Chapter 23

Respiratory System

The main function of the respiratory system is to supply the body with oxygen and dispose of carbon dioxide

this is accomplished by four distinct processes
(this will be our main topics)

1. **pulmonary ventilation**
   moving air into and out of the lungs

2. **external respiration**
   gas exchange or diffusion between the blood and the air in the lungs
   (oxygen loading and carbon dioxide unloading)

3. **storage and transport of respiratory gases**
   movement of gases between the lungs and the tissues

4. **internal respiration**
   gas exchange between the blood and interstitial fluid surrounding the tissue

remember that oxygen consumption and carbon dioxide production by the cell is called cellular respiration

**mechanics of pulmonary ventilation**
the physical movement of air into and out of the respiratory tract

pressure and flow
air will flow from an area of high pressure to an area of lower pressure
this is seen in the lungs
   pressure will drop in the lungs and air flows in inspiration
   pressure will rise in the lungs and air flows out expiration

**why does the pressures in the lungs (intrapulmonary pressure) change**

**Boyle’s law**: Gas pressure and Volume

Boyle’s law \( V_1 P_1 = V_2 P_2 \)
if you decrease the volume of a gas its pressure rises
if you increase the volume of a gas its pressure falls
thus
pressure of a gas varies inversely with its volume
during breathing changes in volume result in changes in gas pressures
and this fuels airflow into and out of the lungs
air will flow from an area of high pressure to an area of low pressure

**movement of air into and out of the lungs** (pulmonary ventilation)

**during inspiration**
the volume of the parietal (thoracic) cavity and thus the lungs increases
due to
1. contraction of the diaphragm which causes it to drop
2. contraction of the external intercostals, sternocleidomastoid, serratus anterior, scalenes, and pectoralis minor
   which elevate the rib cage
thus intrapulmonary or intra-alveolar pressure drops to then atmospheric and air flows into the lungs
air flows until pressures inside and outside lungs are equal

**during exhalation**
volume of the parietal (thoracic) cavity and thus lungs decrease
due to
1. relaxation of the diaphragm
2. relaxation of the external intercostals, sternocleidomastoid, serratus anterior, scalenes and pectoralis minor
3. during active exhalation contraction of internal intercostals transverses thoracis and abdominal muscles help reduce cavity size
thus **intrapulmonary or intra-alveolar** pressure rise to 1mmHg above atmospheric and air flows into the lungs.

Air flows out until pressures inside and outside lungs are equal.

**Exhalation is added by the tendency of the lungs to collapse due to**

1. **Elastic recoil**
   - Lungs are rich in elastic fiber and try to assume the smallest size possible.

2. **Surface tension** of the alveolar fluid
   - The fluid in the alveolar tries to collapse the alveoli.
   - Surface tension is reduced greatly by a lipoprotein named **surfactant**
   - Produced by type II alveolar cells and reduced the attraction of water molecules.

Premature babies have inadequate surfactant, infant respiratory distress syndrome.

The tendency of the lungs to collapse is opposed by the suction created between the lungs and the rib cage.

Boyle’s law $V_1P_1 = V_2P_2$

If intrapleural pressure is equal to intrapulmonary or atmospheric pressure the lungs will collapse pneumothorax.

**Gas exchange at the respiratory membrane (external respiration)**

**Dalton’s law of partial pressures**
- The total pressure exerted by a mixture of gases is the sum of the pressures exerted independently by each gas.

Atmospheric pressure is 760mmHg ($760 = 100\%$)

- **Nitrogen** is 79% = $PN_2 = 600 \text{ mm Hg}$
- **Oxygen** is 21% = $PO_2 = 160 \text{ mm Hg}$

$N + O = 99\%$ or atmosphere
- Other gases $\text{H}_2\text{O}, \text{CO}_2, \text{CH}_4, \text{etc}$
the question
what fuels the movement of gas molecules from the air to the blood and from the blood to the air of the lungs?

differences in partial pressures move gas molecules from one place to another
gases move down partial pressure gradients

But we want to move O2 from the air into the liquid of the plasma

partial pressure differences affect the movement of gas molecules including the movement of gas molecules into and out of solutions like blood

Henry’s law
when a mixture of gases under pressure is in contact with a liquid each gas will dissolve in the liquid in proportion to its partial pressure

thus gas partial pressures will force gas molecules into solution eventually an equilibrium will be reached between the gas in the gas phase and the gas in the liquid phase as a molecule goes in one comes out

if the partial pressure goes up more gas molecules will go into solution
if goes down gas molecules will come out of solution

the amount of gas that is dissolved in a solution depends on several other factors the main factor is solubility of the gas in the liquid

gases in air
carbon dioxide is most soluble in plasma oxygen is 1/20 as soluble nitrogen is half as soluble as oxygen

air of the alveoli
P02 of 104 mmHg
PCO2 of 40 mmHg

blood traveling to alveoli
P02 of 40 mmHg
PCO2 of 45 mmHg
blood traveling from alveoli
P02 of 104 mmHg
PCO2 of 40 mmHg

interstitial fluid
P02 of 40 mmHg
PCO2 of 45 mmHg

Have a large PO2 but a low PCO2
but move the same amount of both
Due to the solubility of CO2

diffusion at the respiratory membrane
five reasons gas exchange at the membrane is efficient

1. large differences in partial pressure across the respiratory membrane
   larger the differences the more gas diffusion

2. gas solubility
   both CO2 and O2 are lipid soluble so can pass through the membrane
   the pressure gradient for oxygen diffusion is much steeper than carbon dioxide but equal amounts of the two gases are exchanged because carbon dioxide is 20 times more soluble

3. respiratory membrane is very thin
   thicker membranes or fluid buildup blocks gas exchange
   smoking

4. surface area for gas exchange
   greater air more exchange
   less area emphysema where walls between alveoli break

5. blood flow and airflow are coordinated
   ventilation-perfusion coupling
   blood flow is greater to alveoli with the highest partial pressure of O2
   passageways servicing areas where alveolar CO2 levels are high are dilated allowing elimination
transport of respiratory gases by blood

**oxygen**
- carried in two ways
  - bound to hemoglobin 98.5% carried here
  - dissolved in plasma
    - oxygen is lipid soluble but is very insoluble in water
    - so not very effective

**hemoglobin saturation**
- association and dissociation of oxygen and hemoglobin
  - with oxygen is oxyhemoglobin
  - without is deoxyhemoglobin

\[ Hb + O_2 \leftrightarrow HbO_2 + H \]
(tissues) (lungs)

**cooperation**
- hemoglobin as four oxygen binding sites
  - if four are bound it is called fully saturated 100%
  - if two are bound 50% saturation

- the binding of the first oxygen makes it easier for the binding of the next and so on
  - each oxygen binding changes the shape of hemoglobin and increases the affinity for another O2

**oxygen-hemoglobin dissociation curve**
- describes the effect of Parietal pressure of O2 versus saturation of hemoglobin

**important points**
1. if PO2 increases more O2 is stored on the Hemoglobin
   this happens at lung capillaries

2. if PO2 declines O2 is released from the hemoglobin
   this happens at peripheral capillaries

3. is not linear relationship due to cooperation

4. normal resting conditions arterial blood is 98% saturated
5. at the tissues saturation drops to 75% (Po2 of 40) thus have a substantial venous reserve so vigorous activity can occur without increase in respiratory rate or cardiac output

4. hemoglobin is almost completely saturated at PO2 of 70 mmHg so can survive high altitude and cardiopulmonary disease

**factors that influence hemoglobin saturation**

1. increase temperature
2. increase levels of H (Bohr effect)
3. increase levels of CO2
4. 2,3-bisphosphoglycerate (BPG) from anaerobic break down of glucose production is stimulated by fever thyroid hormones growth hormone testosterone epinephrine

these all enhance oxygen unloading at the tissues they all increase where tissues are active

**carbon dioxide transport**

CO2 is produced by the tissues as removed by the lungs

three ways of transport

1. **dissolved in plasma- 7 to10%**

2. **chemically bound to hemoglobin- 20 to 30%**
   more is loaded when PCO2 is high
   more is loaded when PO2 is low (Haldane effect)

3. **bicarbonate ion in plasma-60 to 70%**
   \[
   \text{CO2} + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^- \]

**Systemic gas exchange**

For every O2 used one molecule of CO2 is produced

CO2 loading and O2 unloading
Tissue PCO2 gradient 46 to 40 in blood
Tissue PO2 is 95 in blood 40 in tissue fluid
CO2 diffuses into blood steam
O2 diffuses into tissue fluid
1. Most CO2 diffuses into RBC and combines with water forming carbonic acid which is unstable and dissociates into hydrogen ions and bicarbonate ions

\[
\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^-
\]

CO2 + H2O is catalyzed by carbonic anhydrase in RBC

The HCO3 diffuses from cell into blood results in chloride shift into cell

the H binds to hemoglobin aiding in O2 unloading the Bohr effect
O2 is already unloading due to partial pressure gradient

2. some CO2 binds to the amino acids of hemoglobin producing carbaminohemoglobin
this form of Hb has a lower affinity for O2 so more is unloaded
Haldane effect
O2 is already unloading due to partial pressure gradient

3. small amount will dissolve in the blood steam

alveolar gas exchange

in the lungs where PCO2 is lower (40 in lungs vs. 46 in blood)
PO2 is 104 in lungs 40 in blood

CO2 diffuses from blood to lungs
O2 diffuses from lungs to blood

1. this forces the carbonic anhydrase to reverse its direction and bicarb reenters the RBC and CO2 and H2O are produced and removed by diffuse into the lungs
here have a chloride shift into out of the RBC
also are removing the H so Hb has greater affinity of O2 reverse the Bohr effect
2. CO2 diffuses of the Hb and this also increases affinity of Hb for O2 so load more O2
thus loss CO2 and H

control of respiration

respiratory center of medulla oblongata
called the respiratory rhythmicity center
two areas of the reticular formation
1. dorsal respiratory group
   sends neurons to intercostal muscles and diaphragm
   controls inspiration
   is called the pacesetter
2. ventral respiratory group
   sends neurons to control muscles of active exhalation
   active only during forced expiration
sets the basic pace of respiration which can be modified by inputs from other areas

modifiers of the medullar respiratory center

pons respiratory center
   sends neurons to medulla oblongata
   smooth out the transition from inspiration and expiration
   adjust respiratory rate and depth of respiration
the respiratory centers are primarily controlled by information set from
chemoreceptors
   central chemoreceptors of the medulla
   peripheral chemoreceptors
      located in the aortic bodies and the carotid bodies
they monitor levels of CO2 O2 and H
1. CO2
   is most potent and most closely controlled
in the central chemoreceptors it is actually the fact that high CO2 levels gives H and it is the H that increase respiration

2. H levels
   peripheral chemoreceptors

   even if O2 and CO2 levels are ok
   low pH stimulates increased ventilation
   this will blow off CO2 and raise pH

3. PO2
   very low PO2 levels (60mmHg) will stimulate the receptors to increase respiration

baroreceptors
   located in the carotid bodies and aortic bodies
   drop in blood pressure increases respiratory rate
   increase on blood pressure decreases respiratory rate

stretch receptors
   Hering-Breuer reflexes
   Inflation reflex
   Stretch receptors prevent the over inflation of the lungs by inhibiting the dorsal respiratory group
   Deflation reflex
   Stretch receptors prevents under inflation of the lungs during forced exhalation by inhibition the ventral respiratory group

voluntary control of respiration

hypothalamic control
   sends neurons to pons
   emotions activate the limbic system which influence the hypothalamus with signals the respiratory centers

cortical controls
   sends neurons to hypothalamus with are forwarded to the pons
   we can exert conscious control over rate and depth of breathing