Respiratory Physiology

Three steps to respiration:
1. Pulmonary ventilation (breathing): involves the physical movement of air into/out of lungs
2. Gas exchange: involves gas diffusion between respiratory membrane and alveolar capillaries
3. Gas transport: involves the transport of O_2 and CO_2 to and from alveolar capillaries and the capillary beds in tissues

Problems with Respiration

If any of these processes are hindered, reduced gas exchange occurs – reducing cell metabolism.

- Hypoxia – low tissue O_2 levels causes reduced metabolic activities of affected areas
- Anoxia – O_2 supply completely cut off causing cell death in local area. Damage to tissue seen in:
  - Strokes
  - Heart attacks

Pulmonary Ventilation

- Physical movement of air into/out of respiratory tract
- Respiratory cycle (single breath): consists of
  - Inspiration (inhalation)
  - Expiration (exhalation)
- Respiratory rate: number of breaths per minute
  - Typical normal adult rate ~ 12-18 breaths/min
  - Typical child rate ~ 18-20 breaths/min

Pulmonary Ventilation

- Breathing maintains adequate alveolar ventilation (movement of air into/out of alveoli)
  - Provides constant supply of O_2 for bloodstream
  - Prevents built up of CO_2 in alveoli

Airflow into the Lungs

- Caused by air moving from an area of higher pressure to an area of lower pressure
- Pressure gradient: difference between air pressure at high and low pressure
- Remember: each lung is enclosed in a pleural cavity
  - Covering the lung is the visceral pleura
  - Covering the inner wall of the thoracic cavity is the parietal pleura
  - Pleural fluid in the pleural space links the pleura

Airflow into the Lungs

- As the thoracic cavity increases:
  - The parietal pleura “pulls” on the visceral pleura
    *Remember: the pleural fluid links the two pleura
  - The lung expands and the pressure of the air inside the lungs decreases
- As thoracic cavity contracts:
  - The parietal pleura “pushes” on the visceral pleura
  - The lung contracts and the pressure of the air inside the lungs increases

Airflow into the Lungs

- Changes in thoracic cavity results from movement of the diaphragm and rib cage
  - Diaphragm: forms floor of thoracic cavity
    - Flattens when contracted, increases thoracic cavity volume
    - Projects upward when relaxed, decreases thoracic cavity volume
  - Rib cage:
    - Elevation of ribs increases thoracic cavity volume
      - Caused by external intercostal and accessory muscles
    - Lowering of rib cage decreases thoracic cavity volume
      - Caused by internal intercostal and abdominal muscles

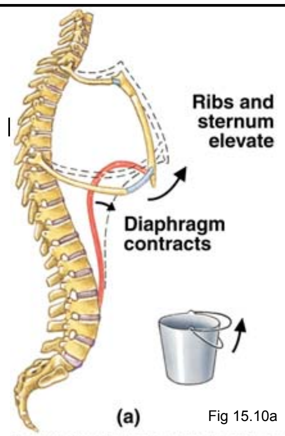

Fig 15.10a

The Respiratory Cycle

Starts with pressures inside and outside of lungs being identical: no movement of air occurs.

1. Diaphragm and respiratory muscles contract, causing:
   - Enlargement of the thoracic and pleural cavities.
   - Lungs expand, creating lower air pressure inside (P_i) compared to atmospheric pressure (P_o)
2. Air enters respiratory passageways
   - Since P_i is lower than P_o (atmospheric air pressure)

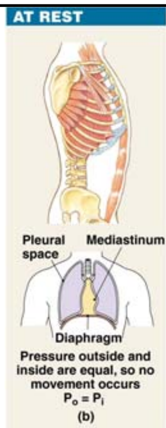

Fig 15.10b

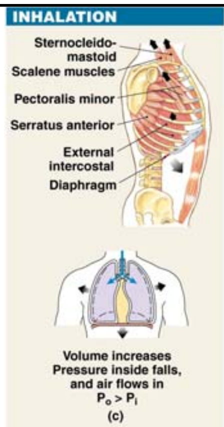

Fig 15.10c

The Respiratory Cycle

3. Diaphragm relaxes, moves up; rib cage moves down causing:
   - Compression of the thoracic and pleural cavities.
   - Lungs compress, creating higher air pressure inside (P_i) compared to atmospheric pressure (P_o)
4. Air moves out of the lungs

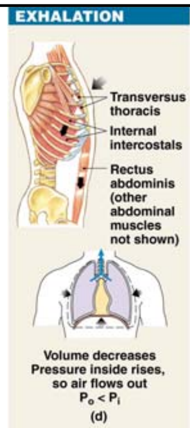

Fig 15.10d

Compliance

Compliance – resilience and ability of lungs to expand. Depends on elasticity of lungs and surface tension in alveoli

- Low compliance – greater force needed to fill and empty lungs
  - Seen in reduced surfactant production (respiratory distress disorder)
- High compliance – less force needed to fill and empty lungs
  - Seen in emphysema (loss of supporting tissue)

Modes of Breathing

Two modes:

1. Quiet breathing: inspiration involves muscle contractions but expiration is passive
   - Inspiration: contraction of diaphragm and external intercostal muscles
   - Expiration: relies on elastic recoil of lungs and relaxation of muscles to push air out

Modes of Breathing

2. Forced breathing: both inspiration and expiration uses muscles
   - Inspiration: external intercostal **and** accessory muscles (sternocleidomastoid, scalene, pectoralis minor, serratus anterior) contract
   - Expiration: internal intercostal **and** abdominal muscles contract

Lung Volumes

Tidal Volume (V_T): amount of air moved into/ out of lungs in a respiratory cycle (~500 ml)

Expiratory reserve volume (ERV): amount of air that can be expelled after the end of normal expiration (~1000 ml)

Inspiratory reserve volume (IRV): amount of air that can be taken in over normal inspiration (~3300 ml in males, ~1900 ml in females due to difference in lung size)

Lung Volumes

Vital capacity: maximum amount of air that can be moved into/out of the respiratory system in a single respiratory cycle (VC = V_T+IRV+ERV)

Residual volume: amount of air that remains in your lungs after maximal expiration (~1200 ml in males, ~1100 ml in females)

*Note: some air (~150 ml) inspired never reach the alveoli. They remain in the respiratory passages - anatomic dead space of the lungs

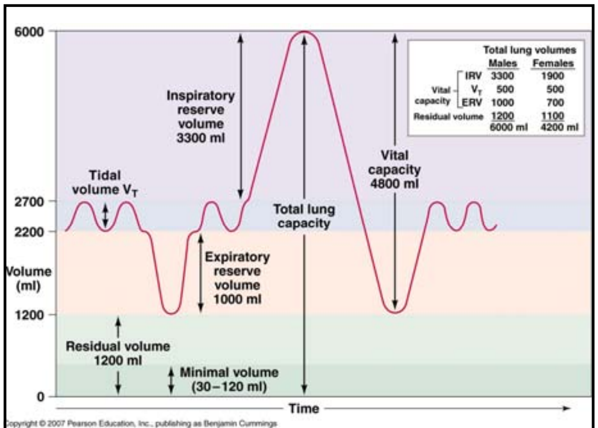

Fig 15.11

Gas Exchange

Gas exchange between the alveolus and alveolar capillary depends on:

1. Partial pressure of gases involved
   - At sea level, the partial pressure of O_2 is 159 mm Hg, the partial pressure of CO_2 is 0.3 mm Hg
2. Diffusion of molecules between a gas and a liquid

Partial Pressures

Main components of air:

1. Nitrogen (78.6%)
2. Oxygen (20.9%)
3. Carbon dioxide (0.5%)

Each gas contributes to the overall pressure of air. Their contribution is called the partial pressure of that gas. At sea level, the partial pressure of O_2 (P_{O_2}) is 159 mm Hg, the partial pressure of CO_2 (P_{CO_2}) is 0.3 mm Hg

Partial Pressures

TABLE 15-1 *Partial Pressures (mm Hg) and Normal Gas Concentrations (%) in Air*

SOURCE OF SAMPLE	NITROGEN (N_2)	OXYGEN (O_2)	WATER VAPOR (H_2O)	CARBON DIOXIDE (CO_2)
Inhaled air (dry)	597 (78.6%)	159 (20.9%)	3.7 (0.5%)	0.3 (0.04%)
Alveolar air (saturated)	573 (75.4%)	100 (13.2%)	47 (6.2%)	40 (5.2%)
Exhaled air (saturated)	569 (74.8%)	116 (15.3%)	47 (6.2%)	28 (3.7%)

Partial Pressures

As air enters the respiratory tract, the partial pressures of gases change since:

1. Air becomes warmer
2. Air becomes more humid
3. Inspired air mixes with air already in the respiratory tract (in the “dead space”)

At the alveoli, the P_{O_2} is 100 mm Hg and the (P_{CO_2}) is 40 mm Hg.

External Respiration

Difference between the P_{O_2} (100 mm Hg) of the alveolus and alveolar capillary (40 mm Hg) drives O_2 into the capillary.

Movement of CO_2 out of the capillary is also driven by difference in the P_{CO_2} in the alveolar capillary (45 mm Hg) and the alveolus (40 mm Hg)

This exchange of gases between the alveolar air and blood is called <u>external respiration</u>

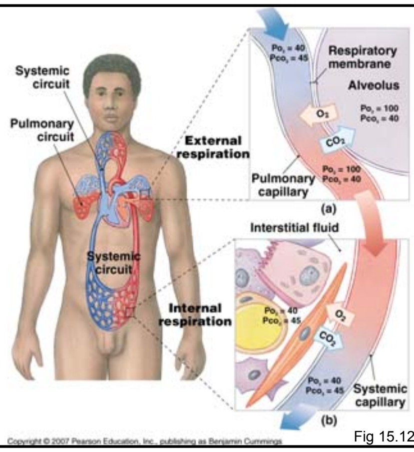

Fig 15.12

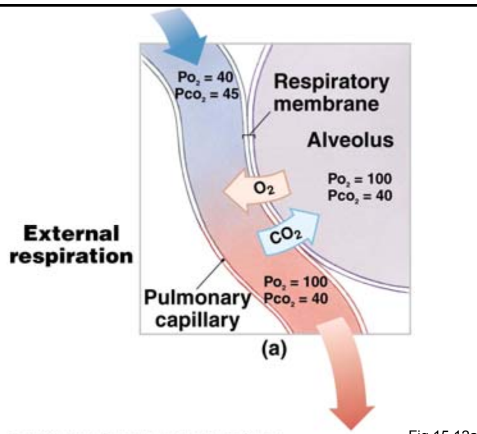

Fig 15.12a

Internal Respiration

During internal respiration, diffusion of gases occur between the oxygenated blood in the capillary and the interstitial fluid (tissues). O2 enters tissues and CO2 leaves tissues since:

- Normal interstitial fluid has a P_{O_2} of 40 mm Hg and P_{CO_2} 45 mm Hg
- Capillary blood at the arteriole end has a P_{O_2} of 100 mm Hg and P_{CO_2} 40 mm Hg

Therefore, there is a driving force of 60 mm Hg on O_2 into tissue, and 5 mm Hg of CO_2 out of tissue

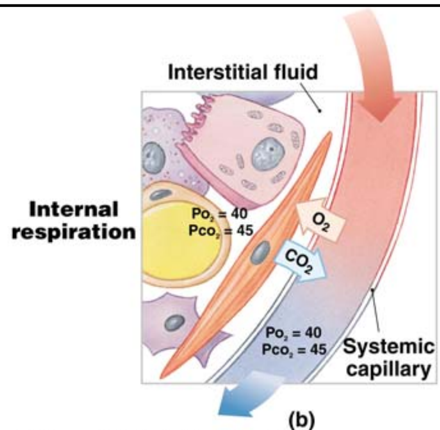

Fig 15.12b

Gas Transport: O_2

Most O_2 transported in blood is bound to hemoglobin (Hb) in red blood cells

- Only 1.5% of O_2 are transported dissolved in plasma
- Release of O2 from Hb is influenced by:
  - Partial pressure of O_2
  - pH (active tissue = lower pH)
  - Temperature (active tissue = higher temp)

Gas Transport: O_2

- More active a tissue, the lower the P_{O_2} of that tissue and the more O2 will be released from Hb
- Inactive tissue ~ P_{O_2} of 40 mm Hg, causes release of 25% of Hb bound O_2
- Active tissue ~ P_{O_2} of 15-20 mm Hg, causes release of 80% of Hb bound O_2

Gas Transport: CO_2

CO_2 is transported in blood using three reversible methods:

1. Dissolved in plasma
2. Bound to hemoglobin
3. Converted to carbonic acid (H_2CO_3)

CO_2 Transport

- Only about 7% of CO_2 is transported in blood in dissolved form
- About 27% of CO_2 can be transported by red blood cells.
  - CO_2 binds onto the protein "globin" of hemoglobin to form carbaminohemoglobin.
  - Binding of CO_2 to Hb does not alter Hb's O_2 transport function.

CO_2 Transport

- Most CO_2 (~70%) transported in the body as bicarbonate ions (from carbonic acid)
  - CO2 is converted to carbonic acid by carbonic anhydrase in red blood cells

$$CO_2 + H_2O \underset{\text{carbonic anhydrase}}{\leftrightarrow} H_2CO_3 \leftrightarrow H^+ + \underbrace{HCO_3^-}_{\text{bicarbonate ion}}$$

  - Carbonic acid rapidly dissociates into bicarbonate and H^+
    - H^+ binds to Hb
    - The RBC pumps HCO_3^- out, and Cl^- in (chloride shift)

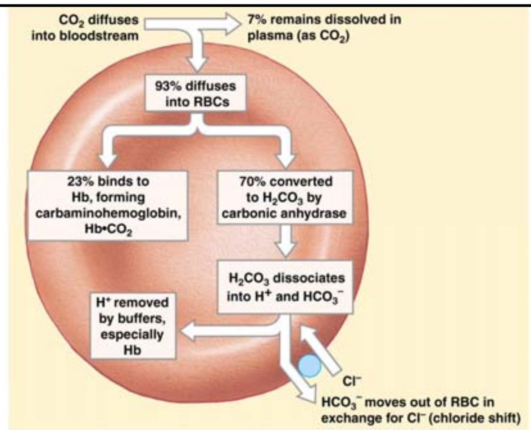

Fig 15.13

CO_2 Transport

When venous blood reaches the alveoli, CO_2 diffuses out of the plasma and the process seen in Figure 15.13 occurs in reverse to convert bicarbonate ions to CO_2 which then diffuses into the alveolus.

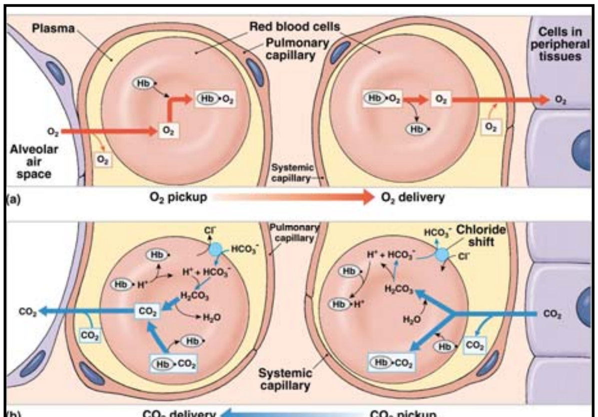

Fig 15.14

Control of Respiration

To supply a constant supply of O_2 and to remove the CO_2 generated, the body can:

1. Adjust the blood flow and O_2 delivery by local controls
2. Change the depth and rate of respiration (under the control of the brain's respiratory center)

Local Control of Respiration in Tissue

Increased tissue activity uses more O_2 (thus lowering P_{O_2}). This increases the difference in P_{O_2} between capillary blood and interstitial fluid.
Increased tissue activity also generates more CO_2. This causes relaxation of smooth muscles of arterioles in the area (increases blood flow).

Local Control of Respiration in Lung

Increased tissue activity also generates more CO_2. The CO_2 is transported to alveolar capillaries and released into the alveolar space. The increase in CO_2 causes lung bronchioles to dilate (to increase airflow to lung lobules with higher P_{CO_2}).

Respiratory Centers of the Brain

Two components:

1. Involuntary respiratory centers: medulla oblongata and pons regulate respiratory muscles to control breathing rate and depth
2. Voluntary control: cerebral cortex gives voluntary control on:
   - The output of respiratory centers
   - Respiratory muscles

Reflex Control of Respiration: Mechanoreceptor Reflexes

Activities of respiratory centers modified by information from two types of receptors:

- Mechanoreceptors: stretch and pressure receptors
  - Respond to changes in lung volume:

Hering-Breuer reflexes

- Inflation reflex prevents lungs from over inflating during forced inspiration (stretch receptors become stimulates as lungs expand, stops lung expansion near maximum volume)
- Deflation reflex prevents lung collapse during forced expiration (inhibits expiratory center and stimulates inspiratory center)

  - Respond to changes in pressure (carotid and aortic baroreceptors)

Reflex Control of Respiration: Chemoreceptor Reflexes

- Chemoreceptors: respond to changes in blood and cerebrospinal fluid. Stimulation of these chemoreceptors causes increase in respiration rate and depth.
- Centers located in carotid bodies and aortic bodies respond to:
  - pH: decreased pH caused by increase in lactic acid
  - P_{CO_2}: very sensitive. Slight drop in CO_2 is detected
  - P_{O_2}: not as sensitive as CO_2
- Receptors in medulla oblongata respond to pH and P_{CO_2} in cerebrospinal fluid

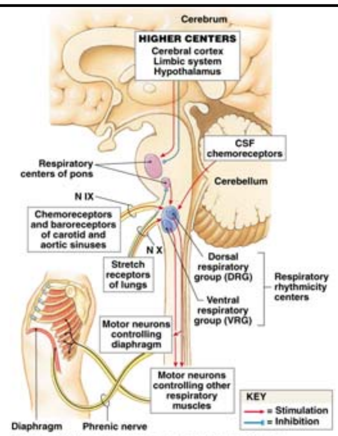

Fig 15.16

Respiratory Problems

Decompression sickness: painful condition that occurs when a person is exposed to a sudden drop in atmospheric pressure (nitrogen gas comes out of solution, forms bubbles in joint cavities, blood, cerebrospinal fluid)

Respiratory Problems

Emphysema: chronic, progressive condition characterized by shortness of breath, inability to sustain physical exertion. Cause linked to inhalation of toxic vapors (cigarette smoke), genetic factors, normal aging process

Carbon monoxide poisoning: CO has high affinity for Hb compared to O_2 and prevents O_2 binding to Hb. Treatment includes:

- Administration of pure O2
- Transfusion of red blood cells

Respiratory Problems

Lung Cancer: originate in bronchial passages or alveoli. Caused by inspiration of carcinogens (smoke, etc), genetics, high-fat/high-cholesterol diet. Symptoms include chest pain, shortness of breath, cough/ wheeze, weight loss. Treatments include surgery, radiation exposure, chemotherapy.