# Physiology of Respiratory System

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# Brief Anatomy

- Alveoli are microscopic thin-walled air sac that provide an enormous surface area for gas diffusion
  - The region of the lungs where gas exchange with the blood occurs is known as the respiratory zone
  - The trachea, bronchi, and bronchioles that deliver air to the respiratory zone comprise the conducting zone
- The thoracic cavity is limited by the chest wall and diaphragm
  - The structures of the thoracic cavity are covered by thin, wet, pleural membranes
  - The lungs are covered by a visceral pleura that is normally flush against the parietal pleura that lines the chest wall
  - The potential space between the visceral and parietal pleurae is called the intrapleural space

# Physical Aspects of Ventilation

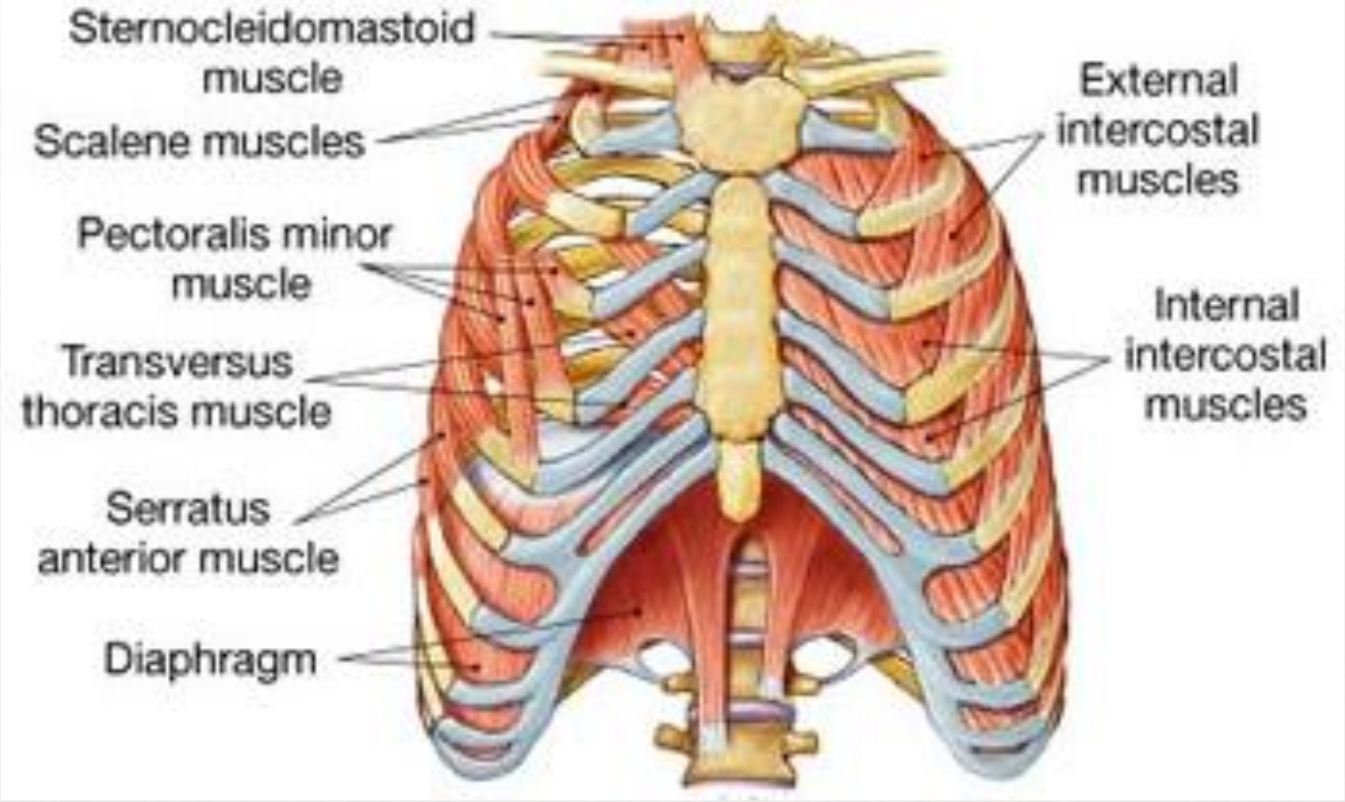
- The intrapleural and intrapulmonary pressures vary during ventilation
  - The intrapleural pressure is always less than the intrapulmonary pressure
  - The intrapulmonary pressure is subatmospheric during inspiration and greater than the atmopheric pressure during expiration
  - Pressure changes in the lungs are produced by variations in the lung volume, in accordance with the inverse relationship between the volume and pressure of a gas described by Boyle's law

- The mechanics of ventilation are influenced by the physical properties of the lungs
  - The compliance of the lungs, or the ease with which they expand, refers specifically to the change in lung volume per change in transpulmonary pressure (the difference between intrapulmonary pressure and intrapleural pressure)
  - The elasticity of the lungs refers to their tendency to recoil after distension
  - The surface tension of the fluid in the alveoli exerts a force directed inward, which acts to resist distension

- On first consideration, it would seem that the surface tension in the alveoli would create a pressure that would cause small alveoli to collapse and empty their air into larger alveoli
  - This would occur because the pressure caused by a given amount of surface tension would be greater in smaller alveoli than in larger alveoli, as described by the law of LaPlace.
  - Surface tension does not normally cause the collapse of alveoli, however, because pulmonary surfactant (a combination of phsopholipid and protein) lowers the surface tension sufficiently
  - In hyaline membrane disease, the lungs of premature infants collapse because of a lack of surfactant

# Mechanics of Breathing

- Inspiration and expiration are accomplished by the contraction and relaxation of striated muscles
  - During quiet inspiration, the diaphragm and external intercostal muscles contract and thus increase the volume of the thorax
  - During quiet expiration, these muscles relax, and the elastic recoil of the lungs and thorax causes a decrease in thoracic volume
  - Forced inspiration and expiration are aided by contraction of the accessory respiratory muscles
- Spirometry aids the diagnosis of a number of pulmonary disorders
  - In restrictive disease, such as pulmonary fibrosis, the vital capacity measurements is decreased to below normal
  - In obstructive disease, such as asthma and bronchitis, the forced expiratory volume is reduced to below normal because of increased airway resistance to air flow.


Sternocleidomastoid muscle
Scalene muscles
Pectoralis minor muscle
Transversus thoracis muscle
Serratus anterior muscle
Diaphragm
External intercostal muscles
Internal intercostal muscles

# Gas Exchange in the Lungs

- According to Dalton's law, the total pressure of a gas mixture is equal to the sum of the pressures that each gas in the mixture would exert independently
  - The partial pressure of a gas in a dry gas mixture it thus equal to the total pressure times the percent composition of that gas in the mixture
  - Since the total pressure of a gas mixture decreases with altitude above sea level, the partial pressures of the constituent gases likewise decrease with altitude
  - When the partial pressure of a gas in a wet gas mixture is calculated, the water vapour must be taken into account

- According to Henry's law, the amount of gas that can be dissolved in a fluid is directly proportional to the partial pressure of that gas in contact with the fluid.
  - Normal arterial blood has a P(O2) of 100mmHg, indicating a concentration of dissolved oxygen of 0.3ml per 100ml of blood; the oxygen contained in red blood cells (about 19.7 per 100ml of blood) does not affect the P(O2) measurement

- The P(O2) and P(CO2) measurement of arterial blood provide information about lung function

- In addition to proper ventilation of the lungs, blood flow (perfusion) in the lungs must be adequate and be matched to air flow (ventilation) in order for adequate gas exchange to occur

- Abnormally high partial pressures of gases in blood can cause a variety of disorders, including oxygen toxicity, nitrogen narcosis and decompression sickness

# Regulation of Breathing

- The rhythmicity center in the medulla oblongata directly controls the muscles of respiration
  - Activity of the inspiratory and expiratory neurons varies in a reciprocal way to produce an automatic breathing cycle
  - Activity in the medulla is influenced by the apneustic and pneumotaxic center in the pons, as well as by sensory feedback information
  - Conscious brething involves direct control by the cerebral cortex via corticospinal tracts

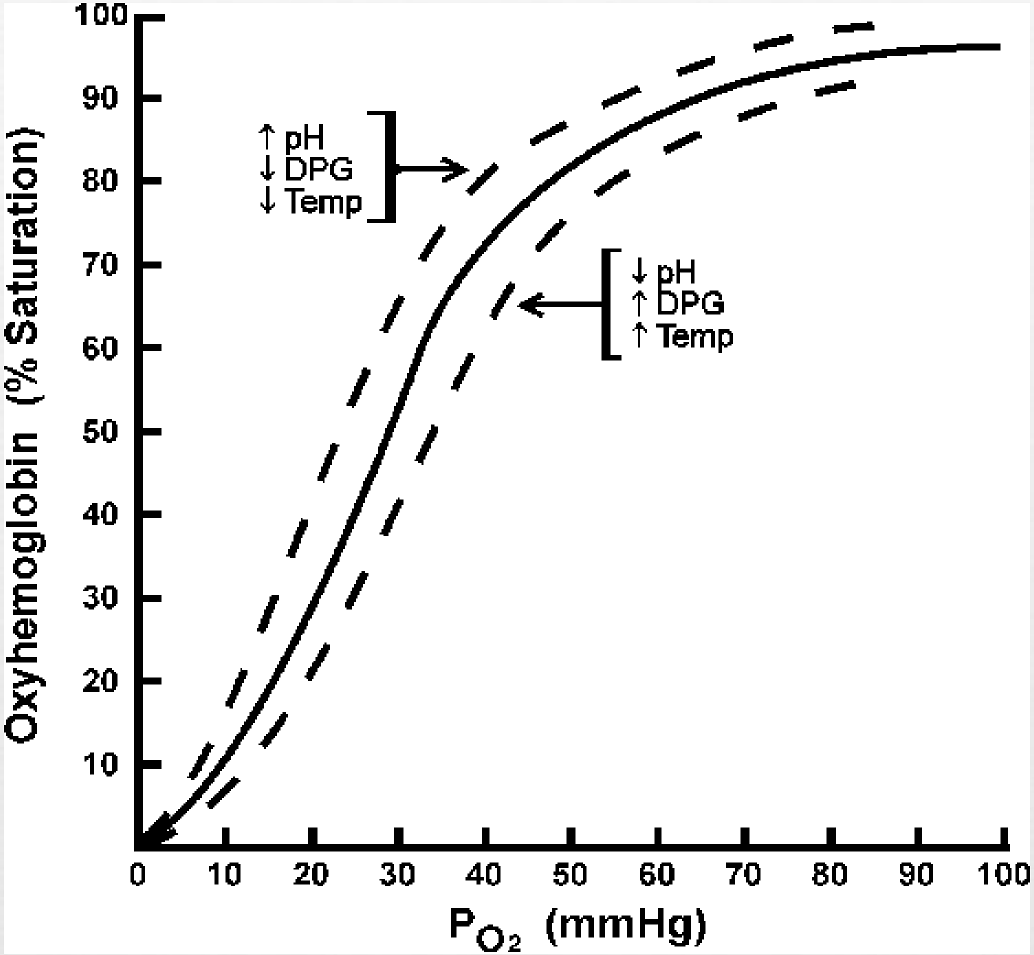
- Breathing is affected by chemoreceptors sensitive to the P(O2), pH and P(CO2) of the blood
  - The P(CO2) of the blood and consequent changes in pH are usually of greater importance than the blood P(O2) in the regulation of breathing
  - Central chemoreceptors in the medulla oblongata are sensitive to changes in blood P(CO2) because of resultant changes in the pH of the cerebrospinal fluid.
  - The peripheral chemoreceptors in the aortic and carotid bodies are sensitive to changes in blood P(CO2) indirectly, because of consequent changes in blood pH

- Decreases in blood P(O2) directly stimulate breathing only when the blood P(O2) is lower than 50mmHg. A drop in P(O2) also stimulates breathing indirectly, by making the chemoreceptors more sensitive to changes in P(CO2) and pH.
- At tidal volumes of 1L or more, inspiration is inhibited by stretch receptors in the lungs (the Hering, Breuer reflex). A similar reflex may act to inhibit expiration.
  - Hering Breuer reflex
    - A reflex triggered to prevent over0inflation of the lungs

# Haemoglobin and Oxygen Transport

- Haemoglobin is composed of two alpha and two beta polypeptide chains and four haeme groups, each containing a central atom of iron
  - When the iron is in the reduced form and not attached to oxygen, the haemoglobin is called deoxyhaemoglobin, or reduced haemoglobin; when it is attached to oxygen, it is called oxyhaemoglobin
  - If the iron is attached to carbon monoxide, the haemoglobin is called carboxyhaemoglobin.
  - Deoxyhaemoglobin combines with oxygen in the lungs (the loading reaction) and breaks its bonds with oxygen in the tissue capillaries (the unloading reaction). The extent of each reaction is determined by the P(O2) and the affinity of haemoglobin for oxygen.

- A graph of percent of oxyhaemoglobin saturation at different values of P(O2) is called an oxyhaemoglobin dissociation curve




At rest, the difference between arterial and venous oxyhaemoglobin saturations indicates that about 22% of the oxyhaemoglobin unloads its oxygen to the tissues

During exercise, the venous P(O2) and percentage of oxyhaemoglobin saturation are decreased, indicating a higher percent of oxyhaemoglobin unloaded its oxygen to the tissues

- The pH and temperature of the blood influence the affinity of haemoglobin for oxygen and thus the extent of loading and unloading
  - A fall in pH decreases the affinity of haemoglobin for oxygen, and a rise in pH increases the affinity. This is called the Bohr effect.
  - A rise in temperature decreases the affinity of haemoglobin for oxygen
  - When the affinity is decreased, the oxyhaemoglobin dissociation curve is shifted to the right. This indicates a greater percentage unloading of oxygen to the tissues
- The affinity of haemoglobin for oxygen is also decreased by an organic molecule in the red blood cells called 2,3-diphosphoglyceric acid (2,3-DPG)
  - Since oxyhaemoglobin inhibits 2,3-DPG production, 2,3-DPG concentrations will be higher when anaemia or low P(O2) [as in high altitude] causes a decrease in oxyhaemoglobin
  - If a person is anaemic, the lowered haemoglobin concentration is partially compensated for because a higher percent of the oxyhaemoglobin will unload its oxygen as a result of the effect of 2,3-DPG
  - Foetal haemoglobin cannot bind to 2,3-DPG, and thus it has a higher affinity for oxygen than the mother's haemoglobin. This facilitates the transfer of oxygen to the foetus
- Inherited defects in the amino acid composition of haemoglobin are responsible for such diseases as sickle-cell and thalassaemia
- Striated muscles have myoglobin, a pigment related to haemoglobin, which can combine with oxygen and deliver it to the muscle cell mitochondria at low P(O2) values.

# Carbon Dioxide Transport and Acid-Base Balance

- Red blood cells contain an enzyme ~~called carbonic~~ anhydrase, which catalyses the reversible reaction whereby carbon dioxide and water are used to form carbonic acid
  - This reaction is favoured by the high P(CO2) in the tissues capillaries, and as a result, carbon dioxide produced by the tissues is converted into carbonic acid in the red blood cells
  - Carbonic acid then ionizes to form H+ and HCO3- (bicarbonate)
  - Since much of the H+ is buffered by haemoglobin, but more bicarbonate is free to diffuse outward, an electrical gradient is established that draws Cl- into the red blood cells. This is called the chloride shift
  - A reverse chloride shift occurs in the lungs. In this process, the low P(CO2) favours the conversion of carbonic oxide to carbon dioxide, which can be exhaled

- By adjusting the blood concentration of carbon dioxide and thus of carbonic acid, the process of ventilation helps to maintain proper acid-base balance of the blood
  - Normal arterial blood pH is 7.40; a pH less than 7.35 is termed acidosis, and a pH greater than 7.45 is termed alkalosis
  - Hyperventilation causes respiratory alkalosis, and hypoventilation causes respiratory acidosis
  - Metabolic acidosis stimulates hyperventilation, which can cause a respiratory alkalosis as a partial compensation