SYNCHRONOUS TRACER INJECTION FOR O₂ UPTAKE AND CO₂ PRODUCTION

MEASUREMENT

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Existing methods for measuring O₂ consumption and CO₂ production require either air-tight connections to patients in the form of masks or nose pieces, or the patient is placed in a sealed box for monitoring expired gas volume and concentration.

Many patients, particularly infants and young children, don't tolerate such obtrusive interfacing to the monitoring equipment. The method described in this paper eliminates this requirement.

THEORY

In cases where CO₂ production is measured, alveolar ventilation is calculated using the relationship

\[ \dot{V}_{CO₂} = V_A F_{A CO₂} \]

where \( \dot{V}_{CO₂} \) is CO₂ production, \( V_A \) is alveolar ventilation, and \( F_{A CO₂} \) is the alveolar CO₂ fraction. Inspired CO₂ is assumed to be zero. O₂ consumption is a little more complicated since the calculation uses the inspired O₂ fraction and both O₂ and CO₂ alveolar fractions. The equation is:

\[ \dot{V}_{O₂} = V_A \left( F_{O₂} \frac{1 - F_{A O₂} - F_{A CO₂}}{1 - F_{O₂}} - F_{A O₂} \right) \]

where \( \dot{V}_{O₂} \) is oxygen consumption, \( F_{O₂} \) is the inspired oxygen fraction, and \( F_{A O₂} \) is the alveolar oxygen fraction.

Note that both \( \dot{V}_{CO₂} \) and \( \dot{V}_{O₂} \) are functions of \( V_A \) and gas
concentrations only, and it's the measurement of the $V_A$ factor that requires the air-tight seal. The central idea of this new method is to obtain $V_A$ without using such a seal. Once this is achieved, $V_O_2$ and $V_CO_2$ are obtained easily by knowing the inspired and expired gas fractions.

The alveolar ventilation is measured using helium as a tracer inserted as a bolus into the nostril synchronous with inspiration. The injection takes place early enough in the inspiratory phase so that all the tracer is carried into the alveolar compartment. After several breaths, a steady state condition is reached in which the rate of tracer injection equals the amount of tracer expired and is given by:

$$\dot{V}_{He} = \dot{V}_A \cdot F_A He$$  \hspace{1cm} (3)

where $\dot{V}_{He}$ is the rate of tracer injection (the product of known bolus volume and respiratory rate), and $F_A He$ is the steady state alveolar He fraction which is measured along with the alveolar $O_2$ and $CO_2$ gas fractions.

Equation 3 applies strictly to a hypothetical lung in which all alveoli have a common ventilation time constant. In a real lung and to a much greater degree in the diseased lung, a distribution of ventilation time constants exist. The degree to which equation 3 can estimate $V_A$ depends therefore on the variance of the time constant distribution and the timing of the bolus injection with the inspiratory phase.

**LUNG MODEL**

By computer simulation of a lung model in which arbitrary distributions of specific airway conductance, specific compliance, and ventilation/perfusion ratio could be assigned, the associated error in measurement of $V_A$, $V_O_2$, and $V_CO_2$ was calculated. With this simulation, the effects of varying the time of injection of the helium tracer bolus during inspiration and the time of sampling the expired gas during expiration could be studied and optimized for measurement accuracy.

The first model was designed to estimate the accuracy of measuring $V_A$. In this model the distribution of perfusion was not a consideration since there is negligible transfer of helium between blood and gas. The model consisted of a lung of 10 compartments in which specific airway conductance and specific compliance can be arbitrarily assigned or can be distributed as log-normal with respect to lung volume (FRC) with varying mean and standard deviation. In addition, the dead space can be assigned for each compartment, or it can be distributed as a fixed