In vitro model of prepacked CO_2 absorber use: development and testing

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Introduction

The canister life of prepacked CO_2 absorbents has been studied in vitro for various brands over a range of fresh gas flows (FGF) using a metric called 'fractional canister usage' or FCU [1]. FCU is the reciprocal of the time (in hours) for the inspiratory CO_2 fraction (F_ICO_2) to reach 0.5% (= the fraction of total canister life used per hour). The FGF - FCU relationship, previously found to be linear, has only been tested with a 160 mL/min CO_2 load (VCO_2) and 5 L/min minute ventilation (MV). We now extend the model to include the effects of VCO_2, target end-tidal CO_2 fraction ($F_{ET}CO_2$), MV, and dead-space ventilation (V_D).

Methods

We derived 4 models from first principles (see Figure 1) and tested them prospectively in vitro. In model A and B, MV was derived from spirometry, in model C and D from the alveolar air equation (Nunn): $MV = (VCO_2/F_{ET}CO_2)/(1\text{-}fVD)$, with fVD (dead space fraction) = 0.29, calculated with Bohr's formula: $fVD= (F_{ET}CO_2\text{-}F_{ME}CO_2)/F_{ET}CO_2$, with $F_{ME}CO_2$ = mixed-expired FCO_2 determined using a mixing bottle. In models B and D, an additional parameter (machine factor), allowing the intercept with the FGF to differ from MV, was empirically determined using Excel's solver function: minimization of squared differences between modeled and observed FCU.
Canisters (Medisorb, Molecular Products, UK, lot # LO1A-00903) were inserted into an Aisys machine (GE, Madison, WI) ventilating a 2 L bag with a known VCO_2 into its tip. To test whether the FCU intercept of the FGF - FCU curve varied proportionally with VCO_2, FCU of 5 canisters was determined with either 80, 120, 160, 240 and 320 mL/min VCO_2 while adjusting MV to 4.2% $F_{ET}CO_2$ with a 0.3 L/min FGF, and linear regression applied to the data. To test whether the FCU intercept was independent of MV, the measurements were repeated with a constant MV (5 L/min) and a paired t-test was performed to compare FCU values amongst this and the previous experiment ($p < 0.05$ denoting statistical significance). Secondly, we hypothesized that an increase in VCO_2 accompanied by a (proportional) increase in MV to keep $F_{ET}CO_2$ constant would shift the straight line describing the FGF-FCU relationship in a parallel manner. To test this, FCU was determined for 19 canisters with different combinations of VCO_2 (80, 160, 240 and 320 mL/min) and FGF (range 0.3 - 5L/min); MV was adjusted to maintain $F_{ET}CO_2$. Model performance when compared to observed FCU was assessed using Varvel's criteria [2], median performance error (MDPE) and median absolute performance error (MDAPE).

Results

FCU is proportional with VCO_2 and independent of ventilation (constant F_ACO_2 group: $FCU = VCO_2 * 0.046 - 0.87$; $r^2 = 1.00$; constant MV group: $FCU = VCO_2 * 0.048 - 1.32$; $r^2 = 1.00$). VCO_2-FCU pairs did not differ between the 2 groups ($p = 0.96$) indicating that FCU intercept is ventilation independent. Of the 4 models, model B and D performed best (see Figure 1) and confirmed the hypothesized parallel shift.

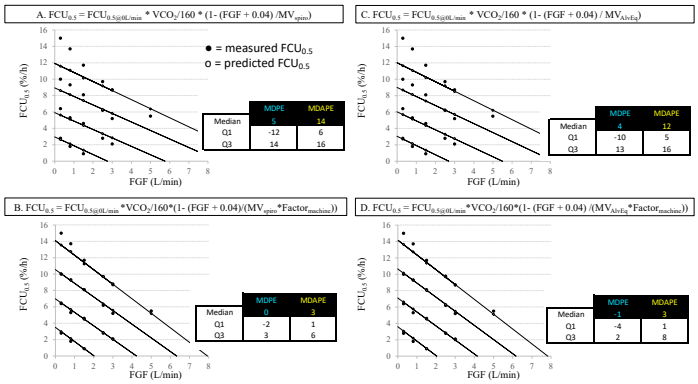

Figure 1 Four models derived from first principles and tested in vitro

Discussion

Over a 20-100% rebreathing range, the FCU-FGF models that allow the FGF intercept to deviate from MV by introducing the machine factor performed very well, with only small deviations from linearity during high FGF and VCO_2 extremes. Why the FGF intercept is lower than MV remains speculative but is possibly related to machine specific flow dynamics. These models will help us determine the economic and ecologic impact of anesthesia.

References

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