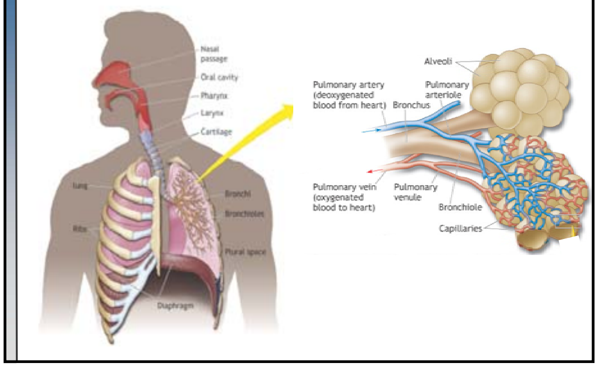
Respiratory System

Objectives

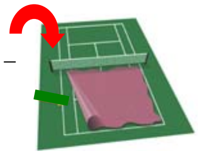
- Pulmonary Structure & function
- Gas exchange and transport
- Exercise & pulmonary ventilation

Pulmonary Anatomy



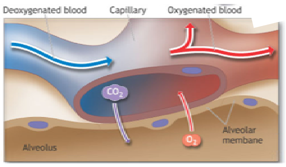
Respiration Generals

- Respiration:
  - a) Process of gas exchange, which for the human body involves oxygen and carbon dioxide
    - ✓Internal respiration (cellular)
    - ✓External respiration (lung)
- Lungs
  - a) Provide a large surface area (50 – 100 m^2)
  - b) Highly vascularized



Respiration Generals (cont.)

- Alveoli (~300 million)
  - a) Elastic & thin walled (~ 0.3mm in diameter
    - ✓During *submaximal exercise*, the integrity of wall does not change
    - ✓*Maximal exercise* may induce stress on the wall
      - ✓Large ventilation & pulmonary blood flow



Lung Specifics

- Surfactant (within the alveoli):
  - a) Phospholipoprotein molecule secreted by specialized cells of the lung that lines the *surface of alveoli & respiratory bronchioles*
  - b) Lowers surface tension of the alveolar membranes
    - ✓Prevents the collapse of alveoli during exhalation
    - ✓Increases compliance during inspiration
  - c) Distribution aided by Pores of Kohn

Mechanics of Ventilation

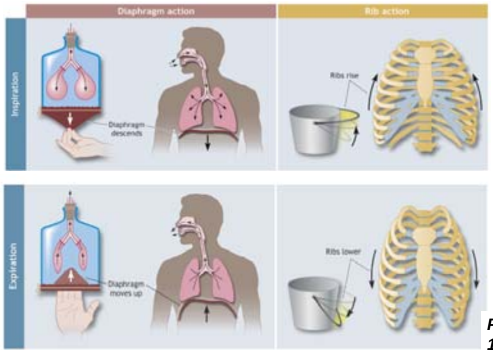
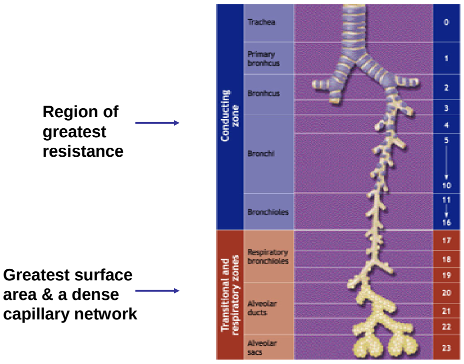


Figure 12.3

Inspiration & Expiration

- Inspiration (*muscles involved*):
  - a) Diaphragm: primary ventilatory muscle during exercise
    - ✓Scalene and external intercostals assist diaphragm
- Expiration (*during rest and light exercise*):
  - a) Predominantly passive
  - b) During strenuous exercise:
    - ✓Internal intercostals
    - ✓Abdominal muscles assist

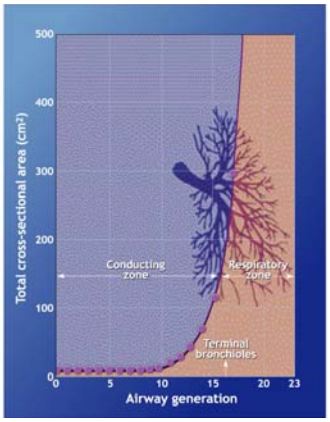
Mechanics of Ventilation (cont.)



Region of greatest resistance

Greatest surface area & a dense capillary network

Airflow in the Lungs

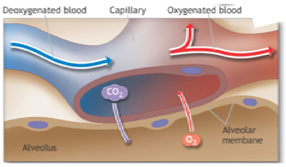


Forward airflow increases as cross-sectional area increases

Figure 12.5

Fick's Law of Diffusion

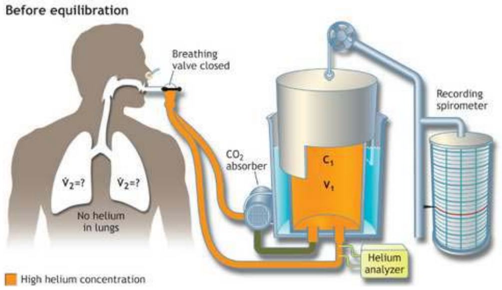
- Explains gas exchange through the alveolar membranes



- Gas diffuses through a tissue at a rate:
  - a) *Proportional to surface area (or tissue area)*
  - b) *Inversely proportional to its thickness*

Lung Volumes & Capacities

- Measured using a spirometer



Lung Volumes & Capacities (cont.)

- Lung volumes vary with:
  a) Age
  b) Size (mainly stature)
  c) Gender

1. TV: Tidal Volume *(0.4–1.0L)*
2. IRV: Inspiratory Reserve Volume *(2.5–3.5L)*
3. ERV: Expiratory Reserve Volume *(1.0–1.5L)*
4. FVC or VC: Vital Capacity *(3.5L)*
5. RLV: Residual Lung Volume *(0.8–1.4L)*

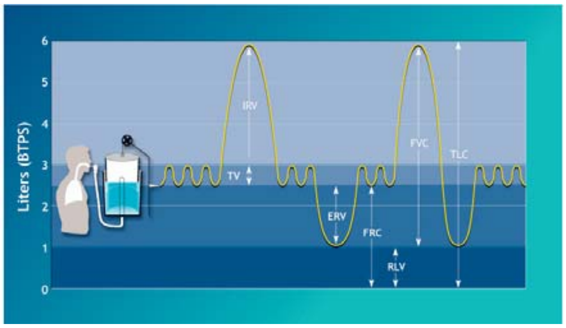


Figure 12.6

Estimating Residual Volume

- Normal-weight men & women:

$$\boxed{RLV = 0.0275(AGE) + 0.0189(HT) - 2.6139}$$

- Overweight men and women:

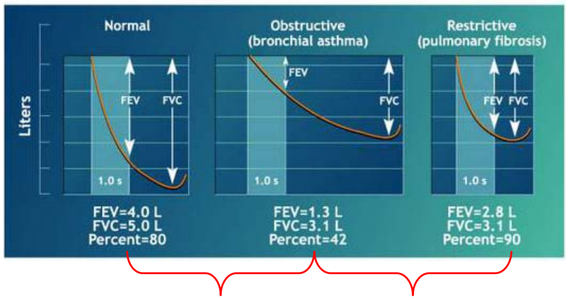
$$\boxed{RLV = 0.0277(AGE) + 0.0048(WT) + 0.0138(HT) - 2.3967}$$

  ✓ Age = years
  ✓ HT = cm
  ✓ WT = kg

Dynamic Lung Volume

- Dynamic ventilation dependent upon:
  a) FVC *(Forced Vital Capacity)*
  b) Rate (or speed) of breathing
    - ✓ Dictated by lung compliance
- Measurement techniques:
  a) FEV to FVC Ratio
    - ✓ Forced Expiratory Volume over 1 second (**FEV$_{1.0}$**) / Forced Vital Capacity
      - ✓ *Pulmonary airflow capacity*
    - ✓ Average person ~ 85% of FVC in 1 second
    - ✓ Pulmonary disease ~ as low as 40%

Examples of FEV$_{1.0}$/FVC



Variation between disease states

Dynamic Lung Volume (cont.)

  b) Maximum Voluntary Ventilation (MVV)
    - ✓ Evaluates rapid and deep breathing for 15 seconds & extrapolates to 1 minute
    - ✓ ~ 25% higher than ventilation during max exercise
      - ✓ College aged men ~ 140 to 180L·min^{-1}
      - ✓ College aged females ~ 80 to 120L·min^{-1}
- Gender differences
  a) Compromised in trained females
    - ✓ Mechanical constraints & pulmonary ventilation may affect arterial saturation
- Variations in MVV measurements will *not* predict exercise tolerance

Pulmonary Ventilation

- Minute ventilation:
  - a) Volume of air breathed each minute, V_E

V_E = Breathing rate x Tidal Volume

- Minute ventilation increases dramatically during exercise
  - a) Average person ~ 100L·min^{-1}
  - b) Values up to 200L·min^{-1} have been reported
- Despite huge increases in V_E during maximal exercise, tidal volumes rarely exceed 60% VC

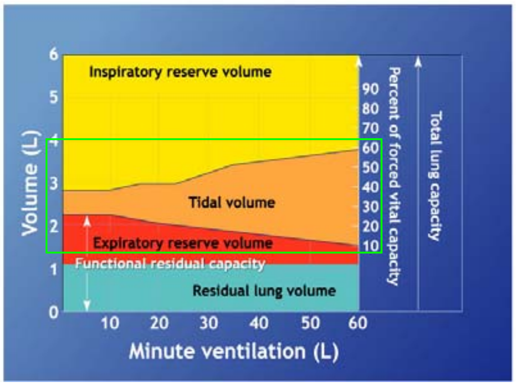


Figure 12.10

Alveolar Ventilation

- Anatomic Dead Space:
  - a) Averages 150 – 200 mL
- Only ~ 350 mL of the 500 mL TV enters alveoli

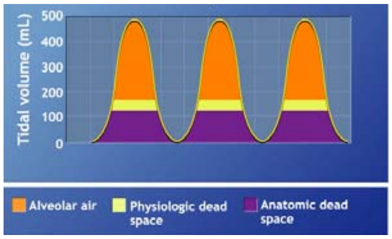
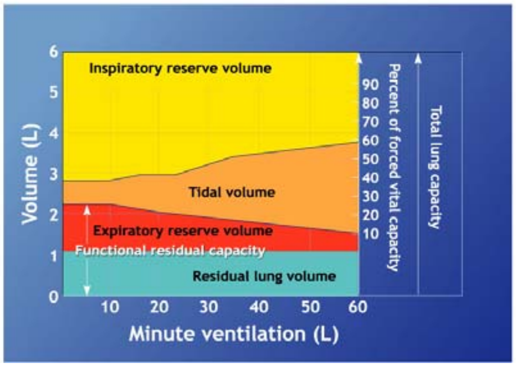


Figure 12.9

Ventilation Comparisons

- Dead Space vs. Tidal Volume
  - a) Anatomic Dead Space increases as TV increases
    - ✓ Despite the increase, increases in TV result in more effective alveolar ventilation
- Ventilation-Perfusion Ratio
  - a) Ratio of alveolar ventilation to pulmonary blood flow
    - ✓ V/Q during light exercise ~ 0.8
    - ✓ V/Q during strenuous exercise may increase up to 5.0
- Physiologic dead space
  - a) Negligible in healthy lung

- Rate vs. Depth

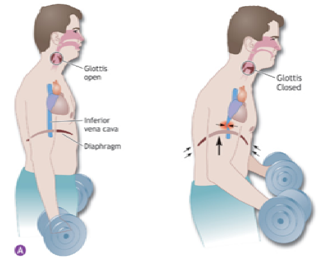


Variations in Breathing

- Hyperventilation
  - a) An increase in pulmonary ventilation that exceeds O_2 needs of metabolism
    - ✓ Decreases PCO_2
- Dyspnea
- Valsalva Maneuver
  - a) Closing the glottis following a full inspiration while maximally activating the expiratory muscles
    - ✓ Increase intra-thoracic pressure
    - ✓ Stabilizes chest during lifting

Physiologic Consequences of Valsalva

- An acute drop in BP may result from a prolonged Valsalva maneuver
  - a) Decreased venous return & blood flow to brain



Gas Exchange & Transport

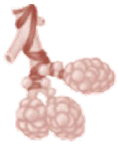
Concentration & Partial Pressure of Respired Gases

- *Partial Pressure:* percentage of concentration x total pressure of a gas
  - a) PO_2, PCO_2
- *Dalton's Law:* total pressure = sum of partial pressure of all gases in a mixture
  - a) Ambient Air
    - ✓O_2 = 20.93% or 159mmHg PO_2
    - ✓CO_2 = 0.03% or 0.23mmHg PCO_2
    - ✓N_2 = 79.04% or 600mmHg PN_2

- Tracheal air:
  - a) Water vapor reduces the PO_2 in the trachea about 10mmHg to 149mmHg

$\boxed{0.2093 \text{ x } (760 - 47\text{mmHg})}$

- Alveolar air:
  - a) Alveolar air contains ~ 14.5% O_2, 5.5% CO_2, and 80.0% N
    - ✓Average alveolar PO_2 = 103mmHg, PCO_2 = 39mmHg



$\boxed{PO_2 = 0.145 \text{ x } (760 - 47\text{mmHg})}$

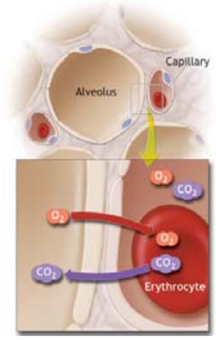
$\boxed{PCO_2 = 0.145 \text{ x } (760 - 47\text{mmHg})}$

Movement of Gas in Air & Fluids

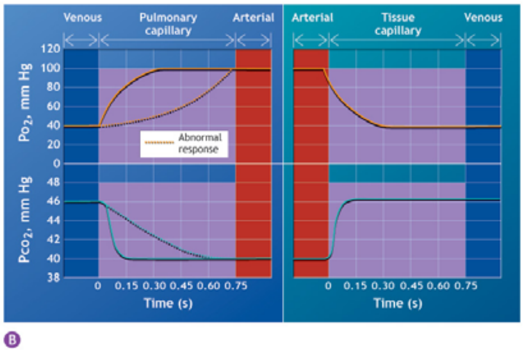
- *Henry's Law*: gases diffuse from high pressure to low pressure
- Diffusion rate depends upon:
  - a) Pressure differential (*of specific gas*)
    - ✓ Capillary to alveolar sacs
  - b) Solubility of the gas in the fluid
    - ✓ CO_2 is about 25 times more soluble than O_2
    - ✓ CO_2 and O_2 are both more soluble than N_2

Gas Exchange in Lungs:

- PO_2 in alveoli ~ 100mmHg
  - a) Drop due to venous myocardial shunt & venous draining in lungs
- PO_2 in pulmonary capillaries ~ 40mmHg



Time required for gas exchange



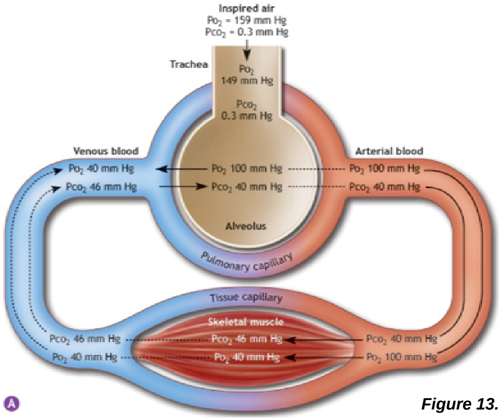


Figure 13.2

O_2 Transport in Blood

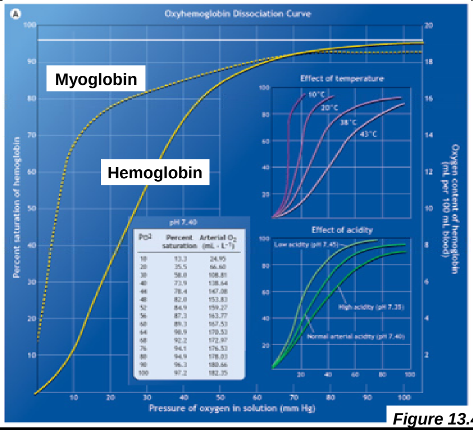
1. *Dissolved in plasma (~ 1%)*
2. *Combined with hemoglobin (~ 99%)*

- Hemoglobin (Hb)
  - a) Iron-bearing protein contained in RBC
  - b) Hb has potential to carry 4 O_2 molecules
  - c) Each gram of Hb combines with 1.34mL O_2

Blood's O_2 carrying capacity (mL·dL blood^{-1}) = Hb (L·dL blood^{-1}) x O_2 capacity of Hb

20mL O_2 = 15 x 1.34

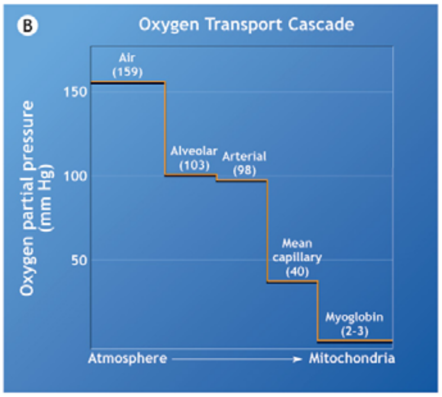
- PO_2 is primary determinant of %Hb saturation



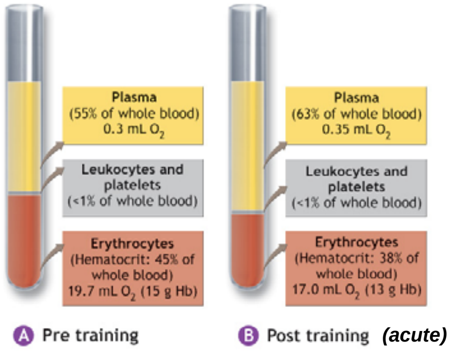
pH 7.40

PO2	Percent saturation	Arterial O_2 (mL · L^{-1})
10	13.3	24.95
20	35.5	66.60
30	58.0	108.81
40	73.9	138.64
44	78.4	147.08
48	82.0	153.83
52	84.9	159.27
56	87.3	163.77
60	89.3	167.53
64	90.9	170.53
68	92.2	172.97
76	94.1	176.53
80	94.9	178.03
90	96.3	180.66
100	97.2	182.35

Figure 13.4



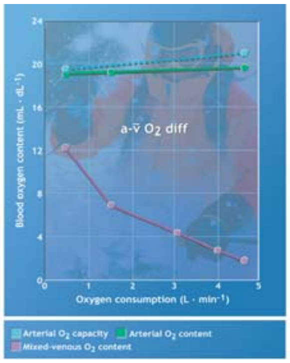
Centrifuged Whole Blood



(acute)

Arteriovenous O_2 Difference

- The a-vO_2 difference shows the amount of O_2 extracted by tissues
- During exercise a-vO_2 difference increases up to 3 times the resting value



Bohr Effect

1. An increased PCO_2 content
   - Decreases affinity of Hb for O_2
     - ✓ Hb unloads more O_2 than normal at the tissue level
2. Increased acidity
   - Increased acidity results in greater concentration of CO_2 (from carbonic acid)
3. Increased temperature
   - Results in more unloading (exercise)
4. 2,3 DPG
   - Produced by RBC when Hb is low

RBC 2,3 DPG

- RBC contain no mitochondria
  a) Rely on glycolysis
- 2,3 DPG increases with intense exercise and may increase due to training
- Helps deliver O_2 to tissues by reducing affinity of O_2

Myoglobin, Muscle's O_2 Store

- Myoglobin is an iron-containing globular protein in skeletal and cardiac muscle
- Stores O_2 intramuscularly
- Myoglobin only contains one iron atom
- O_2 is released at low PO_2

CO_2 Transport

- Three mechanisms:
  a) Bound to Hb
  b) Dissolved in plasma
  c) Plasma bicarbonate
- *Haldane effect*: Hb interaction with O_2 reduces its ability to combine with CO_2
- This aids in releasing CO_2 in the lungs

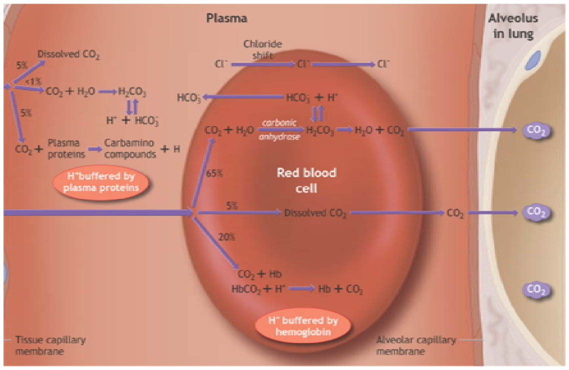


Figure 13.6