



Respiratory system physiology

Doctor yanal shafagoj's notes

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• Pulmonary resistance ($R_{\text{pulmonary}}$)

We have previously discussed AIRWAY resistance, which refers to the resistance encountered by AIR in the airways. It's influenced by the radius and net cross-sectional area, impacting air flow.

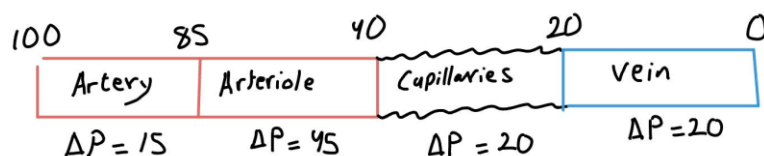
In this lecture we will delve into **pulmonary vascular resistance**.

- ✓ According to ohm's law, flow is directly proportional to the driving force and inversely proportional to resistance.

$$\text{Flow} = \Delta P / R$$

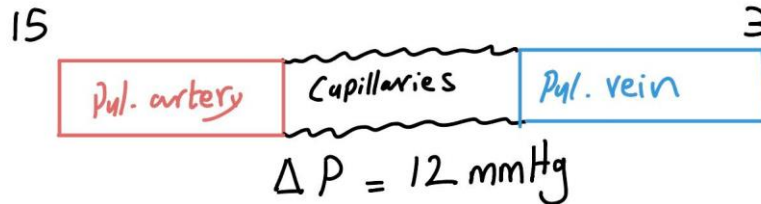
➤ Pulmonary resistance Vs Systemic resistance

- ✓ Blood is in a closed system, so the flow is the same in the pulmonary circulation and systemic circulation (5L).
 - However, systemic Mean Arterial Pressure (100mmHg) is much higher than the pulmonary arterial pressure (14mmHg)
 - This is because blood in systemic circulation encounters **higher resistance** from 4 segments of vessels (arteries, arterioles, capillaries, veins). Therefore, it requires **higher pressure** to overcome the resistance and maintain constant flow.
 - The higher pressure results in **more work** on the left ventricle pumping blood against greater resistance, explaining the thicker wall in the left ventricle.

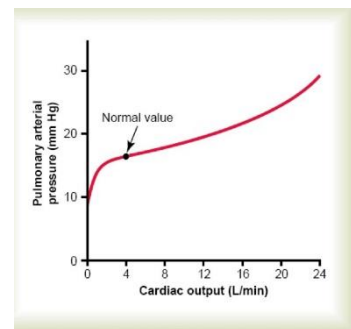


- analyzing ΔP values reveals that the highest value in the arterioles was to overcome the highest resistance offered by them, making them the main contributors of TPR resistance.

- ✓ In the pulmonary circulation (a low-pressure system), the pressure exerted by the right ventricle is to overcome the much lower resistance offered by 3 segments (pulmonary artery, capillaries, pulmonary vein).



- The pressure is somewhat equal in each segment, each contributing by 4mmHg to the total pulmonary resistance.
 - Total contribution of the pulmonary circulation to TPR is 1% (negligible).
- Pulmonary resistance during exercise
- ✓ As stated by ohm's law, arterial pressure is the product of cardiac output(Q) and Resistance(R) $\Delta P=Q \times R$
 - During exercise, cardiac output increases 5 times its normal value at rest (5L→25L)
 - One might expect an equal increase in arterial pressure, but what actually happens is that the ΔP increases Less than 2 times its normal value at rest (15mmHg→25mmHg, less than 30)
 - This is because pulmonary resistance decreases significantly ($R \downarrow \downarrow$) during exercise, making it easier for the driving force to push this extra blood. Thus, pulmonary pressure rises very little even during maximum exercise. Otherwise, each time you exercise you will pose yourself to the risk of pulmonary hypertension.
 - it's considered pulmonary hypertension if: $\Delta P= 25$ at rest & $\Delta P= 30$ during exercise



How can the body decrease pulmonary resistance significantly? By 2 mechanisms:

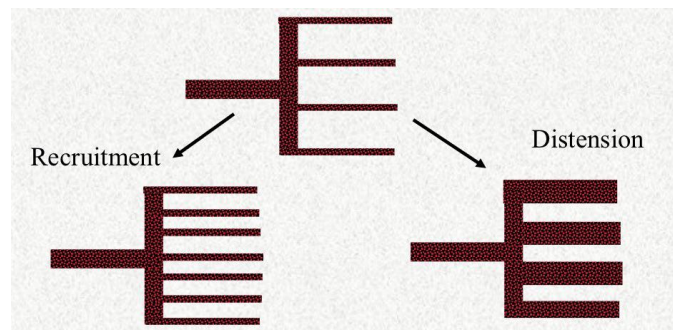
- R is inversely proportional to radius ($R=1/r^4$), so you can increase the radius of capillaries → **Distention**

Distention: distending all capillaries and increasing the rate of flow.

- R is inversely proportional to the net cross-sectional area, so you can increase the number of capillaries → **Recruitment**

Recruitment: increasing the number of open capillaries.

- ❖ At rest, only one-third of capillaries are open due to the contraction of precapillary sphincters.
- ❖ During exercise, the remaining two-thirds of capillaries open due to the relaxation of precapillary sphincters.



- This property makes pulmonary vessels much more compliant than systemic blood vessels.

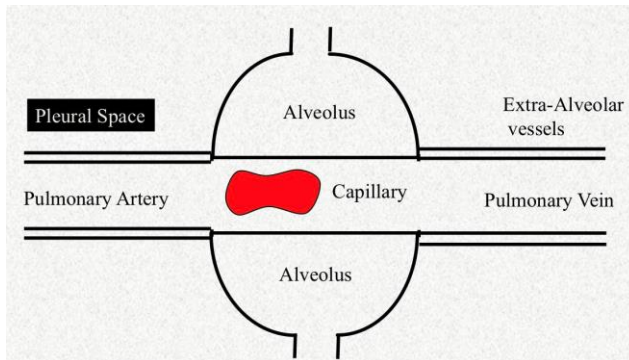
Q: true or false, all of the following decreases during exercise:

1. Time RBCs spend in capillaries (True, remember cardiac cycle is shorter during exercise)
2. Arterial blood gases (False, they remain unchanged)
3. Pulmonary vascular resistance (True, by recruitment and distention of capillaries)

➤ pulmonary vascular resistance and volume of air

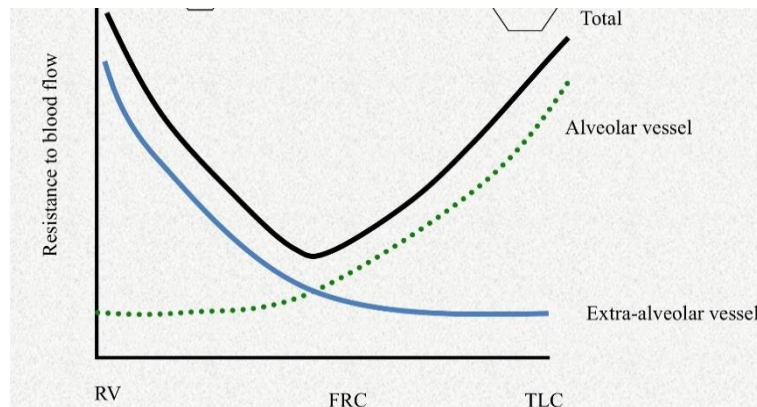
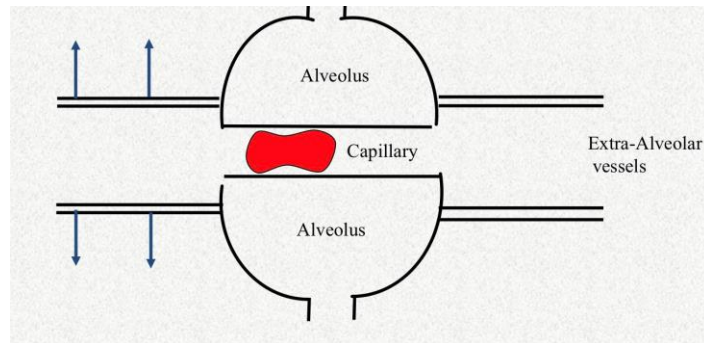
Something special about pulmonary circulation resistance is that it's under the influence of an additional factor that increases or decreases the total resistance, which is the **volume of air in the lungs**.

- ✓ Alveolar air pressure divides pulmonary vessels into **alveolar** and **extra-alveolar vessels**
- ✓ **Alveolar vessels** are the pulmonary capillaries, which are **compressed** by the alveolar air pressure on their outside, increasing the resistance inside them.
- ✓ **Extra-alveolar vessels** are the pulmonary artery and vein, which are **distended** by negative intrapleural pressure, decreasing the resistance inside them.



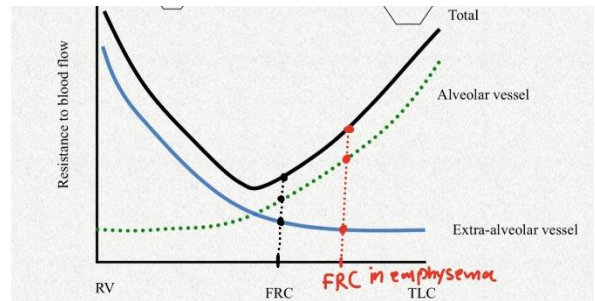
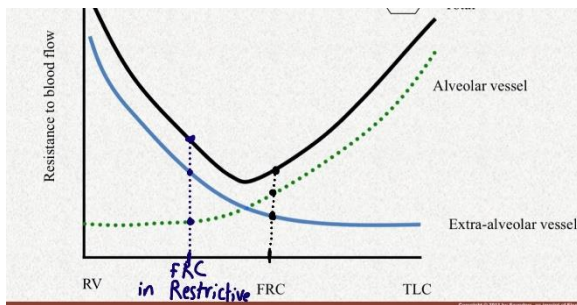
- **Increasing lung volume above FRC**, increases alveolar air pressure, which crushes **alveolar vessels**, **increasing the total pulmonary resistance**. On the other hand, intrapleural pressure will be more negative, which has a distending effect on extra-alveolar vessels.
- **Decreasing lung volume below FRC** (at RV) will make intrapleural pressure positive, compressing the **extra-alveolar vessels**, **increasing the total pulmonary resistance**.
- That's why lung volume is normally kept at FRC.

- ✓ During inflation; notice how alveolar vessels are compressed, and their vascular resistance is higher than the distended extra-alveolar vessels. Vice versa when the lung volume is decreasing below FRC. But in both cases, total pulmonary resistance is INCREASED.

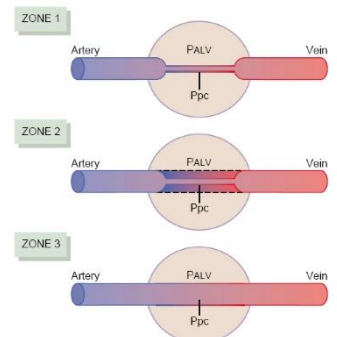


- looking at the total pulmonary resistance curve, **it's the sum of alveolar and extra-alveolar resistance**. Their contribution differs at different points of lung volume as explained.
- **At RV**, total R_p is at its highest value, mainly due to extra-alveolar resistance, while alveolar vessels are at their lowest resistance.
- **At TLC**, total R_p is at its highest value, mainly due to alveolar vessel resistance, while extra-alveolar vessels are at their lowest resistance.
- **At FRC**, the total R_p is at its lowest value, alveolar and extra-alveolar vessels are contributing equally. Total $R_p = 2 \times$ alveolar or extra-alveolar resistance.

- ❖ A person with emphysema has hyperinflated lung, so FRC will be higher.
 - Extra-alveolar resistance will be lower.
 - Alveolar resistance will be higher.
 - **Total R_p will be higher.**
- ❖ A person with restrictive lung disease is unable to inhale properly, so FRC will be lower.
 - Extra alveolar resistance will be higher.
 - Alveolar resistance will be lower.
 - **Total R_p will be higher.**

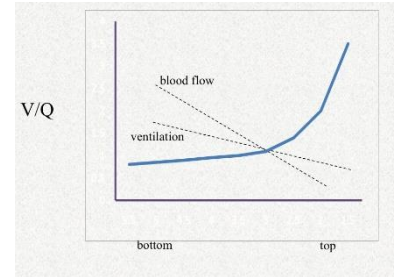


- ✓ $\uparrow R_p \rightarrow \uparrow \Delta P \rightarrow$ pulmonary hypertension $\rightarrow \uparrow$ afterload on right ventricle \rightarrow ventricular dilatation \rightarrow right ventricular failure (cor pulmonale)
- There are three possible patterns (zones) of pulmonary blood flow under different normal and pathological lung conditions, depending on the alveolar air pressure:
 - 1- Zone 1: $P_A > P_a > P_v$, in this case the capillaries will close and there's **no blood flow during any part of cardiac cycle.**
 - 2- Zone 2: $P_a > P_A > P_v$, in this case the flow is **intermittent** (only during systole).
 - 3- Zone 3: $P_a > P_v > P_A$, in this case the flow is **continuous.**
- ✓ in a normal lung, zone 1 is generally ABSENT. it has only 2 zones for blood flow:
 - zone 2 is observed at the apices, starting approximately 10 cm above the mid-level of the heart.
 - Zone 3 in all the lower areas.



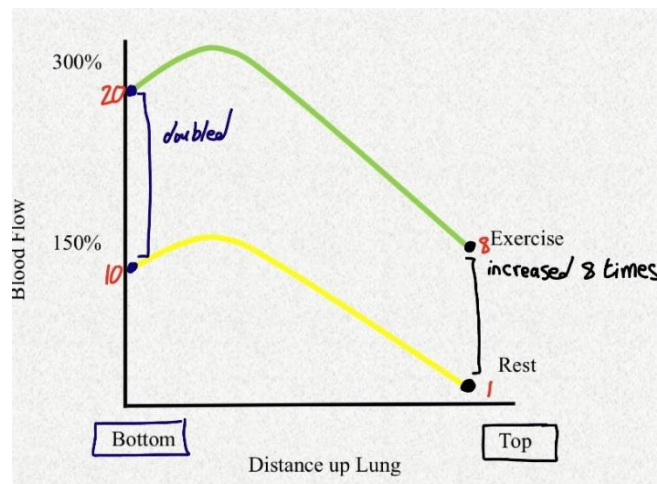
- ✓ Zone 1 and zone 2 may expand in scenarios like: **bleeding** (resulting in decreased perfusion), and **elevated intra-alveolar pressure** above required, as seen in controlled ventilation during artificial respiration (increased ventilation), this increase begins mainly in the apex.
- ✓ **During exercise, The ENTIRE** lung operates at zone 3 (including the apex).
- Distribution of blood volumes, pulmonary Vs systemic circulation
 - ✓ in systemic (5L):
 - 2 thirds (3L) in veins since they're the most compliant
 - 750ml in arteries
 - 350 in capillaries
 - ✓ In pulmonary circulation (450ml):
 - 190ml in arteries
 - 190ml in veins
 - 70ml in capillaries
- **Ventilation to perfusion ratio (V/Q)**
 - ✓ For efficient gas exchange, we need 2 things: adequate ventilation and adequate perfusion.
 - ✓ Not only that, they also need to be **MATCHED**. Otherwise:
 - Ventilation>perfusion → wasted ventilation $V/Q > 0.8$
 - Ventilation<perfusion → wasted perfusion $V/Q < 0.8$
 - ✓ In these cases, gas exchange efficiency is less, and blood won't yield normal ABGs, so you need to have $V/Q = 0.8$
- In the Normal lung, the V/Q ratio is mostly matched, except for 2 areas:
 - **Apex** has the **highest V/Q value**, as ventilation is much higher relative to perfusion at this area (underperfused). So, the apex is said to be **hyperventilated**. The blood derived from apical regions has the highest PO₂ value in the lung= 130mmHg. This explains why bacterial infections arises more from the apices.

- **Base** has the **lowest V/Q value**, because perfusion is much greater relative to ventilation at this area (overperfused). So, it's said to be **hypoventilated**. The blood derived from the basal regions has the lowest PO₂ values=90mmHg.
- Don't be confused, when we say ventilation is higher in the basal regions, we mean the **ALVEOLAR VENTILATION**. **But the PaO₂ derived from different areas in the lung, is determined by the gas exchange efficiency there (the matching of ventilation to perfusion)**. So yes, apical regions' derived blood is hyperventilated (more O₂, Less CO₂) and basal regions' is hypoventilated.



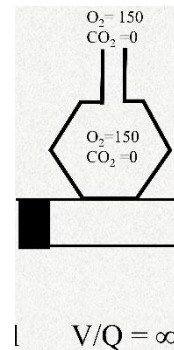
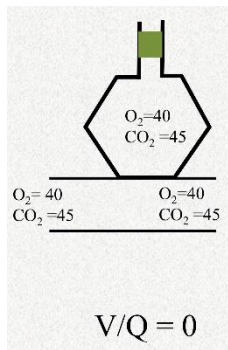
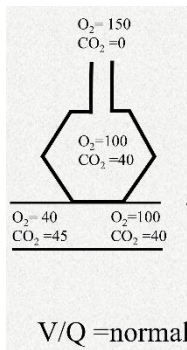
➤ Lungs during exercise;

- Both ventilation and perfusion increase.
- V/Q ratio doesn't change.
- It's true that both apical and basal flow increase, but the apical flow increase is much greater (by 8 times) than basal flow increase (doubled).
- Despite that, no uniformity of perfusion along the lung is achieved, the basal regions' alveoli still have more ventilation and perfusion. (look at the green curve, does it look uniform to you?)

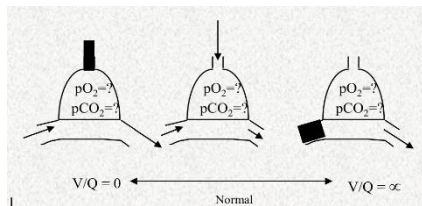


➤ V/Q ratio and ABGs

- If ventilation and perfusion are matched, then $V/Q=0.8$ and normal ABGs are achieved.
- If the ventilation is zero but alveolar perfusion is adequate, then $V/Q=0$ and ABGs resembles mixed venous blood.
- If ventilation is adequate but perfusion is zero, then $V/Q=\infty$ and ABGs resembles inspired air.



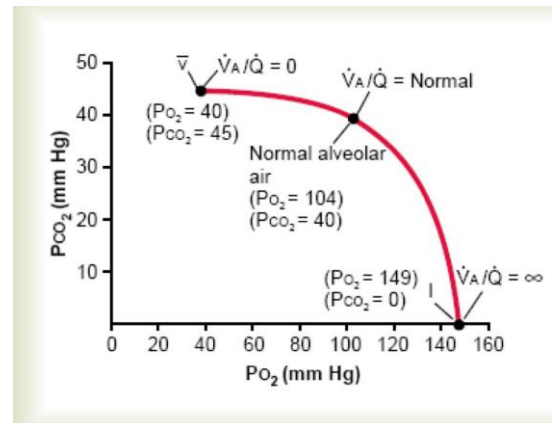
- Note that at a ratio of 0 or infinity, there's NO exchange of gases through the respiratory membrane of the affected alveoli.



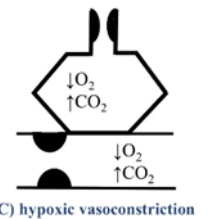
➤ Alveolar dead space and physiologic shunts

❖ This curve represents ABGs at different V/Q ratios.

- At $V/Q = \infty$, there's wasted ventilation, so this area is called alveolar dead space that contributes to physiologic dead space.
- At $V/Q = 0$, there's wasted perfusion, and a process called physiologic shunt takes place.
- Physiologic or functional shunt is an anatomical arteriovenous shunt where blood bypasses capillaries and goes directly to the pulmonary veins side without exchanging gas in capillaries.



- As expected, shunted blood has $\uparrow\text{PCO}_2$, $\downarrow\text{PO}_2$.
 - Normally, 2% of cardiac output is shunted (contributing to the pollution of arterial blood).
 - If this percentage increases to 10%, then **it's a pathological shunt**.
 - According to that, a decrease in PaO_2 may suggest pathological shunt. But how can we ensure that?
 - o You increase the fraction of inspired oxygen by 1% (FiO_2 21% \rightarrow 22%)
 - o If this results in an increase of PaO_2 by 3-5 mmHg, then it's a **respiratory membrane problem** (a diffusion problem).
 - o If it results in an increase of PaO_2 by less than 1mmHg, **then it's pathological shunt** (increasing PAO_2 is not helping because blood is not passing through capillaries).
-
- Hypoxic vasoconstriction
 - ❖ To prevent wasted perfusion in cases where we have reduced ventilation ($V/Q < 0.8$), **hypoxic vasoconstriction** takes place (was explained in the previous file).
 - ❖ Hypoxic vasoconstriction is an adaptive mechanism that happens in people who live at high altitudes (where there's reduced PO_2 in inspired air).
 - ❖ It brings V/Q to normal but leads to **pulmonary hypertension** with time.
 - V/Q ratio is increased in:
 - o Pulmonary embolism (pulmonary arteries are obstructed and perfusion is reduced) \rightarrow alveolar dead space is increased, and PAO_2 resembles inspired air \rightarrow expired PO_2 is increased.
 - o Emphysema, cigarette smokers, pulmonary hyperventilation.



Whenever V/Q is increased, alveolar dead space \uparrow , mixed expired $\text{P}_{\text{E}}\text{O}_2$ \uparrow , mixed expired $\text{P}_{\text{E}}\text{CO}_2$ \downarrow

- ❖ Physiologic dead space (the doctor didn't mention many details)
- ✓ The sum of anatomic dead space and alveolar dead space
- ✓ Portion of air that doesn't participate in gas exchange because it either remains in the conducting airways (anatomical) or reaches alveoli that are not perfused with blood (alveolar, main contributor is apical regions).
- ✓ Increased physiologic dead space can indicate ventilation-perfusion mismatch and impaired gas exchange in the lungs.

➤ Why is arterial PaO₂ less than Alveolar PAO₂?

Why is PAO₂ = 100 while SYSTEMIC PaO₂ is only 95mmHg?

1- Venous admixture (pollution)

- Bronchial circulation: 50% of venous return goes to right atrium, 50% goes to left atrium and pulmonary veins.
- Cardiac veins: Thebesian veins empty into left ventricles.
- Pulmonary circulation: 2% of all venous blood doesn't pass through pulmonary capillaries (A-V anastomosis) "physiological shunted blood".

2- Low V/Q in the base of the lung, that's not compensated by the hyperventilated apex.

NOTE: at the alveolar capillaries end, there's no pollution yet, so only here the PaO₂ is a mirror image of PAO₂. So at this site, the PAO₂-PaO₂ is 0, not 5.

● Oxygen transport

- ✓ Oxygen is transported in two forms: 1.5% dissolved O₂ in plasma and 98% bound to hemoglobin.
 - 1.5% of total blood O₂ is dissolved in plasma and is determined by PaO₂ and O₂ solubility according to Henry's law

[dissolved O₂] = PaO₂ × solubility = 100 × 0.003 = 0.3ml

So, it adds **very little amount** to the total blood O₂

- 98% of total blood O₂ is bound to hemoglobin, a protein that consists of 4 polypeptide chains (2 alpha and 2 beta).

- Each chain contains a heme group that contains iron (Fe)
- 1 oxygen binds to iron in the ferrous state, so each hemoglobin molecule can bind 4 oxygen in its fully saturated state.

Let's make some calculations

- Blood constitutes approximately 7% of total body weight. for a person weighing 70Kg, the blood = 5L, 5000ml, 5×10^6 microL (in each microL of blood we have 5 million of RBCs)
- In each RBCs, Hb = 280 million.
- Hb molecular weight is less than 70000 kilodaltons.
- A healthy male has 14-16g/dL of Hb (15g/dL on average).
- **If Hb molecules were fully saturated then each gram of Hb carry 1.34ml of O₂ (memorize this number).**
- So, a male has $\rightarrow 15\text{g/dL Hb} \times 1.34\text{ml O}_2 = 20\text{ml O}_2 / \text{dL blood, bound to Hb}$
- 1dL = 100 ml, so 100ml of blood has 20ml O₂ AND 0.3 dissolved O₂.
- Total O₂ in 100 ml of blood = 20.3, we consider it 20ml.

2 α chains(141aa)+ 2 β chains(146)= 574aa

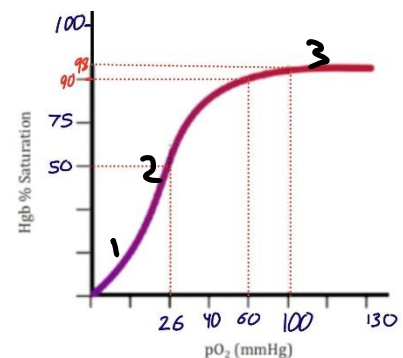
MW= 574 \times average MW(110)
=64500

➤ O₂-Hb Dissociation curve

- Four heme groups do not simultaneously oxygenate.
- First O₂ molecule INCREASES affinity for 2nd molecule, same thing for the 3rd and 4th molecule.
- Affinity of Hb for the last O₂ is 300 times the affinity for first O₂.
- This binding pattern is called \rightarrow **positive cooperativity**, and it makes the O₂-Hb curve **SIGMOIDAL** with 3 phases of affinity.

this curve is full of details, pay attention.

- X axis: partial pressure of oxygen PaO₂.
- Y axis: percentage of hemoglobin bound to oxygen, Hb saturation%



- Due to the cooperativity pattern of binding, the curve is divided into 3 phases
 - **Phase 1:** affinity of O₂ to Hb before the first binding is the lowest, as the Hb molecules are in their Tense state. **So, PO₂ is increasing but Hb saturation barely does.**
 - **Phase 2:** upon conversion of Hb from the Tense state to Relaxed state, affinity is highest, and the curve is almost linear **(any increase or decrease of PO₂ in this phase will affect total [O₂] significantly)**
 - **Phase 3:** The plateau, most of Hb molecules or their binding site are saturated (occupied), so any increase or decrease in PO₂ will have little to no effect on Hb saturation%.
- Important numbers on the curve:
 - At **PO₂= 26mmHg**, **50% of Hb molecules are saturated and total [O₂] = 10ml**, so it's called P₅₀O₂.
 - At **PO₂= 40mmHg**, **75% of Hb molecules are saturated and the total [O₂] = 15ml**, that's the PO₂ value in mixed venous blood.
 - At **PO₂= 100mmHg**, **98% of Hb molecules are saturated and the total [O₂] = 20ml**, that's the PO₂ value in arteries.
 - At **PO₂= 60mmHg**, **90% of Hb molecules are saturated and the total [O₂] = 18ml**, this PO₂ is the beginning of plateau and the regulation point of O₂. What does that mean?
- ❖ We already stated that **during the plateau, no significant change** happens on Hb saturation% (and the total [O₂]) with changing PO₂, and the numbers approve that→ (PO₂ Has changed by 40 degrees between 100mmHg and 60mmHg, yet the saturation% changed only by 8 degrees)
- ❖ So, as long as the **PO₂ is still 60 and more**, the body won't respond to any change (increasing or decreasing) and the respiratory minute ventilation won't change. Because you still have enough saturated Hb, and the total [O₂] is not affected.
- ❖ Once the **PO₂ decreases below 60mmHg**, it will face the steep zone of phase 2. The Hb saturation% and O₂ carrying capacity will start to decrease significantly, decreasing the total [O₂].

- ❖ At this point, the respiratory center in medulla oblongata senses this decrease and responds by increasing respiratory minute ventilation.
- ❖ that's why we consider 60mmHg a **regulation point** → the of firing neurons from the respiratory center won't increase unless PO₂ is less than 60mmHg.
- This whole thing of O₂ being regulated only when decreased below certain point (half tail regulation), explains why **O₂ is NOT self-compensatory**.

Prove that?

- The most demonstrative example to prove this, is the apex of the lung.
- As we said before, apical regions of the lung are hyperventilated, the blood derived from this area has the highest PO₂ value (=130), but does that compensate for the hypoventilated areas in the basal regions?
- Let's go back to O₂ dissociation curve, how does the increase in PO₂ to 130mmHg affect the total [O₂]? → NOTHING (98%→98.5%)
- The Hb saturation is barely increased because the curve **has a plateau at 100% saturation**; it can't increase further no matter how much PO₂ is increased.
- So, the total [O₂] didn't increase, and **the high PO₂ value in the apex didn't compensate for the hypoventilated base**.

To understand more

- ❖ remember that PO₂ values are affected mainly by the lung function, as you increase alveolar ventilation, you will increase PAO₂. But how does that affect total O₂?
- ❖ In the last lecture we agreed that hyper and hypo ventilation don't affect arterial O₂ as they do to arterial CO₂.
- ❖ In this lecture, we can tell exactly why → O₂ has a sigmoidal curve; increasing ventilation and thus PAO₂ won't result in a significant change in total [O₂] after a certain point, and it will only increase dissolved O₂ (the 1.5% of total) leading to almost no change.
→ **SO O₂ IS NOT SELF COMPENSATORY**, you can't fix it with increasing ventilation (unless its partial pressure is below 60mmHg)

all of this is a product of the O₂ SIGMOIDAL dissociation curve, which is not the case in CO₂ curve.

➤ CO₂-Hb dissociation curve

- Illustrates the relationship between the partial pressure of CO₂ and the amount of CO₂ carried by Hb. (note that most of CO₂ travels in the blood in the form of bicarbonate CO₂ and dissolved CO₂).
- Unlike O₂ dissociation curve, the CO₂-Hb curve is relatively **LINEAR**.
- The linear curve indicates a direct straightforward relationship between PCO₂ and Hb-CO₂.
- Any increase or decrease in PCO₂ by hyper or hypo-ventilation, will result in a **PROPORTIONAL CHANGE** in the amount of CO₂ bound to Hb and the total [CO₂].
→SO, CO₂ IS A SELF COMPENSATORY GAS, that can be fixed by increasing or decreasing ventilation.
→also, areas of lower [CO₂] in the lung (hyperventilated) can correct areas of higher [CO₂] (hypoventilated), unlike O₂.

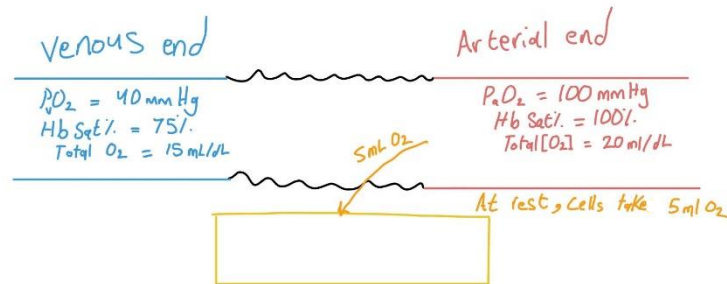
❖ Hysterical hyperventilation

- $PACO_2 = VCO_2 \times 0.863 / V_A$
- in hysterical hyperventilation $\uparrow V_A \rightarrow \downarrow PACO_2 \rightarrow \downarrow H^+ \rightarrow \uparrow pH$
→alkalosis
- Normally, calcium is 50% bound to albumin and 50% free, in alkalosis calcium shifts more to the bound form→ hypocalcemia.
- Since free calcium normally stabilize the INACTIVATION gates of sodium channels in the spinal neurons, hypocalcemia leads to increase sodium permeability, and lower the threshold for neuronal excitation, increasing the firing of the neurons → spasmodic contractions in peripheral muscles (that begins in fingers), and can reach to the diaphragm leading to death.

➤ O₂ consumption (VO₂) and CO₂ production (VCO₂)

- You're now able to tell what are the total [O₂] at different PO₂ and Hb saturation% values. BUT how much [O₂] does the body need from this total [O₂]? How much does it CONSUME?
- This question brings us to **EXTRACTION RATIO**

1- At rest



- Extraction ratio = $\frac{a_{O_2} - V_{O_2}}{a_{O_2}}$ (how much O₂ is extracted from the arterial blood's total [O₂])
 $= \frac{20-15}{20} = \frac{5}{20} = \frac{1}{4} =$ only 25% of total [O₂] is Consumed (5ml of O₂ is taken per 1dL of blood)
- VO₂ is **TOTAL O₂ consumption** = cardiac output × 5 = 50dL blood × 5 ml O₂/dL = **250ml O₂**
- What about VCO₂? We PRODUCE 4ml CO₂/dL, so VCO₂ = Q × 4 = 50dL blood × 4 ml CO₂/dL = **200ml CO₂**
- According to that, respiratory exchange ratio = VCO₂/VO₂ = 200/250 = **0.8 AT BASAL METABOLIC RATE.**

2- **During exercise**, metabolic rate increases

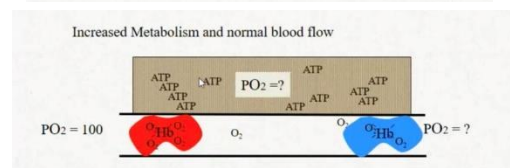
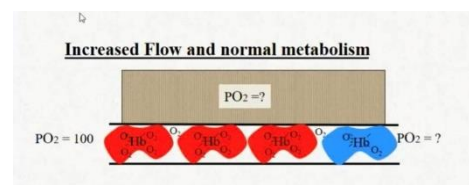
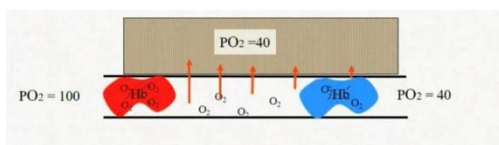
- **Extraction ratio increases** above 25% of total blood [O₂], and VO₂ increases accordingly. It can reach up to 3L in a normal individual during exercise. VO_{2max} is 5L.
- VO_{2max} is the maximum O₂ that can be consumed (=5L). Being able to reach this value is affected **slightly** by exercise (you can increase your VO₂ more than 3L **only by 10% with exercise**). **BUT mainly** by genetic factors (some people are born with predisposition or greater

readiness to increase their VO_2 value to $\text{VO}_{2\text{max}}$, and these individuals can participate in a marathon).

- Don't forget that for that to happen, **Q increases** 7 times its normal value (5L→35L). The VO_2 increases almost 20 times its normal value (250ml→5000L). HOW? Again, because extraction ratio increases.
- Also, exercise leads to **vasodilation of blood vessels** in the muscles, allowing more blood to flow to the exercising tissues
(REDISTRIBUTION)

➤ Blood and muscles

- ✓ Increasing and decreasing blood flow and metabolism rates, affects mainly PvO_2 and PO_2 in the tissues. And usually, they don't affect ARTERIAL PO_2 .
- **At normal blood flow and normal metabolism**, PO_2 in the tissues and mixed venous blood will be 40mmHg.
- **At increased blood flow and normal metabolism**
 - **Increased blood flow, results in a higher oxygen delivery to the tissues**
 - Constant metabolism means the tissues are not extracting more oxygen (VO_2 is not increased, **tissues are not consuming the extra delivered O_2**)
 - O_2 Partial pressure in the tissues and mixed venous blood reflects the concentration of O_2 available. With increased oxygen delivery and constant metabolism, the **PO_2 tends to rise.** ($\text{PO}_2 = 60\text{mmHg}$ in tissues and mixed venous blood)
- **At increased metabolism and normal blood flow**, **PO_2 in the tissues and venous blood tends to decrease** ($\text{PO}_2 = 20\text{mmHg}$)



• Cardiac output estimation

- ✓ Fick's principle is a method to estimate cardiac output based on the measurement of oxygen consumption.
- ✓ It relies on the **principle of conservation of mass**, stating that the amount of a substance entering a system must equal the amount leaving the system.
- ✓ O₂ in the arterial end(q₃) equals the sum of O₂ in the venous end(q₁) and alveolar added O₂(q₂, the VO₂)
- ✓ The formula for estimating cardiac output using Fick principle is:

$$\text{Cardiac Output (CO)} = \frac{\text{Oxygen Consumption (VO}_2\text{)}}{\text{Arteriovenous Oxygen Content Difference (CaO}_2\text{-CvO}_2\text{)}}$$

Where:

- VO₂ is the rate of oxygen consumption.
- CaO₂ is the arterial oxygen content.
- CvO₂ is the mixed venous oxygen content.

- ✓ The principle assumes that oxygen is taken up by the tissues and delivered to the lungs, and the difference in oxygen content between arterial and venous blood reflects the oxygen consumed by the tissues.
- ✓ **At rest Q= 250ml/min/ (20-15)ml O₂/100ml blood = 250/0.05 = 5000ml**

Now let's test your understanding

Q₁: A vasodilator is infused into a paralyzed muscle, what happens to PO₂ within that muscle?

Let's break through this

- Vasodilator means we're increasing blood flow to this muscle, increasing the delivery of O₂.
- Paralyzed muscle means metabolism won't change, **O₂ consumption won't change** (it will probably consume less O₂)
- The tissue is not using the extra delivered O₂ → **PO₂ in the tissue will increase.**

Q₂: Arterial PO₂ is 100mmHg and O₂ concentration= 20ml/dl blood, what is the ARTERIAL PO₂ if half of all the red cells is removed?

That's a tricky question, you'll expect PO₂ to decrease but it actually remains unchanged. HOW?

- Removing ½ of RBCs will decrease Hb content to the half (15g/dL → 7.5g/dl)
- There's nothing in the question that implies that Hb saturation is affected, so yes the amount of Hb is reduced but the available Hb can be fully saturated.
- Dissolved O₂ in the plasma contributes to PO₂, (dissolved O₂= solubility× PO₂). The plasma is not affected according to the question.
- **So arterial PO₂ is NOT affected (PO₂=100mmHg).** if the question asked about total O₂, of course it will decrease ([O₂] = 10ml/dl).

Q₃: same previous question, but what is the VENOUS blood PO₂?

- Venous blood differs from arterial blood in that it's affected by Extraction ratio.
- Removing half of RBCs will decrease Hb content to the half (7.5g/dl)
- Total [O₂] = (Hb × 1.34) + (PO₂×solubility) = 7.5×1.34 + 0.3 = 10ml/dl
- Tissues use 5ml of O₂ → extraction ratio = 5/10= 50% (ER↑)
- **So, the PO₂ in venous blood is at 50% saturation rather than the normal 75% (reduced).** and you can predict the value of PO₂ since it's at 50% saturation, it's **26mmHg!**

Q₄: what happens to the arterial and venous PO₂ values in an anemic person?

- Same idea as the two previous questions, an anemic patient has less RBCs, less Hb, saturation is not affected.
- Total [O₂] is decreased
- **Arterial PO₂ remains unchanged.**
- **Venous PO₂ is reduced (extraction ratio is increased, venous saturation is decreased)**

Q₅: Systemic arterial PO₂ is 100mmHg and hematocrit is 40%. What is the systemic PaO₂ if blood is added to increase hematocrit to 50%?

- Same idea, hematocrit is a measure of RBCs. Increasing this percentage increases RBCs and hemoglobin molecules.
- Arterial PO₂ is unchanged (100mmHg)
- Total [O₂] is increased
- Venous PO₂ is increased (extraction ratio is decreased, venous saturation is increased)

Q₆: A person is breathing from a gas tank containing 45% oxygen, what is the alveolar PO₂?

- 45% of oxygen increases the Fraction of inspired O₂. 760mmHg ×45%= 342mmHg (O₂ in the gas tank is more by 184 points than outside air with 21%)
- in the airways there's 47mmHg H₂O, 760-47= 713mmHg → 713×45%=320
- in the alveoli, after gas exchange:

$$PAO_2 = PO_2 \text{ inspired} - (PaCO_2 / \text{respiratory exchange ratio})$$

$$PAO_2 = 320 - (40 / 0.8) = 270 \text{ mmHg}$$