I. Respiratory Gas Exchange

A. Alveolar ventilation

The volume of air exchanged during each breath of breathing is called the tidal volume, normally about 500 cc (that is, the difference between lung volume at end inspiration and end expiration is normally 500 cc).

Let

\[ V_D = \text{dead space volume} \]
\[ V_E = \text{expired volume (after tidal volume)} \]
\[ V_A = \text{room air volume reaching alveoli} \]
\[ F = \text{breaths/minute} \]

Then,

\[ V_A = (V_E - V_D) F \quad (1) \]

For example, with \( V_E = 500 \) cc as above, and \( V_D = 150, F = 12 \), it follows that normally

\[ V_A = (350)(12) = 4,200 \text{ liters/minute} \]

B. Blood Oxygen

When fully saturated, 1 gram of hemoglobin will hold 1.34 cc of oxygen. With a normal blood hemoglobin content of 15 gram/100 cc blood, it follows that normally blood contains:

20 cc Oxygen / 100 cc blood
Clinically, the 20cc O₂ per 100 cc blood is expressed as 20% saturation. Thus 20% saturation is the maximum saturation of blood erythrocytes. One important assumption made in this calculation is that because the erythrocyte carries most of the blood oxygen (98.5%), no oxygen is assumed carried by other than the erythrocyte.

To saturate the erythrocyte with oxygen, a certain partial pressure of oxygen must be present in blood. For example, normally blood oxygen partial pressure (P_\text{O}_2) is P_\text{O}_2 = 95 \text{ mm Hg}

and the blood oxygen erythrocyte oxygen content then is 20% saturation.

c. Room Oxygen Content and Partial Pressure

The partial pressure of O₂ (P_\text{O}_2) in air at 1 atmosphere is (0.21 \times 760 \text{ mm Hg}) = 159.6 \text{ mm Hg}, using the fact that the air at one atmosphere contains 21% oxygen.

We conclude from the above and Section B that normally an individual breathing room air with 21% O₂ and partial pressure oxygen of 159.6 mm Hg has arterial oxygen content in 20% saturation with a oxygen partial pressure of 95 mm Hg.
We have utilized the well-known result that the partial pressure of a gas equals the total gas pressure multiplied by the percentage of the partial gas:

\[
\text{partial gas pressure} = (\text{mixture gas pressure})(\% \text{ partial gas})
\]

D. Arterial Oxygen Partial Pressure

The partial pressure of oxygen in the blood depends on the partial pressure of oxygen in inspired air and also on the partial pressure of arterial CO2.

Let R, the respiratory exchange ratio, be defined as

\[
R = \frac{\text{Volume CO}_2 \text{ output} / \text{breath}}{\text{Volume O}_2 \text{ uptake} / \text{breath}}
\]

\[
\text{PAO}_2 : \text{alveolar oxygen partial pressure}
\]

\[
\text{P}_{\text{I}O_2} : \text{inspired air oxygen partial pressure}
\]

\[
\text{FI}_O_2 : \% \text{ O}_2 \text{ in inspired air}
\]

Then,

\[
\text{PAO}_2 = \text{P}_{\text{I}O_2} - \text{PCO}_2 \left[ \text{FI}_O_2 + \frac{1 - \text{FI}_O_2}{R} \right]
\]
Assuming \( R=1 \), we conclude from (2) & (3) that increasing \( \% O_2 \) of inspired air increases \\
\( P_{\text{F}}O_2 \) and thus increases \( P_{\text{A}}O_2 \).

On the other hand if \( R \) increases because above one, as with non-zero dead space, \( P_{\text{F}}O_2 \) decreases for any given \( P_{\text{A}}O_2 \) and \( F_{\text{F}}O_2 \). Thus, with dead space created by chronic obstructive lung disease, it is necessary to increase \( P_{\text{F}}O_2 \) to maintain \( P_{\text{A}}O_2 \).

An approach which decreases dead space (directly or indirectly through bypass) and increases \( P_{\text{F}}O_2 \) thus is desirable to treat COPD with increased dead space.
Supplemental Oxygen Requirements

If the % oxygen in inspired air is increased by \( x \% \) where it had been \( a \% \), then the oxygen partial pressure of inspired air is increased by \( (x/a)\% \) because

\[
(a+x) \cdot \frac{P_{\text{I}}}{P_{\text{I,0}}} = a \cdot (1 + \frac{x}{a}) \cdot \frac{P_{\text{I}}}{P_{\text{I,0}}} =
\]

\[
a \cdot \frac{P_{\text{I}}}{P_{\text{I,0}}} + (\frac{x}{a}) \cdot a \cdot \frac{P_{\text{I}}}{P_{\text{I,0}}} =
\]

\[
P_{\text{I,0}2} + (\frac{x}{a}) \cdot P_{\text{I,0}2}
\]

Thus, increasing the % \( O_2 \) of inspired air from 20% to 25% increases the partial pressure of oxygen in inspired air by \( (5/20) \) or 25% of the original partial pressure. If \( R=1 \), then the avelar partial pressure also increases by 25%.

Suppose \( V_a = 4.2 \) liters/minute, \( R=1 \), and inspired air is supplemented with 41% \( O_2 \) to add 5% \( O_2 \) to inspired air. This would require \( (4.2)(0.05) = 0.21 \) liters/minute from oxygen, or 12.6 liters per hour of supplemental oxygen.
RESEARCH PROTOCOL
INTRA-TRACHEAL OXYGEN DELIVERY

Others have shown that intra-tracheal insertion of tubes using cricothyroid puncture is a procedure with benefits greater than risk \([1, 2, 3, 4]\). Our own research \([5, 6]\) in healthy dogs has shown that arterial \(pO_2\) can be increased by as much as a factor of four by delivering oxygen through catheters inserted to and beyond the trachea bifurcation. Implantations have been in place over one year, and all three dogs are free of coughing, evidence of infection, or evidence of other disease. Each dog has recorded repeated white blood cell count and differential, respiratory rate, and temperature. Than animals experienced initial coughing after implantation which diminished with time to eventual freedom from coughing. Bronchoscopy has revealed no major pathological changes.

We now are prepared to use this approach on patients with chronic obstructive lung disease. A selected patient will be one requiring chronic use of oxygen. The patient will have had complete history, physical, lab and pulmonary function testing. Intra-tracheal oxygen delivery will be accomplished in the hospital, in intensive care, if necessary. Proper follow-up in the home will be provided for any patient discharged with intra-tracheal oxygen delivery.
REFERENCES


