INFLUENCE OF GAS PHYSICAL PROPERTIES ON PULMONARY GAS EXCHANGE

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INTRODUCTION

The gas exchange properties of the lung depend on the relative uniformity of the matching of ventilation and perfusion in the individual acinar units. The exchange of inert gases in a homogeneous acinar unit is dependent on the physical properties of those inert gases. This presentation deals with three aspects of the inert gas physical properties governing their exchange. The primary determinant of inert gas exchange is the solubility of the gas in blood. Second, gas exchange is weakly dependent on the molecular weight of the gas. Finally, the exchange of the very soluble inert gases depends on interaction of gas with the airways as air passes through the airways during inspiration and expiration.

Blood-Gas Partition Coefficient

A quantitative analysis of the influence of the blood solubility of an inert gas on its steady-state alveolar gas exchange was first put forward by Farhi (1967) who used the idea to describe a method for analyzing the exchange of two gases of differing solubility using a lung with two compartments, each having a different VA/Q ratio (Farhi and Yokoyama, 1967). If an inert gas dissolved in mixed venous blood enters the alveolus, there is a rapid exchange of that gas between the blood and the gas in the alveolus. Calculations suggest that equilibration will take place within a small fraction of the time available for exchange. In a small gas exchange unit, alveolar partial pressure (PA) is equal to the end-capillary partial pressure (Pa). The fraction of gas retained in the blood (Pa/Pv or R) is a function of the Ostwald partition coefficient (λ) of that gas between the gas phase and blood and the relative amounts of ventilation (VA) and of perfusion (Q) to the alveolus:

\[ R = \frac{\lambda}{\lambda + \frac{VA}{Q}} \]

For an alveolar unit with a fixed VA and Q, retention of a gas is a function of its solubility in blood. If a gas with a \( \lambda = 1 \) is infused into the venous circulation, it will be eliminated by an alveolus with a VA/Q of 1.0 with a retention of 0.5 (\( \lambda = \frac{VA}{Q} \)). A gas with greater \( \lambda \) (say 10.0) will
have a greater retention. A gas with lower $\lambda$ (say 0.1) will have a lower retention. Thus the alveolus acts as a high pass filter retaining gas with high $\lambda$ and eliminating gas with low $\lambda$.

Retention of the gas also depends on the $\dot{V}A/\dot{Q}$ of the alveolus. If a gas with $\lambda = 1$ passes through alveoli of differing $\dot{V}A/\dot{Q}$, there will be a greater retention in the low $\dot{V}A/\dot{Q}$ alveolus and a low retention in the high $\dot{V}A/\dot{Q}$ alveolus. Different alveoli process a gas differently depending on the gas $\lambda$ and the alveolus $\dot{V}A/\dot{Q}$ ratio. Thus the exchange of gas in the lung is highly sensitive to the $\dot{V}A/\dot{Q}$ ratio and the gas $\lambda$.

This approach has been used to advantage in the multiple inert gas elimination technique (MIGET) to provide a method for evaluating the heterogeneity of $\dot{V}A/\dot{Q}$ in the lung. Wagner et al., (1974) have used the analysis of the elimination of six inert gases with varying solubility to assess the multicompartment $\dot{V}A/\dot{Q}$ distribution in the lung. The method provides information about the dead space, shunt and general description of the relative heterogeneity of $\dot{V}A/\dot{Q}$ distribution (Hlastala, 1984). Because MIGET provides such useful information, it has been used with success by a number of investigators to deal with physiological questions about the lung.

**Molecular Weight**

The assumption of diffusional equilibration for inert gases has often been incorporated in analytical models. From analysis of inert gas exchange data, there has generally been no substantial evidence of diffusional impairment. However Scheid et al., (1981) pointed out that the particular approach used in MIGET with gases distributed over a wide range of partition coefficients would be relatively insensitive to small impairments in diffusional equilibrium. An alternative approach is to examine the elimination of inert gases with similar partition coefficients in blood and different molecular weights (Adaro and Farhi, 1971; Hlastala et al, 1982). By the assumptions of the homogenous alveolus model, the retentions and excretions of those different gases should be nearly identical. Robertson et al (1986a) compared the elimination of three inert gases with similar partition coefficients but with molecular weights ranging from 26 to 184.5 and demonstrated a consistent impairment of exchange in the higher molecular weight gases. The difference observed was small, but similar in magnitude to that proposed by Scheid et al., (1981) and Hlastala et al., (1981). The latter papers demonstrated that this degree of molecular weight effect would be perceived by MIGET as representing additional ventilation-perfusion heterogeneity. The importance of these observations does not relate to the resultant relatively small errors induced in the ventilation-perfusion distributions, but rather does establish that there is some form of diffusion impairment that can be measured for the inert gases in dog lungs. In other species, diffusion impairment may be more prominent (Truog et al., 1979).

The original assumption made in the consideration of the inert gas molecular weight effect was that this effect observed during normal gas exchange was related to the molecular weight-dependent separation observed with single breath studies involving bolus of insoluble gases with different molecular weights. This effect has been described as a gas phase diffusion abnormality (also called stratified inhomogeneity; Scheid and Piiper, 1980), or attributed to more complex interactions between the convective and diffusive movements of gases (Paiva and Engel, 1982). Recent studies of tidal gas concentrations by Robertson et al., (1986b) appear to confirm that measurable molecular weight differences in elimination of infused inert gases can be manifested as different Fowler dead spaces in the gases. The magnitude of the effect in these two preliminary reports, however, was not as large as that reported by Robertson et al., (1986a), and it appears likely that other mechanisms may also be involved.