MODELING ALVEOLAR GAS TRANSPORT DURING LIQUID VENTILATION

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Introduction

During gas ventilation, gas transport within the alveolar sac is dominated by diffusion. In liquid ventilation, perfluorocarbon (PFC) introduced into the alveolar space acts as a diffusion barrier to gas transport since the diffusivities of oxygen and carbon dioxide in this medium are four orders of magnitude lower than in air. Therefore convection in the PFC layer resulting from the oscillatory motions of the alveolar sac during ventilation can significantly affect gas transport. We study these effects in both partial (PLV) and total liquid ventilation (TLV) using a simplified theoretical model.

Methods

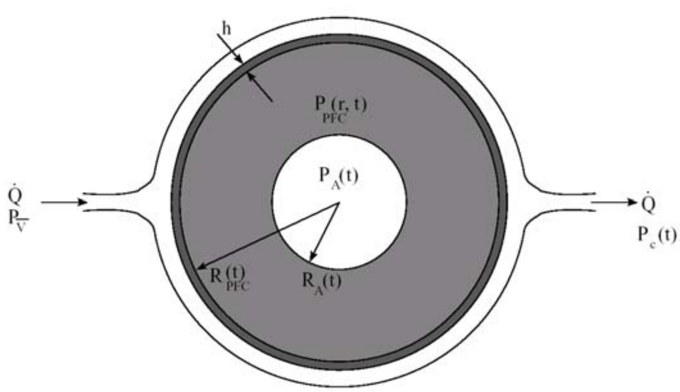

Figure 1. Schematic of the alveolar sac model

The model for a terminal alveolar sac is shown in Figure 1, adapted from VanLöbenSels *et. al.* [1]. It consists of an oscillating spherical structure with three concentric shells: 1) a well-mixed inner core of radius $R_A(t)$ filled with gas (PLV) or PFC (TLV); 2) an intermediate shell of radius $R_{PFC}(t)$ filled with PFC and surrounded by a tissue layer of thickness *h*; and 3) an outer shell representing a well-mixed blood compartment perfused with a constant blood flow, $\dot{Q}$. VanLöbenSels *et. al.* [1] used a similar model to study diffusion limitation in PLV in which the PFC layer acted as a passive diffusion barrier with no convection. We model the effects of tidal breathing and consider the effect of a radial convective flow field within the intermediate shell driven by ventilation of the sac. This results in a convection-diffusion equation for the partial pressure $P_{PFC}(r,t)$. The gas partial pressures in the inner core, $P_A(t)$, and in the capillary compartment, $P_c(t)$, are determined by a mass balance between the gas entering and exiting through ventilation and perfusion and diffusion across the interfaces of the different shells. The resulting set of coupled partial and ordinary differential equations is solved using finite difference techniques to obtain time periodic solutions.

Results

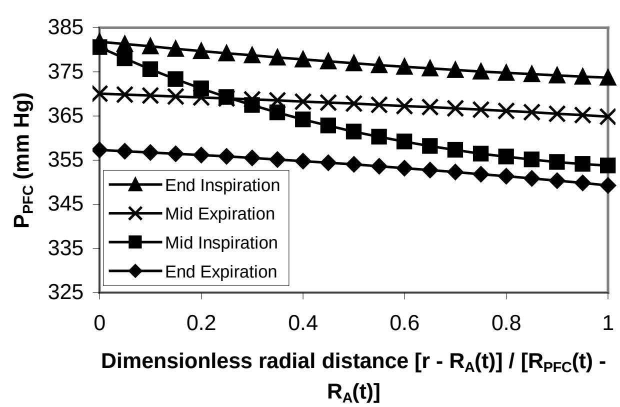

Figure 2. O_2 partial pressure profiles during TLV

Figure 2 shows that O_2 partial pressure gradients exist in the intermediate shell at different times during ventilation cycle in TLV after a time periodic state has been reached. Such gradients were also found to exist for CO_2. Gradients were also found for both gases in PLV. In each case gradients were found to be steepest at mid-inspiration. This is in contrast to gas ventilation where there are negligible gradients within the alveolar space.

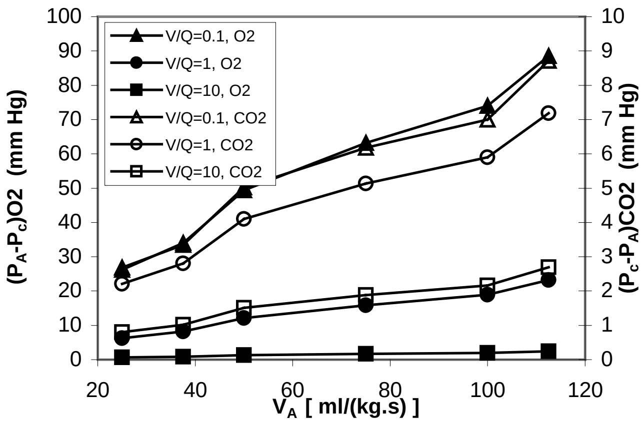

Figure 3. $(P_A - P_c)O2$ (left axis) and $(P_c - P_A)CO2$ vs. V_A during TLV

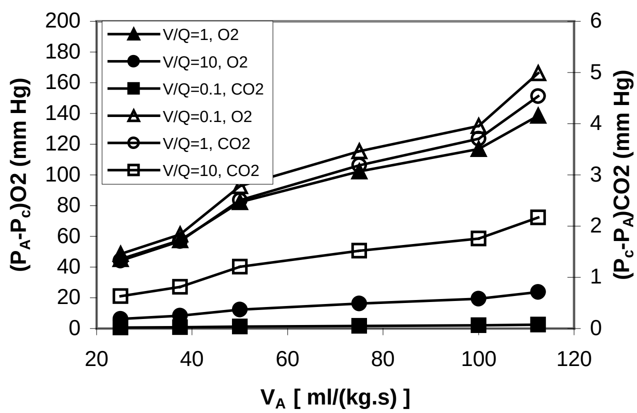

Figure 4. $(P_A - P_c)O2$ (left axis) and $(P_c - P_A)CO2$ vs. V_A during PLV

Another difference between gas and liquid ventilation is the presence of significant O_2 and CO_2 alveolar-arterial pressure differences in the latter. Figures 3 and 4 show the mean values of $(P_A - P_c)O2$ and $(P_c - P_A)CO2$ vs. the ventilation rate V_A averaged over one cycle of ventilation during TLV and PLV respectively. In general, it is seen that the pressure difference is large for low V_A/Q ratios and decreases as V_A/Q increases for both TLV and PLV. While the magnitude of $(P_A - P_c)O2$ is much larger than $(P_c - P_A)CO2$, especially at low V_A/Q ratios, the latter can reach upto 20% of the mixed venous CO_2 partial pressure of 45 mm Hg. In contrast to gas ventilation the alveolar-arterial pressure difference depends not just on the V_A/Q ratio, but also on the magnitude of V_A. $(P_A - P_c)O2$ is found to be more sensitive to changes in both V_A/Q and V_A than $(P_c - P_A)CO2$. Finally, it is seen that $(P_A - P_c)O2$ is larger in PLV than in TLV while the opposite is true for $(P_c - P_A)CO2$.

Acknowledgements

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References

1. VanLöbenSels, E. M., Anderson, J. C., Hildebrandt, J., and Hlastala, M. P., 1999, “Modeling diffusion limitation of gas exchange in lungs containing perfluorocarbon,” Journal of Applied Physiology, **86**(1), pp. 273-284.