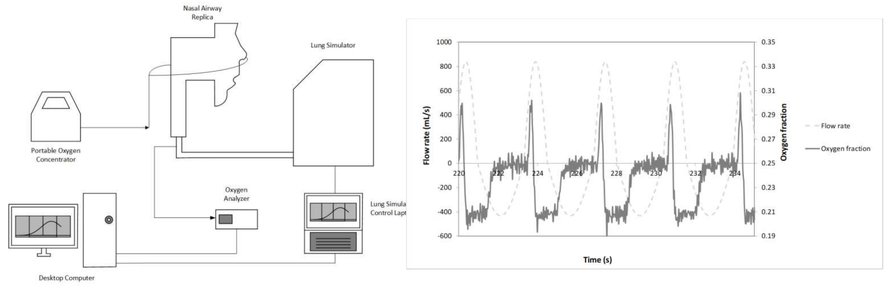

Figure 1. Schematic of apparatus used in experiments involving airway replicas (reproduced from Chen et al[6]). Arrows in schematic indicate direction of oxygen flow. Sample flow and oxygen fraction waveforms generated by the experimental apparatus for pulsed delivery of oxygen (modified from Chen et al[6]).

Results

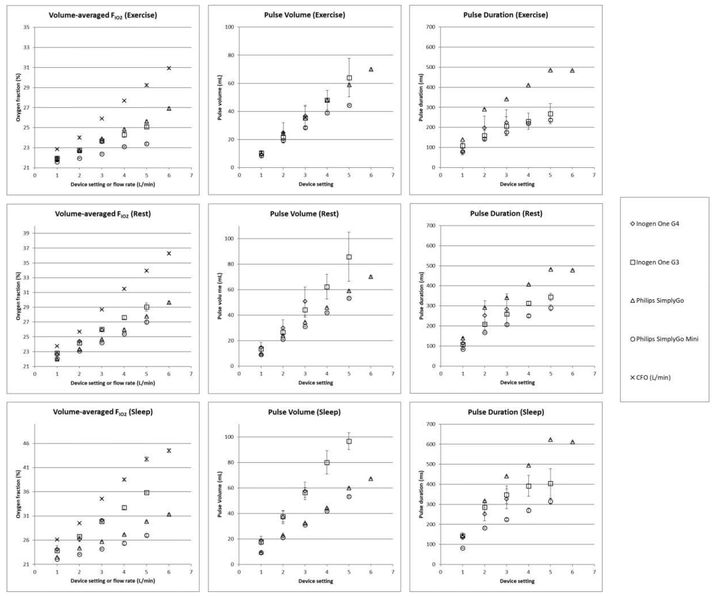

Figure 2. Volume-averaged FiO2 and pulse characteristics for each of the tested portable oxygen concentrators and continuous flow oxygen across three breathing patterns. FiO2 values were averaged over 5 consecutive breaths. Other pulse characteristics averaged over 20 consecutive breaths. Error bars indicate one standard deviation.

➢Due to high repeatability, very small differences in FiO2 were statistically significant. In addition to statistical significance, a threshold for an anticipated clinically significant difference in FiO2 was defined to be > 2% (absolute percentage oxygen) following Zhou and Chatburn[7].

➢Using this more demanding threshold, CFO delivered a significantly higher FiO2 than pulse flow in at least one of the devices at all nominally equivalent device settings of 2 and greater (up to 13% absolute for the sleep breathing pattern, 7% for the rest breathing pattern and 4% for the exercise breathing pattern). Large differences in pulse volumes between POCs at the same numerical device setting tended to result in large differences in volume-averaged FiO2.

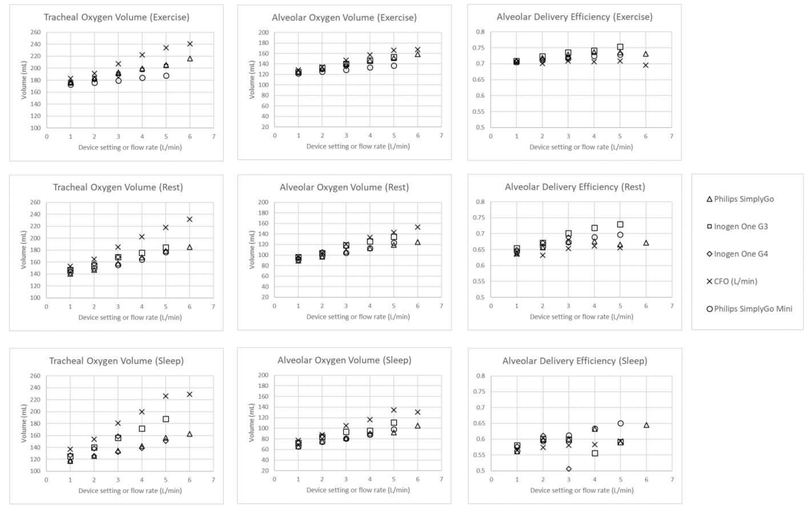

Figure 5. Volume of oxygen passing through the trachea, passing into the alveolar region, and the ratio of ratio of the oxygen passing the trachea vs. oxygen reaching the alveolar region) for all delivery modes.

➢Efficiencies for PF were generally higher than those for CFO. However, absolute oxygen delivery to the gas exchange region remained lower for PF than for CFO, at nominally equivalent settings and flows.

➢Differences in oxygen delivery between CFO and PF were smaller at the acinar region than at the trachea. On average, lower minute volumes resulted in higher differences in delivered oxygen volume.

Conclusions

➢Significant differences in oxygen delivery were found between pulse flow (PF) and CFO, and between PF modes in different POCs. In general, CFO delivered significantly more oxygen to the trachea than PF.

➢Computational modelling revealed that while PF may be a more efficient mode of delivery of oxygen to the alveoli than CFO, CFO delivers a greater absolute per breath for the POCs that were considered.

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