VENTILATION AND PERFUSION OF THE LUNG
Section 3, Part B

I. Oxygen Transport from Air to Tissue

A. PO_2 falls as it moves from the atmosphere to the mitochondria
   1. refer to figure 1
   2. this is hypothetically a perfect lung

B. PAO_2 is the result of two processes
   1. removal of O_2 by the pulmonary capillary
   2. continual replacement by alveolar ventilation
      a. cyclic process
      b. PAO_2 fluctuates approx. 3 mmHg during a ventilatory cycle

C. Balance of CO_2 is similar to O_2

D. Systemic circulation - O_2 diffuses from circulatory system to mitochondria
   1. as PaO_2 decreases the tissue PO_2 must also decrease
   2. impaired pulmonary gas exchange will increase tissue PCO_2

II. Hypoventilation

A. As ventilation dec., PO_2 dec.
   1. PCO_2 will inc.

B. Causes of hypoventilation
   1. respiratory depression
   2. damage to chest wall
   3. paralysis of respiratory muscles
   4. high resistance to airflow or obstruction

C. Relationship between alveolar ventilation and PCO_2

$$PCO_2 = \frac{\dot{V}CO_2}{\dot{V}A} \times K$$

   1. if VA is halved, PCO_2 is doubled

D. The relationship between the fall of PO_2 and the rise of PCO_2 during hypoventilation can be predicted by the alveolar gas equation:

$$PAO_2 = PIO_2 - PaCO_2 \times 1.2$$

   1. 1.2 is a small correction factor
   2. must know the composition of inspired gas and R
      a. R = 0.8
   3. hypoventilation always reduces PAO_2 unless the subject is breathing a gas with a FIO_2 above 21%

III. Shunt

A. Ideally $PAO_2 = PaO_2$; in reality, this does not occur
   1. small difference is due to diffusion
   2. difference inc. when low O_2 mixtures are inspired
   3. the remaining difference is due to shunts

B. Shunt in this instance is blood that enters the systemic arteries without first passing through ventilated areas of the lung
   1. bronchial arteries
   2. Thebesian veins
   3. heart disease - septal defects of the heart

C. Calculation of % shunt will not be discussed at this time

D. Detection of shunts
1. hypoxemia is not removed when the subject breathes 100% O_2
   a. shunted blood is never exposed to the high PAO_2
   b. PaO_2 will inc. due to the inc. of dissolved O_2
2. normal PCO_2 can be maintained with a significant shunt present
   a. may even be low if there is enough secondary drive due to hypoxemia

IV. $\dot{V}A/\dot{Q}c$

A. There are four causes of hypoxemia
1. hypoventilation
2. diffusion defect
3. shunt
4. $\dot{V}A/\dot{Q}c$ inequality
   a. this is the most common yet difficult to understand

B. Model of the lung, figure 3
1. powdered dye is continuously added to unit representing the addition of O_2
   a. alveolar ventilation
2. water is pumped continuously through the unit to represent the blood flow which removes O_2
3. stirrer mixes the alveolar content normally accomplished by gaseous diffusion
4. **QUESTION:** What determines the dye or O_2 in the alveolar compartment and also the effluent water or blood?
5. Two factors determine the concentration of the dye
   a. rate at which the dye is added
   b. rate of which the water is pumped
6. The concentration is actually the ratio of these rates
   a. dye added at the rate of $\dot{V}$ g/min.
   b. water pumped through at $\dot{Q}$ liters/min.
   c. concentration of dye in alveolar compartment and effluent water is $\dot{V}/\dot{Q}$ g/liter
7. concentration of O_2 or PO_2 in any lung is determined by the ratio of $\dot{V}$ to $\dot{Q}$
   a. not only O_2 but also CO_2, N_2 (any gas in the lung)

V. Effect of altering the $\dot{V}A/\dot{Q}c$ of a lung unit

A. The normal $\dot{V}A/\dot{Q}c$ is shown in figure 4

B. Inc. $\dot{V}A/\dot{Q}c$ is seen as perfusion decreases in relation to vent.

C. $\dot{V}A/\dot{Q}c$ dec. as ventilation is reduced in relation to perfusion

D. A more convenient way of depicting these changes is the O_2-CO_2 diagram in figure 5
1. the line beginning at I to A to v represents all possible alveolar gas compositions in the lung when supplied with a gas of composition I and blood of composition v
2. other combinations would be possible if the mixed venous blood or inspired gas were changed

VI. Regional changes in $\dot{V}A/\dot{Q}c$ throughout the lung

A. Ventilation and perfusion increases slowly from top to bottom of the lung as seen in figure 6
   1. Q inc. more rapidly than V
   2. $\dot{V}A/\dot{Q}c$ is abnormally high at the top and low at the bottom
   3. figure 7 shows the upright lung divided into imaginary horizontal "slices"
   4. figure 8 illustrates the values which can be read on a diagram like figure 7

B. Regional changes in $\dot{V}A/\dot{Q}c$ through the lung
   1. volume of the lung in the slices is less near the apex than the base
   2. $\dot{V}A/\dot{Q}c$ dec. down the lung - all differences in gas exchange follow from this
   3. changes in PN_2 (inert gas) is by default because total pressure is the same throughout the lung
   4. pH reflects the differences in PCO_2
   5. minimum contribution of O_2 uptake in the apex is due to low blood flow, VA/Qc is higher at the apex
      a. during exercise the distribution of blood becomes more uniform

VII. Effect of $\dot{V}A/\dot{Q}c$ inequality on over-all gas exchange

A. The over-all ability to exchange gas is more important to the body as a whole as compared to regional differences
   1. $\dot{V}A/\dot{Q}c$ inequality in a lung reduces gas exchange
   2. the amount of O_2 consumed and CO_2 produced is set by the metabolic demands of the body

B. Problems in oxygenating blood with an uneven $\dot{V}A/\dot{Q}c$
   1. PO_2 is higher at the apex of the lung than at the base
      a. uneven perfusion is seen in figure 9
      b. the majority of the blood leaving the lung comes from the bases that are under ventilated as compared to perfusion
   2. O_2 carrying capacity of the blood limits the total amount that may be transported due to regional inequalities of ventilation to perfusion
      a. this condition is described in figure 10
      b. the limitations of O_2 are primarily due to its disassociation curve
      c. CO_2 disassociation curve is almost linear

C. Net results of combined factors
   1. depression of PaO_2 below PAO_2
      a. A-a difference
      b. minimal in the normal lung (4 mmHg)
   2. in a disease condition the lowering of PaO_2 by these mechanisms may be extreme

VIII. Stages of $\dot{V}A/\dot{Q}c$ Inequality

A. Effects of a "pure" ventilation-perfusion inequality
   1. both O_2 uptake and CO_2 output are reduced
      a. figure 11, the lung loses its efficiency
      b. CO_2 may actually be more affected than O_2

B. $\dot{V}A/\dot{Q}c$ "compensation"
   1. PaO_2 dec. further, $PaCO_2$ inc. more, figure 12
      a. this effect returns the O_2 and CO_2 transfer back to normal levels at the expense of causing more hypoxemia and hypercarbia
   2. central chemoreceptors become stimulated
      a. respond to inc. PCO_2

b. react by increasing ventilation until PCO_2 or $[H^+]$ levels are reached
3. PCO_2 is usually restored, PO_2 is much more difficult to compensate
   a. the reason for CO_2 compensation while O_2 does only to a lesser degree is again due to the configuration of their disassociation curves
4. some patients do not respond to inc. PCO_2 levels
   a. chronic obstructive lung patients

IX. Measurement of $\dot{V}A/\dot{Q}c$ Inequality

A. Radioactive gases
   1. usually a gross measurement
   2. cannot distinguish regional differences

B. Alveolar-arterial PO_2 differences, A-a gradient
   1. ideal can be calculated
   2. A-a difference indicates $\dot{V}A/\dot{Q}c$ state

C. Physiological shunt, venous admixture

D. Alveolar Dead Space
   1. Bohr equation
   2. inc. physiologic deadspace indicates more wasted ventilation