EXSS2027 EXERCISE PHYSIOLOGY FOR CLINICIANS

GAS EXCHANGE AND TRANSPORT

- **Understand what O2 is for**
- Oxygen is needed to create ATP, the form of energy we use to create movements.
- Water reacts with phosphate bonds (which store energy), releasing the bonds releases the energy for exercise, and producing ADP which can be reformed into ATP.
- Note: the rate we split ATP determines the type of muscle fibre (i.e fast twitch splits ATP very quickly).
- There are 3 primary mechanisms involving ATP:

Sodium-Potassium Pump	Myosin Head Reloading	Calcium Uptake Pump
▪ There are naturally higher extracellular Na^+ levels and intracellular K^+ levels ▪ Na^+ wants to enter due to [ ] gradient, but this interrupts ATP use, so pumps allow opposite movement (inside to outside). ▪ ATP binds with the pump, releasing energy and allows movement. ▪ $3Na^+$ leave and $2K^+$ enter, leaving charge of -1, causing depolarisation (AP generated).	▪ Myosin and actin form the crossbridge, which when broken, allows the powerstroke that causes muscle contraction. ▪ If ATP is unavailable, the myosin head gets caught on the crossbridge so muscles would have permanent contracture.	▪ The muscles can't relax until calcium is pulled back out of the active state. ▪ This pump allows sucking back of calcium ions into SR so muscle can relax and contract continuously.

- **Explain the physical processes that allow us to inhale and exhale**
- The purpose of the respiratory system is to allow us to consume oxygen and expire CO_2
- The lungs primary role is to absorb oxygen for gas exchange (same role as the entire respiratory system).
- The respiratory system can be broken down into 2 components: the conducting zone and the respiratory zone
  - Air enters the nasal cavity through the pharynx, down to trachea and enters the left and right bronchus which branch into bronchioles, then terminal bronchioles (interface with the alveoli).
  - Conducting zone: pharynx, trachea and everything above the terminal bronchioles which filter the air of bacteria and microbes to prevent infection. They also humidify the air to prevent lungs drying out and ceasing to function.
  - Respiratory zone: where gas exchange occurs
- Boyles Law: $Pressure_1 \times Volume_1 = P_2 \times V_2$. Inverse relationship between volume and pressure.
- During inspiration, the diaphragm and external intercostal muscles contract, increasing intrathoracic volume whilst decreasing intrapulmonic pressure. Due to the reduced pressure, air moves into the lungs.
- During expiration, the opposite happens, inspiratory muscles relax decreasing the intrathoracic volume, and hence increasing intrapulmonic pressure, thus air will move out of the lungs.
- During exercise, other muscles contribute to lung capacity, allowing more efficient respiration.

- **Describe Fick's law of diffusion and how it determines the amount of oxygen reaching arterial blood in healthy lungs and diseased lungs**
- Air is comprised of 20.9% oxygen, constant at all altitudes (reduction in total particles causes hypoxia, due to the weight of air particles at the top of the air column causing greater density at sea level).
- Partial pressure: the pressure exerted by an individual gas in a mixture of gases.
- Dalton's Law: states that the pressure exerted by a mixture of gases is equal to the sum of the partial pressure of each individual gas: $P_{total} = P_1 + P_2 + \ldots P_n$
- PO_2= barometric pressure x $\%O_2$ in the air (remains 20.9% always).

- Thus at sea level when barometric pressure is 760mmHg, PO_2=159mmHg. Compared to PO_2 at summit of Mt Everest where barometric pressure is 253 (x0.209=53mmHg).
- Fick's Law of Diffusion states that a volume of gas diffusing is proportional to the surface area available for diffusion, the diffusion coefficient, thickness of the membrane and the difference in partial pressure of gases:

$$V_{gas} = \frac{A \times D \times (P_1 - P_2)}{T}$$

A= area

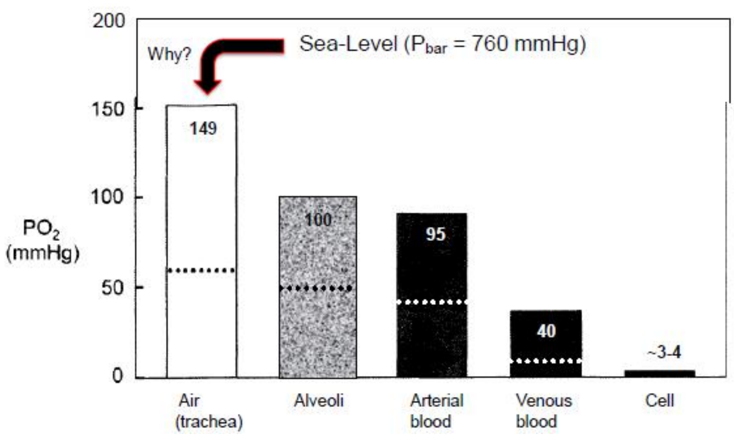
T= thickness

D= diffusion coefficient

P_1-P_2= difference in partial pressure between two sides

- Henry's law states that the amount of gas dissolved in any fluid depends on the temperature and partial pressure of gas (eg. soft drinks). So the amount of gases dissolved in blood is directly dependent on their partial pressures (since temperature remains the same).
- In people with emphysema, there is a reduction of alveoli and hence less surface area for gas exchange. An application of Fick's Law then states that there will be reduced diffusion.
- In fibrotic lung disease, there is a thickened alveolar membrane which slows gas exchange. Loss of lung compliance may decrease alveolar ventilation.

- **Understand the "oxygen cascade" and how and why PO2 changes from ambient to the alveoli, to the arterial blood, then to venous blood**
- The oxygen cascade describes the decline of PO_2 from the environment to the cellular level.
  - Inspired oxygen: 760 x 0.209= 159mmHg
  - Air in the lungs is saturated with water (humidified by the trachea), which has a partial pressure of 47mmHg (thus reduction in partial pressure of oxygen by 47mmHg): (760-47) x0.209 = 149mmHg.
  - At 149mmHg, the oxygen reaches the alveoli, where there is CO_2 present. The oxygen mixes with the CO_2 resulting in an alveolar PO_2 of 100mHg.
  - Alveoli (100mmHg) to arterial blood (95mmHg) has a 5mmHg drop due to imperfect diffusion and shunt (when alveoli of lungs are perfused but ventilation fails to supply perfused region, V/Q is too low)
  - From the arterial blood (95mmHg) to the venous blood (40mmHg) there is a substantial drop due to the mixture of CO_2 (45mmHg), and thus according to Dalton's Law, their combined partial pressures equal the total (rapid diffusion due to the large partial pressure difference).
- Pulmonary Transit Time: the amount of time a red blood cell is in contact with the respiratory membrane (alveoli). The longer the time, the more gas exchange occurs.
- Normally around 0.75 seconds at rest, but reduces to 0.25 during exercise (because of blood being pumped around the body faster). This is still sufficient time to get oxygen.

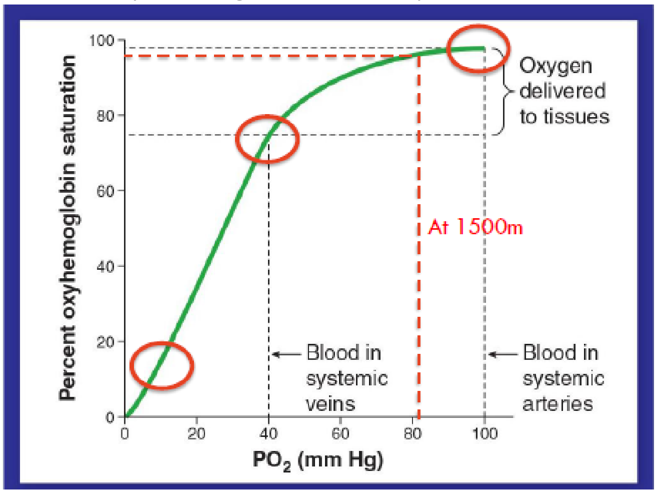


- **Understand how oxygen is transported via the bloodstream, and explain the importance of both ways**
- Oxygen is carried in 2 forms in the blood, either:
  - Bound to haemoglobin (>98%)
    - Forming oxyhaemoglobin. The concentration of haemoglobin determines the amount of O_2 that can be transported.
    - Haemoglobin is 4 subunits with a haem on it which oxygen binds to (so can carry 4 molecules). Once the first bind is made, it attracts more oxygen to bind.
  - Dissolved in the blood (1-2%).

- The amount obeys Henry's Law which states that gas dissolved in any fluid depends on the temperature and partial pressure of the gas.

- Myoglobin transports oxygen throughout the muscles (both cardiac and musculoskeletal). It functions similarly to haemoglobin as both uptake oxygen and take it where it needs to go.
- Myoglobin dissociation curve is similar to haemoglobin, both substances have the ability to become saturated with oxygen, though saturation of myoglobin is always higher than haemoglobin.
- Where haemoglobin starts to release oxygen at around 60mmHg, myoglobin doesn't until around 30mmHg.

- **The haemoglobin-oxygen dissociation curve, its benefits and shifts in response to changes**
- Haemoglobin concentration determines how much oxygen can be transported by the blood.
- Saturation is a measure of how many binding sites are occupied. If every haemoglobin molecule is carrying 4 oxygens, the saturation is 100%, though this level is never reached.
- Arterial oxygen content = saturation x [Hb]
- Saturation depends on the oxygen pressure of the environment. If the oxygen is abundant, greater saturation, but at lower PO_2, the oxygen is unloaded to deoxygenated tissues. So saturation decreases through the tissues.
- The significance of the shape of the curve is that due to the plateau, when oxygen content of alveolar air decreases below normal, saturation remains high.
- Although note that when PO_2 is low, the curve is steep so small changes cause large changes to saturation.
- When PO_2 is at at around 80mmHg, the saturation is 100%, with the point to get as much as possible to transport all of it around the body (plateau).



- At 40mmHg, the saturation is still high, which means still have close to 100% saturation at moderate altitudes.
- The graph will shift to the left when there is more affinity, and shift to the right with less affinity (more affinity means they won't let go, so harder to get oxygen into the cells).
  - If body temperature increases, curve shifts to the right, so haemoglobin will release lots of O_2 to be used by the body (eg. exercise).
  - If pH decreases, shifts to the right, as indicates high levels of CO_2 and hence increased need for oxygen.